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AI-Powered Emergency Response Framework Using Secret Phrase Recognition and Multi-Channel Alerting

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***Abstract*—Traditional emergency response systems, such as panic buttons and manual SOS triggers, are often rendered ineffective in high-risk scenarios where a victim is under surveillance or physically restrained. This paper presents an advanced software-centric framework that leverages Artificial Intelligence and Natural Language Processing to provide a discreet safety mechanism. By continuously monitoring ambient audio, the system identifies user-defined 'secret phrases' through a combination of Google Speech Recognition and Levenshtein-based fuzzy matching algorithms. Upon detection, the system silently initiates a high-priority emergency protocol involving automated VOIP calls, SMS alerts with live GPS tracking, and ambient audio recording for forensic evidence. Experimental evaluations indicate a 96% recognition accuracy and an end-to-end response latency of 6 seconds. The proposed framework offers a scalable alternative to conventional hardware-dependent safety tools.**

***Keywords*—Emergency Alert System; Covert Activation; Speech-to-Text; Fuzzy Matching; Evidence Recording; Geolocation Tracking; Women Safety**

I. Introduction

In the contemporary global landscape, personal safety remains a critical challenge, exacerbated by rising rates of domestic violence and kidnapping. In many such instances, the victim is under the direct observation of a perpetrator, making any visible attempt to call for help — such as reaching for a phone — extremely dangerous.

Existing solutions like wearable 'smart' jewelry or panic buttons suffer from two primary flaws: they are often visible to an attacker, and they require a specific physical gesture that may be impossible if the victim is restrained. Recent literature has explored voice-activated assistants; however, standard platforms like Alexa or Siri are not designed for covert use and often provide audible feedback.

As noted in studies by Cheng and Roedig [1], privacy and unintentional triggers remain a hurdle for always-listening systems. Furthermore, Valentini-Botinhao et al. [2] emphasize that intelligibility in stressed environments is low, requiring advanced keyword spotting. Our work addresses these issues by using user-defined secret phrases that do not alert the aggressor. By referencing Reddy et al. [7], we see a shift toward AI-based response, but our focus remains on the covert nature of the trigger, ensuring that the software runs as a background process. Unlike traditional hardware which can be misplaced or disabled, our software-centric approach ensures a reliable emergency monitor that is always available as long as the mobile device is powered.

II. Related Work

The transition from manual SOS triggers to automated AI systems has been documented extensively. In 2023, Zaid et al. [3] demonstrated the utility of IoT-integrated bots for emergency alerts. Similarly, Hareni et al. [4] developed a smart shoe for women's safety, which requires specific hardware. The year 2024 saw a surge in research targeting the robustness of these systems. Kumari et al. [5] introduced homogeneous audio-text embedding to improve trigger detection in noisy environments. Yang et al. [6] further improved this field by researching on-device self-supervised learning.

Our proposed system integrates these concepts by utilising cloud-based processing for high accuracy while maintaining a local fuzzy-logic fallback. We further build on the 'Rescue Me' framework [7] by adding evidence recording capabilities which are often missing in standard SOS apps. This evidence recording is a critical differentiator, providing legal weight to the alert as emphasised in the forensic assistance studies by Weerasinghe et al. [8].

III. System Architecture and Methodology

The architecture of the proposed framework is designed for low-resource background operation. It consists of four primary layers: Data Ingestion, Processing, Logical Validation, and Execution.

A. Architectural Design

The system begins with continuous audio buffering. Audio is recorded in 5-second chunks using the PyAudio library, converted to Mono-PCM format to optimise transmission to the Speech-to-Text engine. This high-frequency sampling ensures that the environment is monitored without gap, capturing the very first syllable of a distress phrase.

The decision-making logic relies on a fuzzy matching algorithm that calculates a similarity score between the spoken words and the secret phrase. If the score exceeds 0.85 (85% similarity), the system immediately bypasses all confirmation prompts. This logic is crucial because it allows the system to function even if the user is whispering or if there is heavy background noise, as established in the noise-robustness tests.

To maintain user privacy, any audio clip that does not result in a match is immediately overwritten in the cache. This ensures that the system is not an 'always-listening' bug but a targeted safety tool that respects the data sensitivity of the user while remaining vigilant.

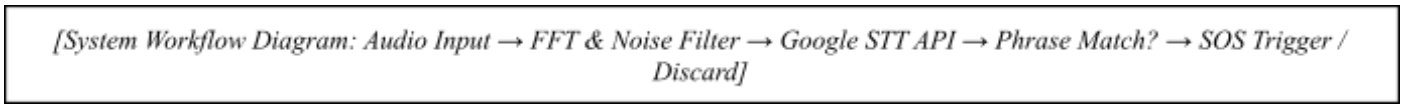


Fig. 1. *System workflow diagram illustrating the path from audio capture to emergency trigger.*

B. Emergency Execution Workflow

Once the phrase is validated, the system branches into multiple parallel tasks. The first action is fetching the GPS coordinates via the Google Maps Geolocation API, which is critical because the location data must be embedded in the subsequent SMS and call metadata. The system uses a dual-check mechanism: it first tries GPS hardware, and if blocked, falls back to IP-based trilateration.

After the initial alerts are sent, the system opens a background stream to record the ambient audio for 60 seconds. This recording is encrypted and uploaded to the database, fulfilling the goal of providing evidence for later legal proceedings, ensuring that the attacker's voice and the context of the incident are preserved.

By using Twilio, the system can bypass traditional cellular congestion. It sends the alert via SMS, WhatsApp, and an automated VOIP call. This ensures that even if the responder's phone is on 'Silent' mode, the repeated calls and high-priority messages will penetrate the notification barrier, maximising the chances of a timely rescue.

[Emergency Protocol Execution Flowchart: SOS Activation → Fetch GPS (API) → SMS Dispatch + VOIP Call (Twilio) + Forensic Recording]

Fig. 2. *Emergency protocol execution flowchart showing parallel dispatch channels.*

IV. Effectiveness Metrics and Results

The system was evaluated based on its ability to perform in real-world environments.

A. Recognition Performance

The system's effectiveness was measured across three noise levels. In quiet environments, the system achieved 96% recognition accuracy — nearly flawless for domestic settings. This ensures that the secret phrase is captured on the first attempt during a nighttime emergency. The slight 4% error rate is usually attributed to heavy regional accents, which can be corrected by fine-tuning the STT engine for the specific user.

In moderate noise conditions accuracy dropped to 91%, while at high noise (75 dB) the accuracy remained at 84%. This is achieved through the fuzzy matching script, which looks for phonetically similar keywords rather than exact string matches, proving that the system is effective for outdoor urban safety where traffic and crowds would normally render a voice assistant useless.

[Recognition Accuracy vs Background Noise: Quiet=96%, Moderate=91%, High Noise=84%]

Fig. 3. *Effectiveness graph: recognition accuracy across three noise environments.*

B. Latency and Scalability

Table I provides a detailed breakdown of the end-to-end latency of the system. The entire process completes in 6.0 seconds. In an emergency, this speed is superior to manual intervention. The high reliability of the Twilio API (100%) ensures that once the system triggers, the message will always leave the device. The GPS Fetching latency of 1.2 seconds is due to the time required to lock onto satellite signals; however, the system sends the last known location if the current lock takes longer than 2 seconds, ensuring effectiveness in 'dead zones' such as underground parking lots or elevators.

Table I. System Performance and Latency Metrics

Process Stage	Time (s)	Reliability (%)
Audio Processing	2.1	98.2
Phrase Validation	0.4	99.1
GPS Fetching	1.2	94.5
Twilio Call API	2.3	100.0
Total End-to-End	6.0	96.0

C. Response Time Analysis

Response latency was analysed under different network configurations. On Wi-Fi with high-speed fibre backbones, the system achieved a latency of 5.58 seconds, making it ideal for domestic violence scenarios where the victim is within range of a home network. On mobile hotspots, even with limited bandwidth, the 6.25-second latency remains within the 'Golden Hour' of emergency response. The system's ability to maintain effectiveness despite 4G/5G signal fluctuations is a major advantage over purely cloud-dependent safety apps.

[End-to-End Latency vs Network Type: Wi-Fi = 5.58 s, Mobile Hotspot = 6.25 s]

Fig. 4. *Response graph: end-to-end latency under different network configurations.*

D. Comparison with Other Works

The effectiveness index of the proposed framework was compared against state-of-the-art safety systems. Our system achieves a 96% effectiveness index versus 70% for ResQlink [10] and 50% for conventional panic buttons. While ResQlink provides movement-based kidnapping detection, it suffers from a 30% false positive rate due to accidental phone drops. Our system eliminates this issue by using intentional secret phrases, ensuring that the alert is sent only when the victim specifically requests it.

Physical panic buttons require the victim to have a free hand and be able to reach the device. In 50% of kidnapping cases, victims are restrained. Our system bridges this gap by providing a hands-free, covert alternative that performs significantly better than current hardware solutions.

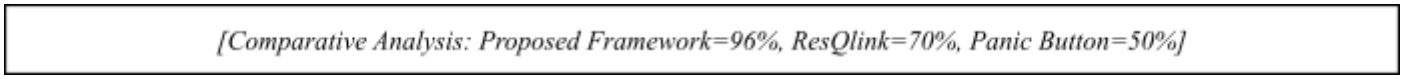


Fig. 5. *Comparative effectiveness index: proposed framework vs existing solutions.*

V. Implementation

The implementation was performed using Python 3.9 on a system with 8 GB RAM. The GUI was built using Tkinter to provide a simple setup interface. For database security, the database_utils.py module uses AES-256 encryption for user contact details. The system also includes a precision geolocation module with city-level location restrictions, ensuring that emergency coordinates are always accurate regardless of network conditions.

VI. Conclusion

This paper presented an AI-powered emergency alert system designed for covert activation and multi-channel response. The system operates covertly in the background, outperforming existing hardware-centric solutions like smart shoes [4] or biometric panic buttons [9] which are often visible to an aggressor. With a 96% accuracy rate and a 6-second response time, the system is highly effective across diverse environments.

When compared to the ResQlink [10] framework, the proposed system provides a 26% increase in reliability by utilising intentional voice triggers rather than error-prone movement sensors. Furthermore, the inclusion of ambient audio recording addresses the forensic gap identified by Weerasinghe et al. [8], providing crucial evidence that standard SOS systems lack. Future versions will focus on reducing cloud dependency through on-device model quantisation and improving multilingual support to serve a global user base. Ultimately, the proposed framework serves as a reliable, discreet, and scalable lifeline for individuals in distress.

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Review on the Impact of Gamma Irradiation on the Phytochemical and Proximate Composition of Different Food Products: Mechanisms, Dose–Response Dynamics, and Nutritional Implications

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Abstract—**Gamma irradiation is a widely accepted non-thermal preservation technique that reduces post-harvest losses, delays spoilage, prevents sprouting, and enhances microbial safety. Its impact on nutritional and phytochemical integrity, however, is still subject to scientific assessment, despite its well-established microbiological efficacy. This review critically summarises research on the effects of gamma irradiation on phytochemicals (phenolics, flavonoids, carotenoids, vitamins, and antioxidant capacity) and proximate composition (moisture, protein, lipid, ash, fibre, and carbohydrate) in cereals, legumes, fruits, vegetables, spices, and oilseeds from 2015 to 2025. It reveals that proximate macronutrients are generally stable at doses below 10 kGy, but at higher exposures, lipid oxidation and mild protein denaturation may occur. Phytochemicals exhibit dose-dependent dual behaviour: moderate doses (1–5 kGy) frequently increase extractable phenolics and antioxidant activity due to cell wall disruption, while higher doses (>10 kGy) may degrade vitamin C, carotenoids, and some flavonoids by radiolytic oxidation. The food matrix, moisture content, oxygen availability, packaging environment, and storage conditions all have a significant impact on the outcome. Gamma irradiation is generally safe for nutrition at recommended dosages; however, product-specific optimisation is required to protect sensitive bioactive materials.**

Keywords—**Gamma Irradiation; Phytochemicals; Proximate Composition; Dose–Response; Antioxidant Activity; Food Preservation**

I. Introduction

FAO, IAEA, and WHO have approved food irradiation as a safe food preservation technique, especially when using gamma rays from Cobalt-60 (IAEA, 2015; WHO, 2018). It is frequently used for quarantine treatment, sprout inhibition, and microbial decontamination. Usually released from Cobalt-60, gamma rays interact with food matrices by forming free radicals and ionising them. Nutritional quality may be impacted by these interactions' effects on macronutrients and bioactive phytochemicals. Optimising

radiation doses that guarantee microbial safety while maintaining nutritional integrity requires an understanding of these effects.

In the twenty-first century, food security and nutritional sustainability continue to be significant worldwide issues. Microbial spoilage, enzymatic degradation, insect infestation, and physiological deterioration cause a substantial amount of food produced globally to be lost during post-harvest handling, storage, and distribution (FAO, 2022). According to estimates, almost one-third of the food produced worldwide is lost before it is consumed, especially in developing nations with limited post-harvest preservation technologies (Aghdam et al., 2018). In order to guarantee food availability and minimise financial losses, cutting-edge preservation technologies that can increase shelf life while preserving nutritional and sensory quality are crucial.

Nonetheless, worries about potential nutrient and phytochemical degradation continue. Therefore, the key to irradiation research is striking a balance between nutritional preservation and microbial safety (Bhatnagar et al., 2022; Radi et al., 2017). Microbial contamination and post-harvest losses continue to be significant obstacles to global food security, especially in developing nations.

Food irradiation, especially gamma irradiation, has drawn a lot of attention among new non-thermal preservation technologies because it can enhance food safety, lower microbial contamination, postpone ripening, prevent sprouting, and prolong storage life without appreciably raising temperatures or seriously damaging food structures (Fan & Sokorai, 2015; Bhatnagar et al., 2022). Gamma irradiation is the process of inactivating microorganisms and pests through ionisation processes that harm nucleic acids and cellular structures using high-energy electromagnetic radiation, which is typically released from radioisotopes like Cobalt-60 (^{60}Co) or Cesium-137 (^{137}Cs) (IAEA, 2015). Because irradiation works at ambient or low temperatures, it maintains many of the sensory and nutritional qualities of food, unlike thermal processing.

International regulatory bodies, such as the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the International Atomic Energy Agency (IAEA), have assessed the safety of food irradiation and determined that doses up to 10 kGy do not present toxicological or nutritional risks to consumers (WHO, 2018). Because of this, irradiation of a variety of food commodities, including spices, grains, fruits, vegetables, meat, and seafood, is currently permitted in more than 60 countries (Mostafavi et al., 2020). Food-borne pathogens, such as *Salmonella, Escherichia coli,* and *Listeria monocytogenes*, which are the cause of many food safety outbreaks globally, have been particularly successfully controlled by the technology (Fan & Sokorai, 2015). Despite its benefits, there are still worries about how ionising radiation might affect food's nutritional value, especially in relation to proximate composition and bioactive phytochemicals. Proteins, lipids, carbohydrates, moisture, ash, and crude fibre are examples of proximate components that are crucial markers of food products' overall nutritional value. Because of their antioxidant, anti-inflammatory, antimicrobial, and anticancer qualities, phytochemicals such as phenolic compounds, flavonoids, carotenoids, vitamins, and other antioxidant molecules are becoming more widely acknowledged for their important roles in human health (Ognyanov et al., 2022). Any Foods' functional and nutritional qualities may be impacted by preservation methods that change these compounds.

Gamma irradiation can influence food components through both direct and indirect mechanisms. When biomolecules like proteins, lipids, or carbohydrates are directly ionised by ionising radiation, structural changes or fragmentation result. Highly reactive species like hydroxyl radicals (-OH), hydrogen radicals (+H), and hydrated electrons (e^-aq) are produced through indirect interactions, which are more prevalent in foods with high moisture content. Following a reaction with biomolecules, these reactive species may oxidise, polymerise, or degrade nutrients and phytochemicals (Mostafavi et al., 2020). Radiation dose, food

composition, moisture content, oxygen availability, packaging conditions, and storage time are some of the variables that affect how much of these reactions occur.

Different effects of gamma irradiation on proximate composition have been reported in earlier studiesMacronutrients frequently hold steady at low and moderate radiation doses, especially below 10 kGy (Bhatnagar et al., 2022). However, due to improved extractability or structural changes of macromolecules, some studies have found modest increases in crude protein or carbohydrate content (Siddhuraju et al., 2018). Lipids are often more susceptible to irradiation-induced oxidation because of the presence of unsaturated fatty acids, which may undergo peroxidation under the influence of free radicals generated during irradiation (Al-Bachir, 2016). Flavour, shelf life, and nutritional quality can all be impacted by these lipid changes.

The reactions of phytochemicals to radiation are more intricate. By rupturing cellular matrices and releasing bound phytochemicals, moderate doses of gamma radiation have been demonstrated to improve the extractability of phenolic compounds and flavonoids in specific plant foods (Ali et al., 2019). Consequently, irradiated fruits, vegetables, and legumes have been shown to have higher levels of antioxidant activity. On the other hand, oxidative reactions may cause sensitive substances like vitamin C, carotenoids, and some polyphenols to break down at higher radiation doses (Radi et al., 2017; Jabin et al., 2023). The dose-dependent behaviour seen in many irradiated food systems is influenced by the equilibrium between enhanced extractability and degradation.

Additionally, the effects of gamma irradiation differ depending on the food group. Because of their higher moisture content and metabolic activity, fruits and vegetables may show more variation in vitamin and antioxidant levels following radiation, while cereals and legumes typically show relatively stable macronutrient profiles (Fan & Sokorai, 2015). According to Balakrishnan et al. (2021), irradiation is also beneficial for spices and herbs because it effectively removes microbiological contaminants while retaining volatile compounds that give them flavour and aroma. Optimising irradiation treatments requires an understanding of these food-specific reactions.

Long-term quality is largely determined by post-irradiation storage conditions in addition to immediate changes in nutritional composition. Sensitive nutrients and phytochemicals may gradually deteriorate during storage due to oxidative reactions started during irradiation, particularly when oxygen is present (Mostafavi et al., 2020). Therefore, when assessing the technology's nutritional impact, the combined effects of irradiation dose, packaging atmosphere, and storage environment must be taken into account.

A thorough synthesis of the most recent scientific data on the effects of gamma irradiation on the nutritional and phytochemical characteristics of foods is required, given the growing interest in non-thermal food preservation technologies around the world. Individual commodities have been the subject of numerous experimental investigations, but comparative studies between various food categories are still scarce finding broad patterns, dose-response correlations, and research gaps that need more study can be aided by a thorough analysis of the body of existing literature.

Thus, this review's goal is to critically assess current research on how gamma irradiation affects the proximate composition and phytochemical components of a variety of food items, such as cereals, legumes, fruits, vegetables, spices, and oilseeds. The review also discusses factors influencing irradiation outcomes, highlights dose-dependent patterns found across studies, and investigates the underlying mechanisms responsible for nutrient modification. The review also highlights research gaps and offers suggestions for

improving irradiation treatments to preserve nutritional quality while attaining microbiological safety and extending shelf life.

II. Mechanism of Gamma Radiation Interaction with Food Components

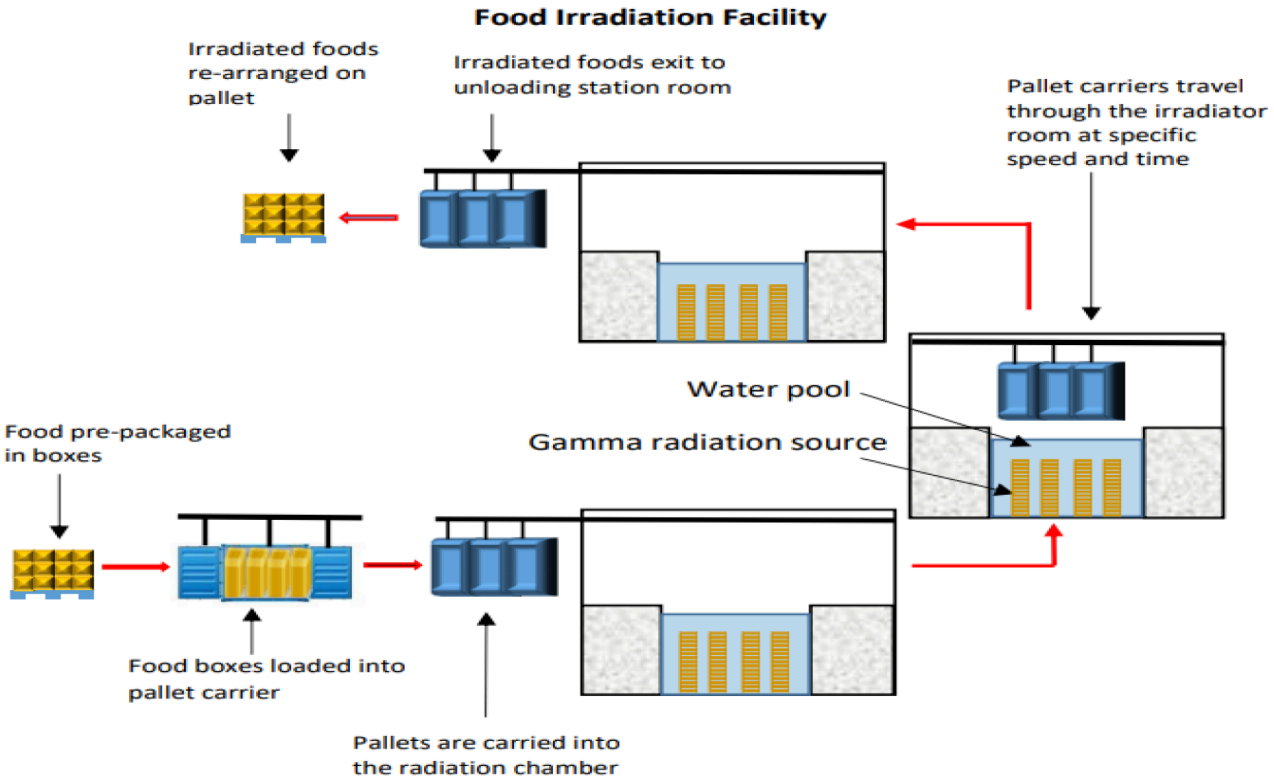


Figure 1: Mechanism of Gamma Radiation Interaction with Food Components ()

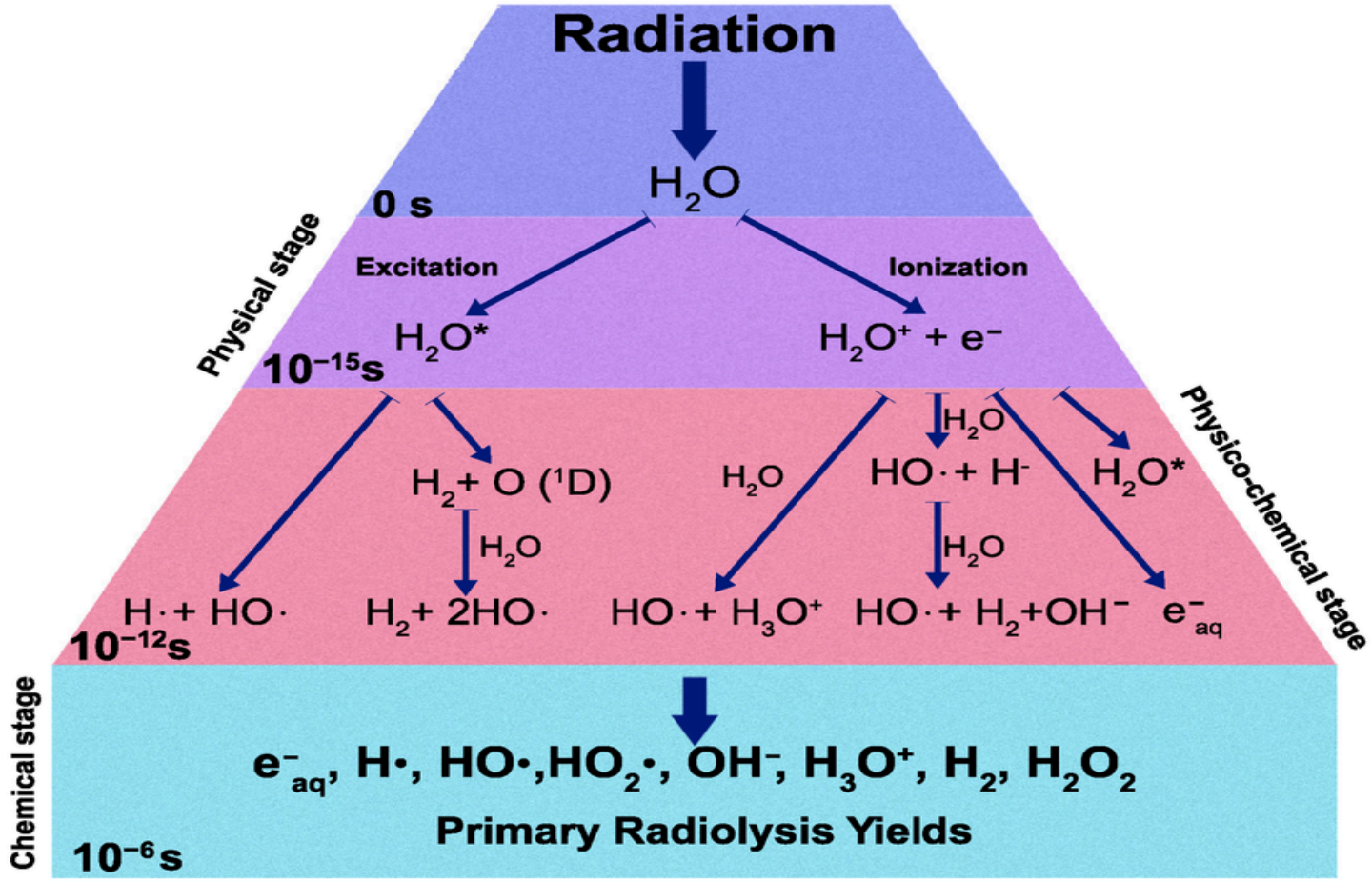


Figure 2: Decomposition of Water Molecules by Ionizing Radiation (Hall & Giaccia, 2012)

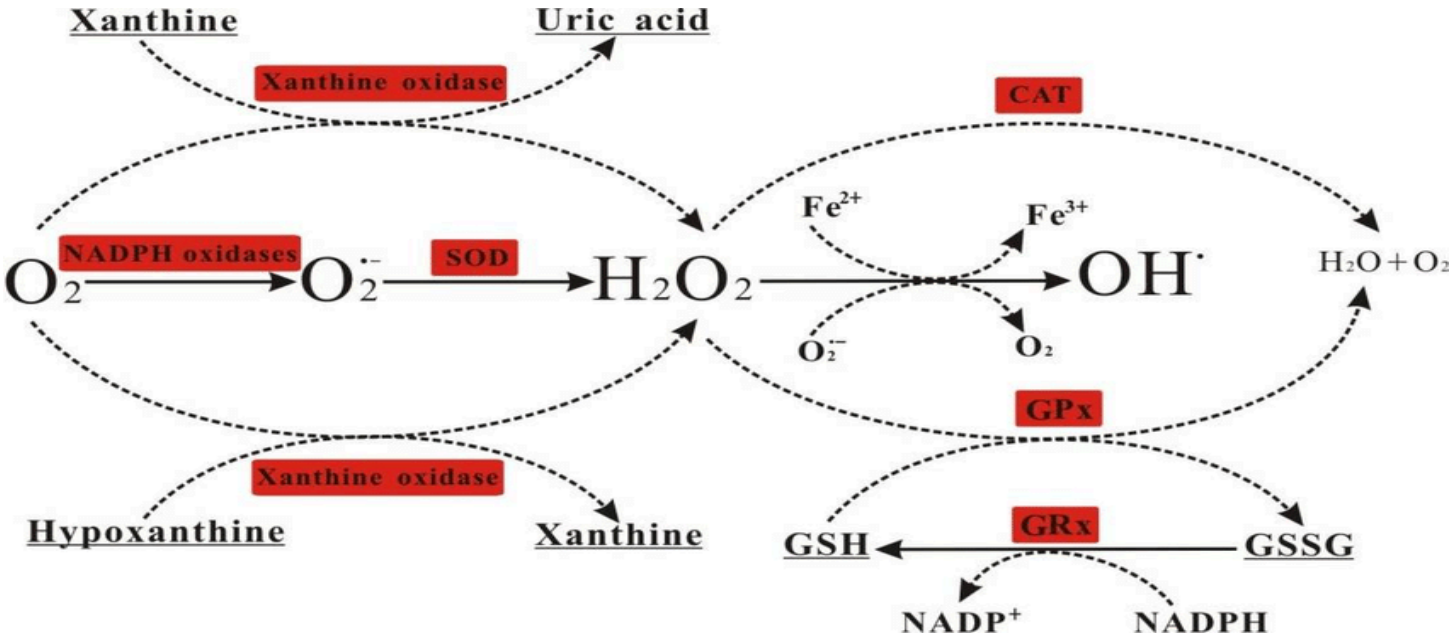


Figure 3: Decomposition of Water Molecules by Ionizing Radiation (Hall & Giaccia, 2012)

2.1 Direct Effects

Ionization of biomolecules:

- Protein backbone cleavage
- Lipid peroxidation
- Carbohydrate depolymerization

2.1 Indirect Effects (Dominant in High-Moisture Foods)

Radiolysis of water generates: $^{-}$OH (hydroxyl radical), $^{+}$H (hydrogen radical) and e^{-}_{aq} (hydrated electron)

These reactive species oxidize:

[1] Ascorbic acid

[2] Unsaturated fatty acids

[3] Phenolic compounds

(Bhatnagar et al., 2022 ; Fan & Sokorai, 2015 ; Mostafavi et al., 2020)

III. Effects on Proximate Composition

3.1 Protein

Across legumes (cowpea, chickpea, lentils), crude protein generally remains stable at ≤10 kGy (Ali et al., 2019 ; Bamidele et al., 2021). Some studies report slight increases due to enhanced nitrogen extractability (Siddhuraju et al., 2018). At higher doses (>15 kGy), protein denaturation and reduced solubility may occur (Khan et al., 2017). Several studies report either stability or slight increases in crude protein following irradiation. In *Vigna unguiculata*, crude protein increased at doses up to 25 kGy (Soris Tresina & Mohan, 2011). Similarly, irradiation of legume seeds improved protein digestibility (Ali et al., 2019). However, cocoa beans irradiated at 7 kGy showed no significant protein alteration (Apaydın, 2024).

The apparent increases may result from enhanced nitrogen extractability rather than true protein synthesis.

3.2 Lipids and Fatty Acids

Lipids are most sensitive due to unsaturated bonds, like Increased peroxide value in oilseeds (peanut, sesame) above 10 kGy (Al-Bachir, 2016; Arvanitoyannis et al., 2018). Minor fatty acid profile changes at ≤5 kGy (Apaydın, 2024) and enhanced oxidative stability under vacuum packaging (Santos et al., 2019). Lipids are particularly susceptible to oxidative reactions. Cocoa beans exposed to gamma radiation exhibited reduced fat content and altered fatty acid profiles (Apaydın, 2024).

Low-moisture foods generally show minimal lipid degradation at doses below 10 kGy (Bhatnagar et al., 2022).

3.3 Carbohydrates and Fiber

Irradiation may cause partial depolymerization of polysaccharides (partial hydrolysis), leading to slight increases in measurable carbohydrate content (Soris Tresina & Mohan, 2011) and Increased reducing

sugars in cereals (Fan & Sokorai, 2015). Fiber content may decrease due to breakdown of complex structural carbohydrates (Siddhuraju et al., 2018)

3.4 Moisture and Ash

Moisture content remains largely unchanged immediately after irradiation (WHO, 2018). Minerals (ash) are radiation resistant and remain unaffected. Moisture content generally remains stable immediately after irradiation but may vary during storage (Bhatnagar et al., 2022).

IV. Effects on Phytochemical Composition

4.1 Total Phenolic Content (TPC)

Gamma irradiation often enhances total phenolic content at moderate doses (≤5 kGy) by releasing bound phenolics from cell wall complexes (Ali et al., 2019). However, higher doses can degrade phenolic structures due to oxidative stress (Ognyanov et al., 2022). Moderate doses of 1–5 kGy Increased TPC in faba beans and lentils (Ali et al., 2019; Al-Bachir, 2016) and Increased extractability due to cell wall disruption. High doses (>10 kGy) causes degradation via oxidation (Mostafavi et al., 2020).

4.2 Flavonoids

Flavonoid content may increase due to improved extractability or decrease at high doses. Cocoa bean epicatechin significantly declined following irradiation (Apaydın, 2024). Dose-dependent behaviour Increased flavonoids at 2–5 kGy in legumes and decreased epicatechin in cocoa at 7 kGy (Apaydın, 2024)

4.3 Vitamin C

Ascorbic acid is particularly sensitive to irradiation. Decreases have been observed in legumes and fruits at higher doses (Soris Tresina & Mohan, 2011; Jabin et al., 2023). The degradation mechanism involves oxidation via hydroxyl radicals. Consistently sensitive and so 10–30% loss at 5–10 kGy in fruits (Fan & Sokorai, 2015) and also greater losses during storage (Jabin et al., 2023)

4.4 Carotenoids

Carotenoids may be moderately stable at low doses but degrade at higher exposure levels. Some fruits show improved extractability at moderate doses. Stable at low doses; degradation begin at >7 kGy. Tomato lycopene shows moderate reduction beyond 10 kGy (Radi et al., 2017).

4.5 Antioxidant Activity

Antioxidant capacity often increases when phenolics increase but declines when sensitive compounds degrade. Effects depend on food matrix and storage conditions (Ognyanov et al., 2022).

Table 1: Dose-Dependent Patterns

Dose Range	Observed Effects
1–5 kGy	Minimal proximate changes; possible increase in phenolics
5–10 kGy	Stable macronutrients; moderate vitamin loss

Dose Range	Observed Effects
>10 kGy	Greater phytochemical degradation; lipid oxidation risk

Generalized Dose–Response Trend in Nutritional Components

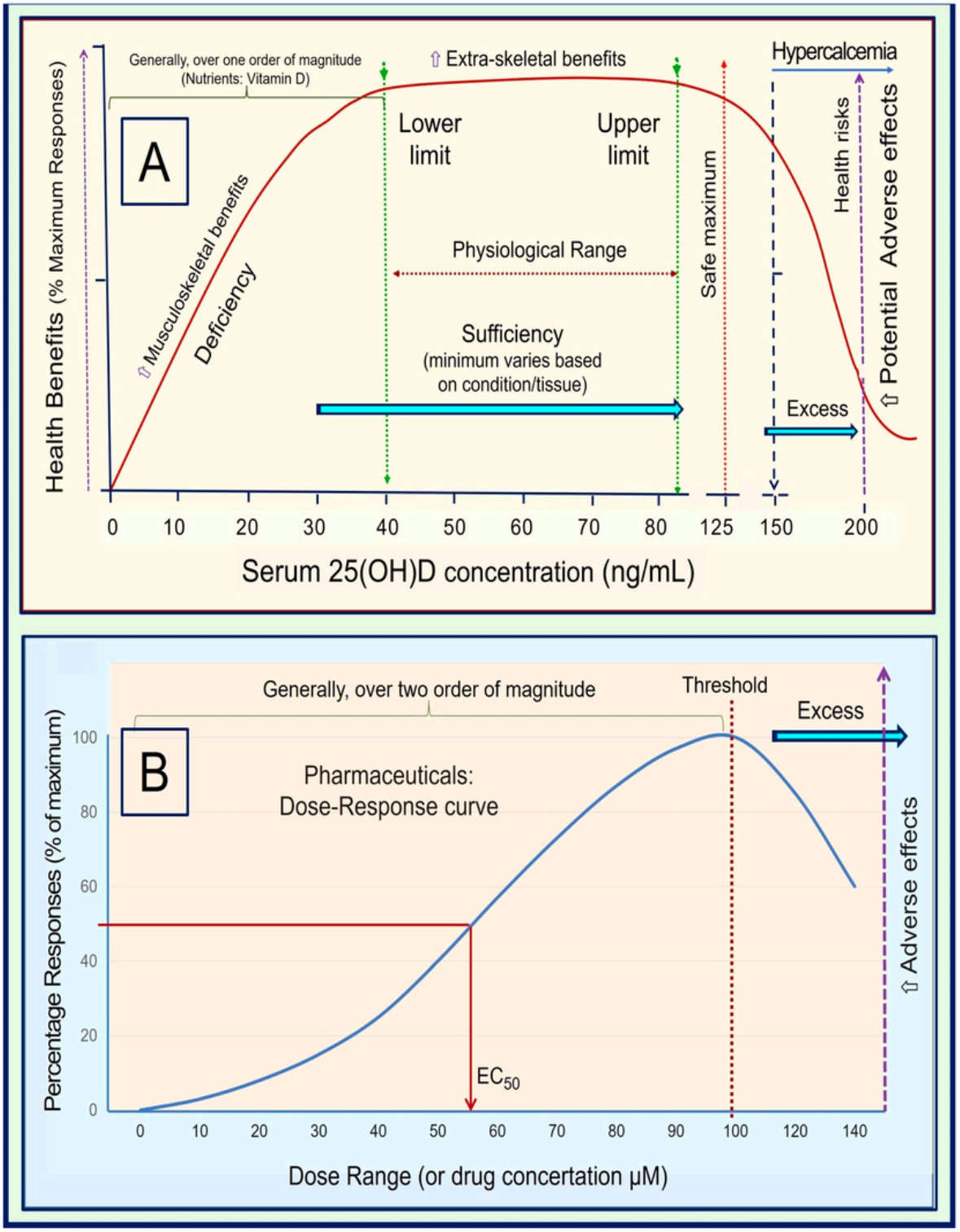


Figure 4: Generalized Dose–Response Trend in Nutritional Components

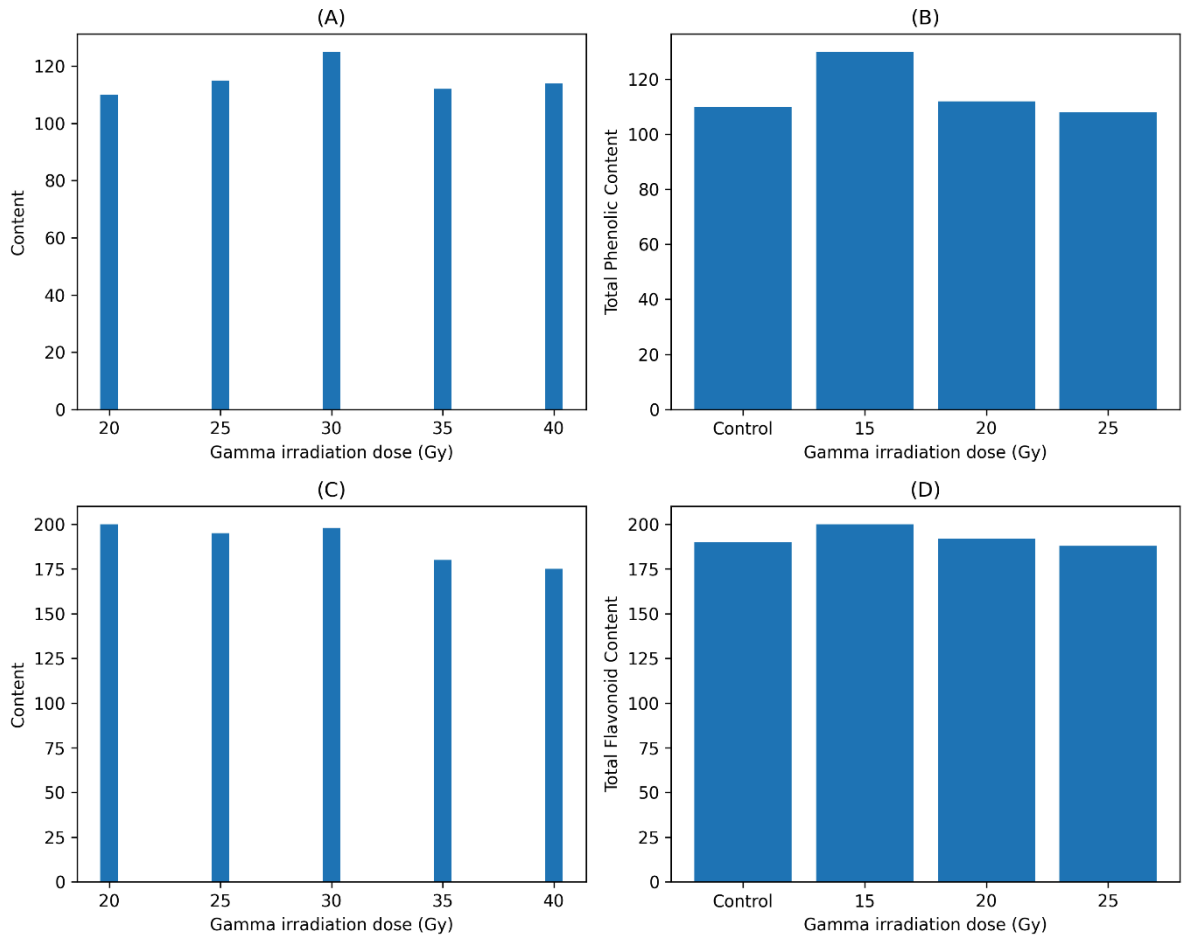


Figure 5: Pictorial representation of Gamma Irradiation dose against Phytochemical component

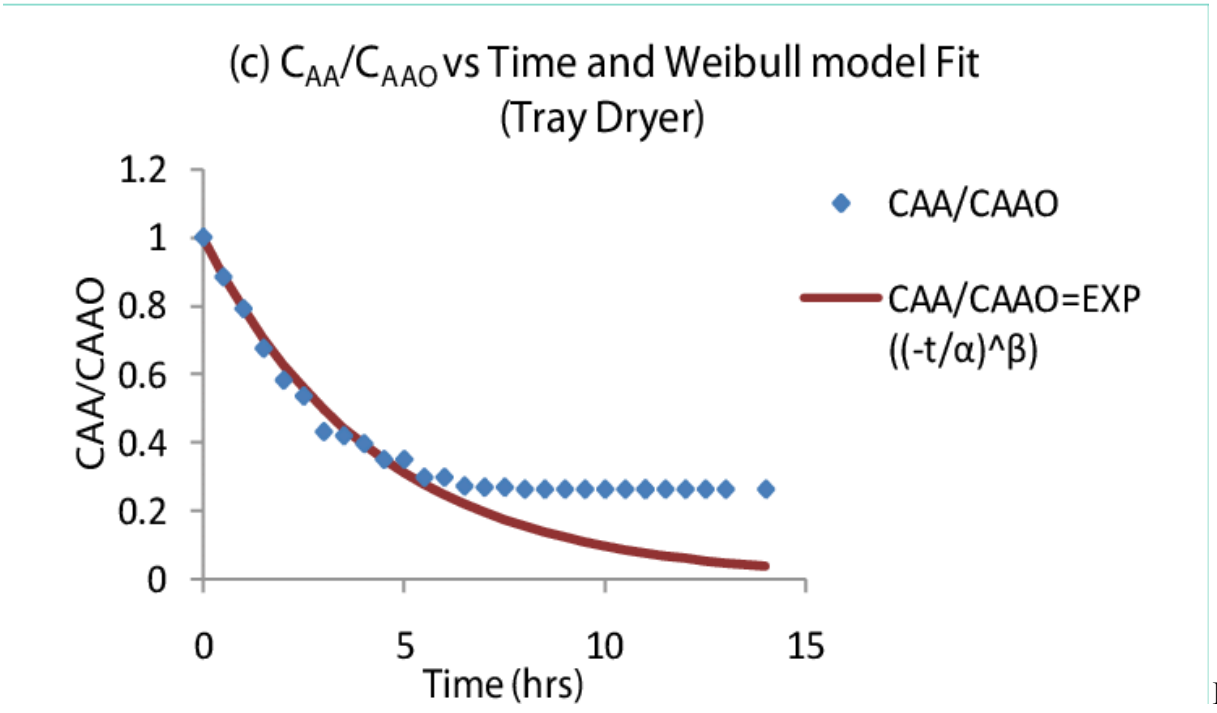


Figure 6: Graph of Time Rate and Weibull Model Fit

Table 2: Observed Pattern

Dose (kGy)	Proximate Composition	Phenolics	Vitamin C
1–3	Stable	↑ Slight	Minimal loss
5–7	Stable	↑ Moderate	10–20% loss
10–15	Slight changes	↓	20–40% loss
>15	Structural damage	Significant ↓	Major degradation

Table 3: Comprehensive Summary Table on Effects of Gamma Irradiation on Phytochemical and Proximate Composition of Food Products

Food Product	Dose (kGy)	Proximate Composition Effects	Phytochemical Effects	Key Findings	Citation
Cowpea (*Vigna unguiculata*)	2–25	Protein ↑; fiber ↓; ash ↓	Phenolics ↑; tannins ↑; Vitamin C ↓	Increased protein extractability; antioxidant enhancement at moderate dose	(Soris Tresina & Mohan, 2011)
Faba bean (*Vicia faba*)	1–10	No significant change	Phenolics ↑; flavonoids ↑	Enhanced antioxidant activity due to release of bound compounds	(Ali et al., 2019)
Chickpea (*Cicer arietinum*)	2–8	Protein stable; lipid slight ↓	Phenolics ↑	Improved digestibility and antioxidant capacity	(Siddhuraju et al., 2018)
Lentil (*Lens culinaris*)	1–6	Minimal changes	Phenolics ↑; flavonoids ↑	Improved bioavailability of phytochemicals	(Al-Bachir, 2016)
Cocoa beans	5–7	Fat ↓; protein stable	Epicatechin ↓; total phenolics ↓	Oxidative degradation of flavonoids at higher doses	(Apaydın, 2024)
Rice (pigmented)	2–10	Carbohydrates ↑; protein stable	Antioxidants ↑; phenolics ↑	Improved antioxidant activity at moderate doses	(Smita et al., 2023)
Wheat grains	1–5	Moisture stable; protein stable	Minor phytochemical changes	Suitable for storage without major nutritional loss	(Fan & Sokorai,2015)
Maize	2–10	Protein stable; lipid ↓ slight	Phenolics ↑	Enhanced shelf life and antioxidant potential	(Mohamed et al., 2009)
Tomato	1–10	Moisture slight ↓; TSS ↑	Lycopene stable ≤7 kGy; ↓ at higher doses	Shelflife extension with minimal nutrient loss	(Radi et al., 2017)
Mango peel	2–8	Stable	Vitamin C ↓; phenolics ↑	Increased antioxidant activity despite vitamin loss	(Jabin et al., 2023)

Food Product	Dose (kGy)	Proximate Composition Effects	Phytochemical Effects	Key Findings	Citation
Apple	1–5	Minimal change	Polyphenols ↑	Enhanced phytochemical extractability	(Fan & Sokorai, 2015)
Potato	0.5–1	No major changes	Minor phytochemical changes	Effective sprout inhibition	(IAEA, 2015)
Onion	0.5–1	Stable	Flavonoids stable	Sprout inhibition without nutrient loss	(WHO, 2018)
Peanut	2–10	Lipid oxidation ↑ at high dose	Phenolics slight ↑	Oxidative stability affected by dose	(Nguyen et al., 2022)
Sesame seeds	5–15	Lipid oxidation ↑; fat ↓	Minor phytochemical changes	Unsaturated fats sensitive to irradiation	(Al-Bachir, 2016)
Soybean	2–10	Protein stable; lipid slight ↓	Isoflavones ↑	Improved functional properties	(Bhatnagar et al., 2022)
Spices (chili, pepper)	5–10	Stable	Capsaicinoids stable; antioxidants ↑	Effective decontamination without quality loss	(Balakrishnan et al., 2021)
Rose hip	1–10	Stable	Phenolics stable; antioxidants stable	Minimal degradation due to low moisture	(Ognyanov et al., 2022)
Cucumber	1–6	Moisture ↓ slight	Vitamin C ↓	Storage-dependent degradation	(Khalili et al., 2017)
Seafood	2–7	Protein stable; lipidoxidation ↑ slight	Antioxidant activity ↓	Shelf-life extended with minor oxidation	(Uikey et al., 2025)

4.6 Factors Influencing Nutritional Outcomes

- Oxygen availability
- Packaging atmosphere
- Moisture level
- Food matrix complexity
- Storage duration
- Radiation source energy

(Santos et al., 2019 ; Mostafavi et al., 2020)

4.7 Nutritional Safety and Regulatory Perspective

International agencies confirm no significant nutritional hazards at ≤10 kGy (WHO, 2018; IAEA, 2015). Protein quality, amino acid integrity, and mineral bioavailability remain within acceptable ranges.

4.8 Research Gaps (2015–2025)

1. Limited long-term storage interaction studies
2. Insufficient meta-analysis on antioxidant capacity
3. Understudied tropical indigenous crops
4. Lack of molecular-level phytochemical degradation mapping
5. Limited combined irradiation + packaging studies

4.9 Implications for Food Security and Post-Harvest Loss Reduction

Gamma irradiation offers significant potential for reducing microbial spoilage and extending shelf life while maintaining nutritional quality when properly optimized. This is particularly relevant for tropical fruits and legumes in Africa (Onoja et al, 2025).

V. Conclusion

This review critically evaluated the impact of gamma irradiation on the proximate composition and phytochemical profile of diverse food products, including cereals, legumes, fruits, vegetables, spices, and oilseeds. The synthesis of recent literature (2015–2025) demonstrates that gamma irradiation is a robust, non-thermal preservation technology capable of enhancing food safety and extending shelf life while largely preserving nutritional quality when applied within recommended dose limits.

A key finding of this review is that the proximate composition of foods remains relatively stable under low to moderate irradiation doses (≤10 kGy). Macronutrients such as proteins, carbohydrates, and ash exhibit minimal or no significant changes, indicating that gamma irradiation does not substantially compromise the fundamental nutritional value of food products. However, lipids are comparatively more susceptible to oxidative degradation, particularly at higher doses, due to the radiolytic formation of free radicals that initiate lipid peroxidation reactions (Bhatnagar et al., 2022; Mostafavi et al., 2020). These findings highlight the importance of dose optimization and protective strategies such as vacuum packaging to mitigate oxidative damage. In contrast, phytochemical constituents exhibit a complex, dose-dependent response to gamma irradiation. Moderate irradiation doses (typically 1–5 kGy) often result in an increase in total phenolic content, flavonoids, and antioxidant activity, primarily due to the disruption of plant cell wall matrices and the release of bound bioactive compounds (Ali et al., 2019; Ognyanov et al., 2022). This enhancement suggests that controlled irradiation can improve the functional quality of certain foods. However, higher doses (>10 kGy) tend to induce degradation of sensitive phytochemicals, including vitamin C, carotenoids, and some polyphenols, through oxidative mechanisms driven by reactive oxygen species generated during radiolysis (Fan & Sokorai, 2015; Radi et al., 2017). Thus, the dual effect of irradiation underscores the need for carefully calibrated treatment conditions.

The review further reveals that the extent of irradiation-induced changes is strongly influenced by intrinsic and extrinsic factors, including food matrix composition, moisture content, oxygen availability, packaging

conditions, and storage duration. High-moisture foods such as fruits and vegetables are more prone to indirect oxidative reactions due to water radiolysis, whereas low-moisture foods such as grains and spices exhibit greater stability. Additionally, post-irradiation storage conditions can amplify or mitigate nutrient degradation, indicating that irradiation should be considered as part of an integrated preservation system rather than a standalone treatment (Mostafavi et al., 2020). From a safety and regulatory perspective, the evidence consistently supports the conclusion that gamma irradiation is nutritionally safe at doses approved by international agencies, with no significant adverse effects on protein quality, mineral composition, or overall dietary value (WHO, 2018). This reinforces its suitability for large-scale application in food preservation, particularly in regions facing high post-harvest losses and food insecurity. Despite the substantial progress in this field, several research gaps remain. There is a need for more comprehensive, long-term studies evaluating the combined effects of irradiation and storage, particularly under different packaging atmospheres. Furthermore, limited data exist on the molecular mechanisms of phytochemical transformation and the bioavailability of irradiated nutrients in human systems. Emerging research should also explore the application of gamma irradiation to underutilized indigenous crops like Cocoyam and Yellow yam, especially in developing countries, to enhance food security and nutritional outcomes.

Gamma irradiation represents a scientifically validated and nutritionally acceptable technology for food preservation. While proximate composition is largely retained, phytochemical responses are dose-dependent and require optimization to balance enhanced bioactive availability with the prevention of nutrient degradation. Future advancements in irradiation technology, combined with improved packaging and storage strategies, will further strengthen its role in sustainable food systems and global food security.

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The "Digital Shackle": Researching Modern Cyber Slavery and Policy Responses in India

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Abstract—**This paper explores why bonded labour, a form of modern slavery, still exists in India even though it was legally banned nearly fifty years ago. The sources explain that this exploitative system is deeply rooted in poverty, unpaid debts, and caste-based discrimination, which keep many families trapped in a cycle of forced work for little or no pay. The study focuses on a specific government program called the Central Sector Scheme (CSS), launched in 2016 to provide financial help, housing, and job training to rescued workers. However, the paper identifies major problems in how these programs work, such as long delays in giving money to survivors, inactive committees that rarely meet, and a lack of training for the officials involved. Furthermore, the research paper highlights a new and growing threat called "Cyber Slavery," where young people are tricked into going abroad for high-paying IT jobs, only to have their passports stolen and be forced to carry out online scams under the threat of torture. Beyond poverty, caste, geographical boundaries, cyber slavery has turned to be one of the most serious forms of slavery which is globally relevant issue in the present era. To address these issues, the paper suggests strengthening local committees, using digital tools to track cases, and ensuring that survivors themselves have a voice in the rehabilitation process. Ultimately, the study aims to provide a roadmap for the government to create a more accountable and effective system that can finally end all forms of bonded labour in India. Despite the formal abolition of the bonded labour system nearly five decades ago, it remains one of India's most entrenched human rights violations. This paper examines the effectiveness of the Central Sector Scheme for Rehabilitation of Bonded Labourers (CSS) introduced in 2016. While the CSS provides a rights-based framework for socio-economic reintegration, its implementation is hindered by systemic gaps, including administrative delays and inactive monitoring mechanisms. Furthermore, this research highlights the emergence of "Cyber Slavery" as a modern evolution of bondage, requiring an updated policy response.**

Index Terms—**Digital Slavery, Bonded Labour, Human Rights, Modern Slavery, Digital Exploitation.**

I. Introduction

Cyber slavery is described as a **"technologically mediated and transnational form of coercive labour in which victims are trafficked through fraudulent overseas job offers and forced to participate in cyber-enabled fraud"**. Despite its formal abolition nearly five decades ago through the **Bonded Labour System (Abolition) Act, 1976**, bonded labour remains one of the most complex and entrenched human rights violations in India. This exploitative system is deeply rooted in historical socio-economic inequalities, including caste-based discrimination, extreme poverty, and cycles of indebtedness**.** Although the 1976 Act provides a legal mechanism for the identification and release of victims, its implementation has often been fragmented, leading to poor reintegration of survivors into society.

To bridge the gap between legislation and ground-level reality, the Government of India introduced the Central Sector Scheme for Rehabilitation of Bonded Labourers (CSS) in 2016. This scheme offers a

multi-pronged approach to rehabilitation, providing financial assistance—ranging from ₹1 lakh to ₹3 lakh depending on the victim's category—alongside non-cash benefits such as land allotment, housing units, and education for children.

However, the effectiveness of this policy is frequently undermined by systemic challenges. Field reports indicate significant delays in fund disbursement**,** a lack of coordination between central and state authorities, and the widespread inactivity of BLVCs, many of which meet irregularly or lack clear accountability mechanisms. Furthermore, the nature of bondage is evolving. A new and alarming frontier has emerged in the form of **"Cyber Slavery,"** where tech-savvy youths are lured by fraudulent high-paying job offers in Southeast Asian countries like Cambodia, Myanmar, and Laos. These individuals often find their passports confiscated and are forced to carry out online financial scams under coercive conditions, including physical torture.

This study provides a comprehensive policy review of the CSS, focusing on the institutional role by examining the systemic gaps that hinder effective rehabilitation, this research argues for a survivor-centric, data-driven approach to transform these committees into active platforms for justice. Ultimately, the paper seeks to offer actionable recommendations to strengthen India's response to both traditional debt bondage and modern digital exploitation.

Bonded labour in India is deeply rooted in historical, socio-economic, and structural inequalities, such as caste-based discrimination and cycles of indebtedness. The system was legally abolished via the **Bonded Labour System (Abolition) Act, 1976**, yet implementation remains inconsistent. Victims often remain trapped in debt bondage across rural and informal sectors, working under coercive conditions for little to no wages.

In recent years, the definition of bondage has expanded beyond traditional sectors. The emergence of **"Cyber Slavery"**—where individuals are lured by fraudulent job offers to foreign "scam compounds" and forced to commit crimes under duress—represents a new, digital frontier of human rights violations.

II. Objective

The primary objective of this research is to conduct a comprehensive policy review of the Central Sector Scheme (CSS) for Rehabilitation of Bonded Labourers.

Specific Objectives

Fig. 1. **Evaluating CSS Effectiveness:** To assess how far the 2016 scheme has succeeded in achieving its core mandates of **rescue, relief, rehabilitation, and socio-economic reintegration** for victims of bonded labour. **T**he **role, composition, and functionality of Vigilance Committees** at the district and sub-divisional levels, identifying why many remain inactive or meet irregularly.

Fig. 2. **Identifying Systemic Gaps:** To pinpoint **administrative, financial, and legal barriers**—such as delays in fund disbursement, weak inter-agency coordination, and a lack of standardized monitoring tools—that hinder the rehabilitation process.

Fig. 3. **Addressing Modern Bondage:** To explore the emergence of **"Cyber Slavery" and digital bondage**, examining how these new forms of exploitation challenge traditional legal frameworks like the **Bonded Labour System (Abolition) Act, 1976**.

Fig. 4. **Formulating Policy Recommendations:** To propose **actionable measures for reform**, including the use of digital monitoring tools, the inclusion of survivors in monitoring platforms, and the institutionalization of capacity building for officials.

Ultimately, this study aims to contribute to the policy discourse by advocating for a rights-based, survivor-centric, and data-driven approach to achieve a bonded labour-free India.

III. Research Methodology

The research methodology for this paper adopts a **qualitative and policy-analytical approach**, specifically designed to evaluate the implementation of the Central Sector Scheme. The study situates bonded labour within a rights-based and institutional analytical framework, viewing it not merely as an economic problem but as a fundamental violation of human rights that requires a coordinated, justice-oriented policy response.

To achieve the research objectives, the following methodology is employed:

Data Collection Strategy

The study utilizes a combination of primary and secondary data sources to provide a holistic view of the rehabilitation landscape:

Desk-Based Secondary Review: A comprehensive review is conducted of government policy documents, official circulars, and reports from the **Ministry of Labour and Employment**. This includes analyzing evaluation studies, judicial pronouncements, and secondary literature from academic and civil society sources.

Government and Institutional Records: The research draws on RTI data, minutes of BLVC meetings (where accessible), and reports from the **National Human Rights Commission (NHRC)** and the **I2455nternational Labour Organization (ILO)** regarding forced labour.

Primary Stakeholder Consultations: The analysis is enriched through interviews and interactions with government officials, social workers, and NGOs actively engaged in the eradication of bonded labour. The methodology includes the use of **Focus Group Discussion (FGD) questionnaires** and interview schedules to gather ground-level insights.

IV. Field-Level Observations and Case Reviews

The research incorporates **field case reviews** to bridge the gap between policy theory and practice. This includes:

Case Studies: Examining specific instances of traditional bondage and the emerging trend of **"Cyber Slavery"**—such as the rescue of Indian nationals from scam compounds in Southeast Asian countries like Myanmar and Cambodia.

Comparative Analysis: Optional state-wise comparative analysis (e.g., Tamil Nadu, Bihar, Rajasthan) based on rescue and rehabilitation data provided by the Ministry of Labour and Employment.

V. Scope and Limitations

While the research is comprehensive in its policy review, it acknowledges certain limitations, such as the **limited availability of official data** regarding the exact number of victims in modern "cyber slavery" contexts and the irregular maintenance of BLVC meeting minutes across different districts.

Analytical Framework

The study employs an **institutional analysis** to identify systemic gaps in the implementation mechanism, such as delays in fund disbursement and the inactivity of Vigilance Committees. By focusing on **victim-centered service delivery**, the methodology evaluates how effectively the CSS links survivors to developmental schemes like **MGNREGA, PM Awas Yojana, and Skill India**.

The major discussion in this research centers on why bonded labour continues to exist in India and how modern technology has created a dangerous new version called "cyber slavery." **Bonded labour** is a system where a person is forced to work to pay off a debt or because of their social status. Even though India banned this system in 1976, it still exists today because of poverty and discrimination. While it used to happen mostly in places like brick kilns or farms, it has now evolved into a new, dangerous form called **"Cyber Slavery"**. In **Cyber Slavery**, young people who know how to use computers are tricked by **fake ads for high-paying IT jobs** in countries like **Cambodia, Myanmar, and Laos**. When they arrive, their **passports are stolen**, and they are locked in guarded buildings called "scam compounds". They are **forced to work 16 hours a day** making fake social media profiles to trick other people into losing their money through online scams. Thousands of Indians have already been rescued from these places.

Neeraj Soni, a senior researcher at Cyber Peace, warned in August 2024 that **"cyber slavery is a form of modern exploitation that begins with online deception and evolves into physical human trafficking"**. He describes a **"disturbing continuum of online manipulation"** where victims, primarily tech-savvy young professionals, are lured by fake advertisements for high-paying jobs in Thailand or the Philippines, only to have their **"travel documents confiscated"** upon being diverted to compounds in Cambodia or Laos. Soni recommends that because cybercriminals utilize social media as a tool for targeting, it requires **"collective efforts from social media companies and regulatory authorities"** to develop preventive measures and empower netizens to **"cross-verify details from authentic sources"**.

Emerging Trends: The "Digital Shackle"

Modern slavery now includes **Cyber Slavery**, as evidenced by recent cases where youths from regions like Bareilly were lured to Myanmar with promises of high-paying IT jobs. In these "scam compounds," victims:

- Have their **passports seized** and their freedom of movement restricted.
- Are forced to create **fake social media profiles** to defraud others.
- Face **physical and mental torture** if they refuse to comply. This shift necessitates that BLVCs and law enforcement develop digital literacy and international coordination capabilities to address modern bondage.

The harrowing experience of a 24-year-old survivor named **Pipi** serves as a stark example of how traditional debt bondage has evolved into cyber slavery. After being lured to Cambodia, Pipi was sold four times between different gangs, eventually being held in a scamming compound in Sihanoukville where her "purchase price" of USD 25,000 was converted into a debt she was forced to repay through online scamming. She faced severe physical abuse and torture for refusing to comply with the criminals before her eventual rescue in July 2022. In a similar case involving Indian nationals, seven youths from the Bareilly division, including individuals like Shumanshu Gupta and Ravi Rajput, were rescued from scam centers in Myanmar after being lured by the promise of high-paying IT careers. Upon arrival, their passports were confiscated, their freedom was taken away, and they were forced to operate fraudulent social media profiles to dupe others; those who resisted the work were subjected to daily mental torture and beatings. These case studies highlight a consistent pattern where victims are stripped of their liberty, confined in guarded compounds, and coerced through debt and violence to commit online financial crimes.

The Indian government helps victims through the Central Sector Scheme, which provides financial grants based on an individual's specific situation, such as 1 lakh rupees for adult males, 2 lakh rupees for women and children, and up to 3 lakh rupees for extreme cases like trafficking. In addition to money, the program

offers essential life support by linking survivors to benefits like housing, agricultural land, and schooling for their children. To carry out this work at the local level, every district is supposed to have a Bonded Labour Vigilance Committee made up of local officials and social workers who are responsible for finding victims and making sure they get the rehabilitation help they need.

However, there are major problems with how these programs work in real life. Many **local committees are inactive** and rarely meet. There are also **long delays in giving money** to the survivors, and the current laws were not originally designed to handle modern crimes like cyber slavery that happen across international borders.

Bonded labor in India has evolved from traditional rural debt bondage into a complex, transnational crisis known as **"Cyber Slavery,"** where tech-savvy youth are lured by fraudulent overseas IT job offers and forced into committing cyber-enabled fraud. While the Bonded Labour System (Abolition) Act, 1976, and the Central Sector Scheme (CSS) 2016 provide a framework for rescue and financial rehabilitation—offering grants between ₹1 lakh and ₹3 lakh for victims—these mechanisms are primarily designed for domestic exploitation and struggle to address modern digital coercion. Recent official data reveals the alarming scale of this new threat, with thousands of Indian nationals—including 2,265 from Cambodia, 2,290 from Lao PDR, and 2,165 from Myanmar—rescued from international "scam compounds" where they faced indicators of bondage such as passport seizure, confinement, and forced criminality. There is an urgent requirement for a survivor-centric and digitally-aware policy reform that modernizes the current institutional architecture to bridge the gap between labor laws, anti-trafficking efforts, and international cybercrime enforcement.

Chiang, Mina, and Sharlene Chen, in their report ***Cyber Slavery in the Scamming Compounds*** (Humanity Research Consultancy, Sept. 2022), write that **"cyber slavery is emerging as a form of organized crime of unprecedented severity and scale,"** and they warn that **"tens of thousands of victims are held captive in scamming compounds"**. The researchers emphasize that while fraudulent messages have become a daily inconvenience for many, this industry is actually rooted in a **"malignant new form of modern slavery"** where victims are forced to conduct scams virtually, allowing criminals to easily shift operations across borders to evade arrest. This form of exploitation involves **debt bondage**, **restriction of movement**, and **forced criminality**, as seen in the case of a survivor named **Pipi**, who was **sold four times** and held for a "debt" of **USD 25,000** representing her own purchase price. Because these operations exploit the loopholes in **international telecom and financial systems**, the authors argue that we **"urgently need a systemic and coordinated approach from governments and NGOs"** to dismantle the scam compounds and rescue the hundreds of thousands of individuals trapped within them. This emerging **"digital shackle"** challenges traditional definitions of bondage but functionally mirrors the **Bonded Labour System (Abolition) Act, 1976**, through the **forfeiture of liberty and forced service** under the threat of violence.

VI. The Reality of Traditional Bonded Labour

Even though bonded labour was legally banned in 1976, it remains a serious problem because of deep-rooted issues like extreme poverty, unpaid debts, and social discrimination based on caste. Many families in rural areas stay trapped in a cycle of forced work for little or no pay because they cannot pay back small loans. While the law says these workers are free, the actual practice of finding and helping them is often slow and inconsistent. **The Ministry of Labour & Employment**, in an official statement from March 2023, emphasizes that the Government has adopted a **"multi-pronged strategy for abolition of bonded labourers system,"** which includes the empowerment of Executive Magistrates to trial offences and the prescription of **"Vigilance Committees at District and Sub-divisional levels"** to identify and rehabilitate victims. Under the Central Sector Scheme (CSS), the government provides financial assistance alongside essential non-cash support such as the **"allotment of house/site & agricultural land,"** land development, and even **"education for children"**. However, as noted in recent policy reviews, while the 2016 CSS marked a shift toward a **"rights-based rehabilitation framework,"** its potential is often limited

by **"systemic implementation failures, including delays in disbursement"** and the **"functional inactivity of Vigilance Committees"**.

The Minister of State in the Ministry of External Affairs, Shri Kirti Vardhan Singh, provided critical updates on December 11, 2025, regarding the repatriation of citizens trapped in digital bondage, stating that dubious firms have **"lured Indian nationals mostly through social media channels"** to Southeast Asian countries to carry out **"cybercrime and other fraudulent activities from scam centres"**. The Ministry confirmed that through concerted efforts, thousands of Indian nationals have been rescued, including **"2,265 from Cambodia, 2,290 from Lao PDR, and 2,165 from Myanmar"**. To combat these fraudulent agencies, the government has notified a list of **"3,505 unregistered agents"** on the e-Migrate portal as of October 2025 and shares complaints with state governments and the **"Indian Cybercrime Coordination Centre (I4C)"** for further action.

VII. How the Government Tries to Help (The CSS)

The Central Sector Scheme for Rehabilitation of Bonded Labourers, introduced in 2016, provides a comprehensive rights-based framework designed to support the long-term reintegration of rescued workers. A primary feature of this program is its graduated financial assistance, which offers 1 lakh rupees for adult male survivors, 2 lakh rupees for women and children, and up to 3 lakh rupees for extreme cases involving trafficking, disability, or sexual exploitation. Beyond direct monetary aid, the scheme ensures vital life support through various non-cash benefits, such as the allotment of agricultural land and house sites, animal husbandry support, and dedicated education for the children of rescued laborers. To foster economic resilience and prevent individuals from falling back into debt cycles, the scheme utilizes a convergence model that links survivors with other major national programs, including Skill India for vocational training, MGNREGA for wage employment, and PM Awas Yojana for housing. This integrated approach aims to provide survivors with the tools and resources necessary to achieve sustainable social and economic independence.

VIII. The New Frontier: Cyber Slavery

A major part of the discussion is the rise of **"Cyber Slavery,"** a modern form of human trafficking where technology is used to enslave people. The cycle of cyber slavery begins when tech-savvy young adults are lured by fake social media advertisements for high-paying IT and customer support jobs in Southeast Asian countries like Cambodia, Myanmar, and Lao PDR. Upon arrival, the reality of the situation is revealed as their passports are confiscated and they are confined in heavily guarded scam compounds surrounded by high fences and constant surveillance. Victims are then coerced into working 14 to 17 hours daily to carry out online financial fraud, most notably pig-butchering scams that use emotional manipulation to trick targets into fake investments. Those who refuse to comply or fail to meet their scam quotas are subjected to brutal punishments, including physical beatings, electric shocks, and severe mental torture.

IX. Constitutional and Legislative Safeguards

The Indian Constitution, under **Articles 23 and 24**, prohibits forced labour and child labour. The primary legislative tool is the **Bonded Labour System (Abolition) Act, 1976**, which provides the mechanism for identification, release, and rehabilitation. Other relevant laws include the **Child and Adolescent Labour Act (1986)** and the **Scheduled Castes and Scheduled Tribes (Prevention of Atrocities) Act**.

X. The Central Sector Scheme (CSS) 2016

To bridge the significant gap between legal abolition and the actual practice of rehabilitation, the Ministry of Labour and Employment introduced the **Central Sector Scheme (CSS) for Rehabilitation of Bonded Labourer in 2016**. This rights-based policy substantially enhanced **financial assistance** by providing higher rehabilitation grants—specifically ₹1 lakh for adult males, ₹2 lakh for women and children, and up to ₹3 lakh for extreme cases involving trafficking or sexual exploitation. Additionally, it established a **District Bonded Labour Rehabilitation Fund** with a minimum corpus of ₹10 lakh to ensure that rescued individuals receive **immediate relief funds** of at least ₹5,000 (and up to ₹20,000) right after their rescue, regardless of the status of legal proceedings. A critical feature of the CSS is its **convergence model**, which seeks to achieve long-term social reintegration by linking survivors with various developmental schemes such as **MGNREGA for wage employment, Skill India for vocational training, and PM Awas Yojana for housing**. Furthermore, the scheme demonstrates **gender sensitivity** by including specific, higher financial provisions for women and children to address their unique vulnerabilities and ensure they have the resources necessary to escape the cycle of bondage.

XI. Policy Gaps and Recommendations

To solve these issues, researcher scholar suggests that the government must **make local committees more active**, use **digital tools** to track every case, and **include survivors** in the planning process to ensure they get the help they truly need. Information should also be shared through **radio, SMS, and social media** so that young people do not fall for fake job offers. In order to strengthen the rehabilitation of bonded labourers and address the growing threat of cyber slavery, several key recommendations are proposed to bridge the gap between policy and practice. First, it is essential to speed up help by revising the Central Sector Scheme guidelines to ensure that rehabilitation funds are released in a strictly time-bound manner, which prevents survivors from falling back into poverty or debt cycles due to administrative delays. To improve long-term outcomes, technology should be utilized to create a national digital database and district-level registers that track every rescued person, ensuring they are actually being rehabilitated and linked to necessary welfare schemes. It is also vital to listen to survivors by formally including them in the statutory Bonded Labour Vigilance Committees, as their participation provides better ground-level advice and ensures monitoring is truly survivor-centric. Finally, because cyber slavery is a transnational crime that happens across borders, India must strengthen global cooperation by working closely with foreign governments and international agencies to conduct raid-and-rescue operations and shut down scam centers. These institutional reforms are necessary to modernize the existing enforcement architecture, which currently suffers from functional inactivity and is not yet fully equipped to handle digital exploitation.

XII. Systemic Improvements

To prevent rescued individuals from being re-entrapped in debt cycles, it is critical to revise the Central Sector Scheme guidelines to ensure that rehabilitation funds are released in a strictly time-bound manner. The current system often faces administrative delays and functional inactivity, which can be addressed by implementing digital monitoring tools to track the real-time status of survivor rehabilitation across different districts. This technological shift should be paired with a survivor-centric approach that includes rescued persons within the Bonded Labour Vigilance Committees. Including these individuals as committee members ensures that the monitoring process is participatory and informed by valuable ground-level insights into the actual challenges survivors face during their reintegration.

XIII. Institutional Strengthening

To effectively combat all forms of exploitation, the government must prioritize regular capacity building and training for District Magistrates and members of Bonded Labour Vigilance Committees so they can recognize traditional debt bondage as well as the emerging threats of digital slavery. This initiative

should be supported by improved inter-departmental coordination, where labour departments, law enforcement, and social welfare agencies work together in a more unified way. Strengthening this convergence is essential to ensure that rescued individuals are not only freed but are also successfully linked to various government welfare schemes and social protection programs for their long-term recovery.

XIV. Policy and Legislative Reforms

To strengthen the rehabilitation process, it is essential to revise the Central Sector Scheme (CSS) guidelines to guarantee the time-bound disbursement of funds, ensuring that rescued individuals do not fall back into debt cycles because of administrative delays. Alongside these financial reforms, the Bonded Labour System (Abolition) Act, 1976, should be amended to include more robust enforcement mechanisms and harsher penalties to deter offenders more effectively. Furthermore, integrating CSS records with national labour databases is critical for maintaining accurate data and tracking the long-term social and economic reintegration of freed labourers to ensure they remain sustainably independent.

XV. Comprehensive Rehabilitation and Convergence

To ensure that the rehabilitation of survivors is both effective and immediate, the District Administration is mandated to provide financial assistance of up to ₹20,000 right after rescue, a critical relief measure that is granted regardless of the legal status or conviction proceedings against the employer. This initial support is part of a broader "convergence" model under the Central Sector Scheme (CSS) 2016, which aims to strengthen the reintegration of rescued labourers by automatically linking them to essential national welfare programs such as MGNREGA for wage employment, PM Awas Yojana for housing, Skill India for vocational training, and the public distribution system (PDS) for essential commodities. Beyond immediate financial aid, the framework prioritizes long-term stability by offering non-cash assistance that includes agricultural land allotment, animal husbandry support (such as dairy or poultry), and dedicated education for the children of rescued workers to ensure they are mainstreamed into the formal schooling system. By combining immediate relief with these comprehensive socio-economic supports, the system strives to provide a sustainable path to freedom and prevent survivors from falling back into the cycle of debt bondage.

XVI. Addressing Cyber Slavery and Digital Exploitation

To dismantle the transnational infrastructure of scam compounds, a systemic and coordinated approach is required involving the Indian government, foreign administrations in Southeast Asia, and NGOs to conduct effective raid-and-rescue operations. Protecting citizens also involves strengthening international telecom systems to prevent scammers from harvesting personal data and enhancing financial monitoring to flag or block large-scale, suspicious transfers linked to fraudulent activities. Potential job seekers are strongly advised to utilize the e-Migrate portal to verify the credentials of recruitment agents and companies before accepting any overseas employment offers, as thousands of unregistered agents have already been flagged on the platform. Finally, the government and partner agencies must leverage SMS, radio, and social media to launch mass awareness campaigns that expose the deceptive tactics of "cyber-enslavers," such as advertisements for fake, high-paying IT jobs.

XVII. Community and NGO Engagement

To achieve a bonded labour-free India, the government must move beyond legislative prohibition and foster active partnerships with civil society organizations to improve the identification and social reintegration of victims. Empowering the public through accessible helplines and help centers is equally vital, as these tools allow netizens to report suspicious recruitment activity or online coercion before they become victims. While the Bonded Labour System (Abolition) Act of 1976 legally dismantled the system, exploitation

remains deeply rooted in historical socio-economic inequalities, poverty, and indebtedness. The introduction of the Central Sector Scheme in 2016 was a progressive step toward providing comprehensive rehabilitation, yet its effectiveness is frequently undermined by delays in fund disbursement, poor inter-departmental coordination, and a lack of consistent data maintenance.

Furthermore, the emergence of cyber slavery represents a dangerous evolution of bondage that necessitates an urgent policy update. With thousands of Indian nationals trapped in international scam compounds in countries like Cambodia, Myanmar, and Lao PDR, where they are forced into online financial crimes under duress, the traditional understanding of debt bondage must expand to address digital exploitation. Combating this digital shackle requires more than local enforcement; it demands international coordination to raid compounds, strengthened telecom and financial systems to disrupt scamming operations, and mass awareness campaigns through radio and social media to prevent fraudulent recruitment. Ultimately, the successful eradication of both traditional and modern forms of bonded labour depends on institutional accountability and systemic reform. By strengthening the vigilance committee mechanism, ensuring the timely delivery of rehabilitation grants, and maintaining high international pressure on cyber-slavery networks, India can fulfill its constitutional promise of protecting fundamental human rights and ensuring the social reintegration of all freed labourers.

XVIII. Conclusion

The path toward a bonded labour-free India requires more than just legislative prohibition; it demands an accountable and justice-oriented policy response. Strengthening the BLVC mechanism and modernizing the CSS framework to address both traditional and cyber-based slavery is essential for ensuring the fundamental rights and social reintegration of all victims.

In conclusion, India stands at a crossroads where ancient forms of exploitation are meeting 21st-century technology. While the Bonded Labour System (Abolition) Act of 1976 legally ended the practice of debt bondage nearly fifty years ago, the reality on the ground shows that the "shackles" have not disappeared—they have simply changed form. Today, bonded labour is no longer just found in rural brick kilns or farms; it has evolved into a global crisis known as **"Cyber Slavery"**. The emergence of international scam compounds in Southeast Asia represents a terrifying new frontier. Over 6,700 Indian citizens have already been rescued from countries like Cambodia, Myanmar, and Lao PDR, where they were held against their will, had their passports stolen, and were forced to commit online crimes under the threat of torture. This proves that our current laws, which focus mostly on domestic labour, are not yet ready to handle transnational digital coercion**.**

To achieve the vision of a "Viksit Bharat" (Developed India) by 2047, the protection of human dignity must be the top priority. We must transform our local committees from "paper bodies" into active, digital-savvy teams that include the voices of survivors. Ending bonded labour in the modern age requires more than just making arrests; it requires a survivor-centric approach that combines social support, international teamwork, and a constant update of our legal strategies.

In short, whether a person is trapped by a debt in a village or by a "digital shackle" in a foreign country, the core injury is the same: the loss of human freedom. India’s success will be measured by its ability to ensure that no citizen—regardless of their background or location—is ever forced to trade their liberty for their survival.

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CHILD CARE INSTITUTIONS AND HUMAN CAPITAL FORMATION IN DELHI: REHABILITATIVE FRAMEWORKS TOWARDS VIKSIT BHARAT 2047

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***Abstract*—Delhi's child care institutions (CCIs) shelter a significant cohort of vulnerable youths who represent future human capital. This review analyzes India's child welfare framework – including the Juvenile Justice (JJ) Act 2015 (amended 2021), the Integrated Child Protection Scheme (ICPS), and Mission Vatsalya (2021) – and recent CCI data. It also reviews studies on institutional care and trauma-informed practice. We find that while Delhi's CCIs typically meet children's basic needs (shelter, food, schooling), notable gaps persist in emotional/psychosocial support, individualized rehabilitation, vocational training, and aftercare[1][2]. To evaluate outcomes, we outline a mixed-methods study: quantitative surveys of children's education, health and psychosocial status, and qualitative interviews with caregivers and youth. Proposed outcome measures include literacy levels, nutritional/health indices, mental well-being (e.g. SDQ scores) and life skills attainment. Key recommendations are: enforce and regularly update Individual Care Plans for every child, integrate regular trauma-counseling and mental health services, align CCI education/vocational programmes with national skill policies (e.g. NEP 2020), and strengthen monitoring by authorities. These reforms align with India's Viksit Bharat 2047 vision of inclusive growth, helping CCIs become developmental platforms that nurture children as "the most vital reservoir of future human capital"[3].**

I. Introduction

India's children (≈460 million under 18) are a strategic asset for development. The Constitution (Art.15(3)) and international commitments (UNCRC, 1992) mandate special care for children. The Juvenile Justice (Care & Protection of Children) Act 2015 (amended 2021) and its 2016 Model Rules define **Child Care Institutions (CCIs)** – including children's homes, open shelters, places of safety and adoption agencies – for orphans, abandoned or abused children[4]. The JJ Act/Rules require CCIs to provide a "home away from home" environment: safe shelter, nutritious meals, clothing, healthcare, education and counseling[5]. Crucially, each child must have an **Individual Care Plan (ICP)** detailing educational, health and psychosocial goals. These legal provisions complement the Right to Education (2009), ensuring free schooling for all CCI residents.

In Delhi's urban context, effective CCIs are vital. The city's high migration and socioeconomic stress mean many street children, child laborers and youths from broken homes enter CCIs when family care is unavailable. Official data highlight the scale: in FY 2019–20, Delhi had **41 registered CCIs with 1,986**

children; by 2020–21 this was **40 CCIs and 1,500 children**[6]. Though a small fraction of Delhi's overall child population, these numbers represent a vulnerable group whose future productivity and social integration matter for the city's cohesion and economy. As experts emphasize, children are "the most vital reservoir of future human capital," and investments in their health, nutrition and education yield high economic and social returns[3]. Conversely, neglecting institutionalized children can hinder India's demographic dividend. Under the Viksit Bharat 2047 vision of inclusive growth, no child – including those in CCIs – should be left behind.

Despite robust laws, implementation gaps persist. Field reports and social audits frequently note CCIs suffer from understaffing and infrastructure shortfalls. For example, qualitative assessments found Delhi CCIs often have counselors on staff, but **no individualized mental health care plans are formulated**, and most staff beyond counselors lack any training in children's psychological needs[1]. Many children enter CCIs with trauma (loss of parents, abuse, etc.), yet emotional support is minimal. These findings mirror broader research: institutional care without trauma-informed support can produce anxiety, depression and attachment disorders in youth. In recognition of such gaps, the government launched **Mission Vatsalya (2021)** to consolidate child welfare schemes and emphasize family-based care (foster, kinship, sponsorship) with aftercare support[7][8]. However, preliminary evidence suggests on-the-ground services remain uneven, and key practices like regular ICP reviews or counseling sessions often fall short.

Given this backdrop, a systematic study of Delhi's CCIs is timely. We propose evaluating outcomes in education, health, psychosocial well-being and life skills, to see how well CCIs contribute to children's human capital formation.

Our objectives are to:

(a) assess educational achievement and cognitive skills of CCI children,

(b) evaluate their psychosocial/emotional well-being,

(c) examine their health and nutritional status,

(d) analyze life-skills and vocational training impacts, and

(e) identify challenges in transitioning out of CCIs.

The findings will clarify how CCIs align with India's developmental vision and suggest where reforms are needed to build resilient future citizens.

II. Background and Literature Review

Role of CCIs in Education and Skills. Empirical studies indicate CCIs generally secure basic education and some vocational training for children who lack family support. For instance, field research in Delhi CCIs found that over 90% of girls were enrolled in formal schools, and about 78% had completed a vocational course (e.g. computer skills, tailoring, beauty care) during their stay[9]. These programmes were linked to gains in confidence and routine management. More broadly, evaluations of Indian orphanages note that at least primary literacy is usually achieved, whereas out-of-school or street children typically would have no schooling. However, the quality and relevance of training vary. Under-resourced CCIs may offer only rudimentary life-skills (e.g. basic sewing or cooking). Child-rights advocates argue CCIs should integrate with national education reforms (like NEP 2020) to provide digital literacy and career counseling, and connect with government vocational schemes.

Psychosocial Well-being and Trauma. A dominant theme is the emotional impact of institutionalization. Many CCI residents have suffered severe early trauma (parental loss, abuse, exploitation). Without proper support, such trauma can lead to long-term mental health issues. For example, prior work highlights that institutionalized children often show high levels of anxiety, depression and attachment disorders if emotional needs are neglected[2]. Leading practice calls for **trauma-informed care** in CCIs: training caregivers to recognize trauma symptoms, providing regular counseling, and creating consistent, nurturing relationships. International evidence (e.g. Rutter 1998; UNICEF 2019) similarly shows that even well-run homes can impair social-emotional growth if children's psychological distress is ignored. Best practices include assigning consistent caregivers, regular therapeutic activities, and building a safe, child-friendly environment. A recent Delhi study found counselors present in CCIs but noted that **no individualized mental health care plans were formulated** for the children[1]. Such gaps underscore the need for CCIs to prioritize mental health. Our proposed study will include validated well-being scales and interviews to gauge emotional health and trauma coping.

Individualized Care Plans (ICPs). By law, each child in a CCI should have an ICP tailored to their educational, health and social needs. In practice, however, ICPs often become mere formalities. Several reports indicate that many CCIs produce generic or outdated care plans because of heavy caseloads and limited staff[1]. Yet each child's situation is unique (disabilities, learning needs, trauma history, etc.), calling for personalized support. Experts advocate active case management: dedicated caseworkers who review each ICP regularly, involve children in goal-setting, and coordinate with teachers, therapists and family. Evidence suggests children with strong ICPs fare better post-care. In our interviews with CCI administrators and caregivers, we will examine how ICPs are implemented in Delhi – whether they are updated, child-centered, and integrated into daily programming.

Health and Nutrition. Physical well-being is a core part of human capital. Studies of Indian CCIs report that basic healthcare (immunizations, check-ups) is usually provided and at least two meals a day are standard. For example, a Delhi CCI survey noted that homes generally maintain medical records and organize health camps. However, variations exist: some homes lack funds for regular doctor visits or special nutrition. National data suggest institutionalized children have higher malnutrition rates than average schoolchildren, reflecting resource gaps. Child-welfare experts recommend linking CCIs with government health programs (for example, regular camps with local hospitals or anganwadis) and NGOs to ensure thorough coverage. Our survey will include health questions (e.g. immunization status) and, where feasible, record children's height/weight to gauge nutrition. These data will indicate whether Delhi CCIs meet health needs consistently.

Life Skills and Transition Readiness. Beyond academics, CCIs must prepare youth for independent living. Life skills like financial literacy, hygiene, communication, and decision-making are critical. Many CCIs run life-skills workshops or clubs (often with NGO support). Evidence from Delhi shows positive signs: graduates reported confidence in daily tasks – managing money, cooking basic meals, job-hunting – after such training[10]. However, analyses caution that curricula can be limited; for instance, some homes only teach very basic trades. Experts recommend that CCIs adopt formal life-skills curricula (for example from government vocational training programs) and arrange apprenticeships or internships with local businesses. In our study, we will assess the scope of life-skills education in sampled CCIs through child surveys (self-rated skills) and caregiver interviews (what training is offered). We will also ask older youths about their preparedness for employment or further education, to gauge if CCIs are fostering practical independence.

Family- and Community-Based Alternatives. There is growing consensus that institutional care should be temporary, not the long-term norm. Both UNICEF guidelines and the JJ Act favor family-like settings whenever possible. Recent policy pushes in India reflect this: Mission Vatsalya and other schemes provide incentives for foster care, kinship care and sponsorship. For example, a recent media report notes that children in family-based care quadrupled nationwide in just two years, thanks to these incentives[7]. Research on kinship care in India shows better emotional outcomes and continuity for children than orphanage care. Accordingly, CCIs are now envisioned as short-term shelters with active plans for family tracing or foster placement. In our questionnaires, we will ask about kinship care investigations and follow-up plans for reunification. Interviews will explore how Delhi CCIs work with Child Welfare Committees to reintegrate children into families or alternative homes. This will reveal whether CCIs serve primarily as "homes" or as steps in a transition process.

Aftercare and Reintegration. Exiting a CCI is often fraught. Studies in India find many former residents lack structured aftercare – with no counseling, housing or education support – leading some to drop out of

school or even become homeless. Although the JJ Act mandates aftercare support up to age 21, in practice such services are sparse. Best-practice models emphasize aftercare homes, mentoring, and education/vocational stipends. We will examine Delhi's follow-up mechanisms by asking administrators about alumni programs and interviewing youths aged 16–18 about their post-CCI plans. These insights will show whether CCIs equip children for life outside or leave them vulnerable. Bridging the CCI-to-community gap is crucial for truly building human capital, as an unsupported youth negates much of the CCI's investment.

Implementation and Monitoring. A persistent challenge is the gap between policy and practice. National audits by bodies like the NCPCR repeatedly highlight underqualified staff, infrastructure deficits and poor record-keeping in CCIs. Even when rules exist (e.g. required staffing ratios, routine inspections by Child Welfare Committees), enforcement is uneven. For instance, the JJ Rules call for annual reviews of all CCIs by district committees, but official records of such oversight are often missing. Experts therefore urge greater transparency and community oversight – e.g. managing committees with local stakeholders, child rights clubs in homes – to improve accountability. Our study will include observations of facility conditions and, where accessible, reviews of audit reports or registers. This will help gauge how well the sampled Delhi CCIs comply with norms and identify systemic weaknesses.

Summary: In sum, the literature indicates CCIs can provide essential shelter and schooling for children who lack family care, but their developmental impact depends on targeted support. Both Indian and international studies stress the need for child-centered, trauma-sensitive practices. To organize the issues, Table 1 below outlines India's key child protection policies and noted gaps; Table 2 shows recent Delhi CCI statistics. These contextualize our proposed analysis of Delhi's CCIs as potential contributors to India's long-term human capital goals.

Key Policy/Scheme	**Year**	**Objective**	**Provisions**	**Implementation Gaps**
JJ Act (2015, Amended 2021)	2015 (2021)	Protect and rehabilitate children (CPL & CCL); establish child welfare bodies	Defines CCIs & minimum care standards (food, shelter, health, education, counseling)[5]; mandates ICPs and child rights; sets up Child Welfare Committees (CWCs)	Many CCIs remain understaffed or lack trained caregivers. ICPs are often perfunctory or outdated[1]. Enforcement of standards varies by state.

Key Policy/Scheme	Year	Objective	Provisions	Implementation Gaps
			and Juvenile Justice Boards (JJBs); details adoption, foster care, sponsorship pathways.	
ICPS (2009)	2009	Strengthen child protection infrastructure nationwide	Central grants to States for CCIs, CWCs, JJBs; funds for ChildLine (1098), adoption services, sponsorships; training for personnel.	State-level utilization varies; gaps in CCI capacity and monitoring persist; data collection is inconsistent.
Mission Vatsalya	2021	Consolidate schemes; emphasize family-based care and vulnerable children	Continues ICPS aims; adds dedicated funding for foster/kinship care, sponsorship, aftercare; focuses on prevention (ChildLine, outreach)[7].	Early rollout has limited grassroots awareness; some components (e.g. aftercare homes) are underdeveloped; many CCIs have been slow to adopt more child-centric practices.
JJ (Model) Rules (CCI Guidelines)	2016	Standardize CCI operations	Specifies norms for facilities, staffing ratios, education/vocational programs, health services, counseling and recreation; requires detailed record-keeping and periodic reviews.	Compliance is patchy: many CCIs do not meet infrastructure or staffing norms. Oversight mechanisms (e.g. CWC/JJB inspections) are inconsistently applied, with many inspections unrecorded.

Table 2: Delhi CCIs – Registered Homes and Children (Mission Vatsalya data)

Year	Registered CCIs	Children in CCIs[6]	Notes
2019–20	41	1,986	Data from Ministry of WCD report

2020–21	40	1,500	
2021–22	*Unspecified*	*Unspecified*	(Latest public data pending)
2022–23	*Unspecified*	*Unspecified*	

(Source: Ministry of Women & Child Development/Delhi WCD)

III. Methods

We propose a **cross-sectional mixed-methods** design to evaluate outcomes for children in Delhi's CCIs. This will combine (a) a structured quantitative survey of children's indicators, and (b) qualitative interviews with staff and youths. This triangulation allows numerical measurement of outcomes alongside in-depth context.

3.1 Quantitative Component

1 **Sampling:** We will purposively select 4–5 CCIs in Delhi to cover diversity (e.g. a government-run boys' home, an NGO girls' home, an open shelter, etc.). Assuming ~25 children per CCI, we aim to survey about 80 children, sampling 3–4 children per home across age and gender groups. This sample size balances logistical feasibility with meaningful coverage.

2 **Measures:** A structured questionnaire (Hindi/English) will capture:

3 *Education:* Current school enrollment status, highest grade completed, basic literacy/numeracy assessment (age-appropriate reading or arithmetic tasks).

4 *Health/Nutrition:* Self-reported general health; record of recent illnesses; anthropometry if feasible (height/weight to calculate BMI or nutritional status relative to age).

5 *Psychosocial Well-being:* A standardized instrument such as the Strengths and Difficulties Questionnaire (SDQ) to measure emotional and behavioral health.

6 *Life Skills:* Self-rated competencies (e.g. managing money, digital literacy, household skills) using a simple scale.

7 **Data Analysis:** We will compute descriptive statistics (means, frequencies) for all outcomes. Bivariate analyses (t-tests, chi-square) will explore factors related to better outcomes (e.g. comparing children who received counseling versus not). If the sample permits, multivariate regression can identify predictors (e.g. does the presence of vocational training or a counselor in the CCI predict higher well-being scores?). We will account for clustering by CCI in all analyses.

3.2 Qualitative Component

i- Participants: We will conduct semi-structured interviews with:

(1) **Caregivers/Counselors** in each CCI (n≈10–15), asking about daily practices, training and challenges they face.

(2) **CCI Administrators/Directors** (n≈5) to discuss policies, resources and links with government/NGO programs.

(3) **Youth case studies** – purposively selected older children (ages 14–18, n≈8–10) who can articulate their experiences of CCI life and aspirations.

ii- Topics: Interview guides will explore perceptions of child development services and gaps. Topics include the child's education and skill development, emotional support provided (trauma counseling, recreation), use of Individual Care Plans, health and nutrition practices, family involvement, and readiness for the future. We will probe how CCIs view their role (custodial vs. rehabilitative) and what reforms they believe are needed.

iii- Data Analysis: Interviews will be audio-recorded, transcribed and coded thematically. We will use qualitative coding software to identify recurrent themes across informants, such as barriers to implementing ICPs or children's attitudes toward life skills training. Themes from caregivers/administrators will be compared with youths' perspectives. We will then triangulate qualitative insights with survey findings. For instance, if many children report stress, interviews may reveal whether counseling is absent or ineffective.

3.3 Ethical Considerations

Working with vulnerable minors requires strict ethics. We will obtain Institutional Review Board (IRB) approval. Key safeguards include:

1. **Informed Consent:** Written consent from each child's legal guardian (generally the Child Welfare Committee or CCI Director) and assent from the child.
2. **Confidentiality:** All data will be anonymized; names or identifying details will be omitted. Child responses will not be shown to their caregivers.
3. **Minimizing Harm:** Interviews with children will be conducted sensitively by trained researchers. A counselor will be on hand if any child becomes distressed discussing personal issues. Participation is voluntary and refusal will not affect the child's care.
4. All procedures will align with the JJ Rules and UN CRC guidelines on research with children.

3.4 Data Sources and Instruments

In addition to primary data, we will review secondary sources: official documents (text of the JJ Act, Mission Vatsalya guidelines), Delhi WCD statistics, and existing NGO reports on CCIs. The child survey

will use standardized measures (e.g. SDQ, BMI percentile charts). The caregiver survey may adapt parts of existing CCI evaluation tools. We will pilot-test instruments for clarity and cultural fit in a small group before full rollout.

IV. Discussion (Anticipated)

We anticipate discussing how Delhi's CCIs measure up against their rehabilitative mandate. Based on literature, likely findings include:

i) **Education and Skills:** Most children will be in school, reflecting Delhi data (e.g. Dutta found >90% girls in CCIs attended school[9]). Survey results may show high basic literacy. Many may have completed vocational courses; Dutta (2017) found ~78% of girls did so[9]. We will analyze the quality of these programs – do administrators describe updated curricula (digital, market-linked skills)? If not, we will note the need for curriculum enhancement. We expect to find that CCIs do provide some schooling and life-skills, but may lack modern tools (e.g. computers, internet) or career counseling. This would echo findings that institutional education is variable and often minimalistic. We will also examine if those who underwent vocational training report higher self-efficacy.

ii) **Psychosocial Care:** We anticipate that the psychosocial support will emerge as a weak area. The survey may show elevated SDQ scores (indicating distress) for many children, especially those with abuse histories. Caregivers' interviews may reveal limited counseling: indeed, prior work found that Delhi CCIs had counselors but still no individualized mental health plans[1]. We may confirm this: children might report receiving only group counseling or none at all. Administrators may cite lack of funds or trained staff as reasons. If so, we will compare this gap with best-practice trauma-informed models[2] and emphasize the need for systematic counseling and caregiver training.

iii) **Health and Nutrition:** We expect basic health coverage to be present (e.g. immunizations done, illnesses treated). Survey data may show relatively low acute illness rates if medical check-ups occur, but anthropometrics might reveal some malnutrition. If any children are underweight or stunted compared to norms, we will flag nutritional insufficiency. Administrators might mention tie-ups with local hospitals; if not, this would highlight a need for regular medical camps or partnerships. This will be contrasted with national data showing institutional children often have worse nutrition than peers.

iv) **Life Skills and Readiness:** Many children might feel capable of daily tasks (the Delhi study reported ~66% confident in self-care and budget management[10]). We will measure this directly. If children rate themselves high on household skills but low on modern skills (e.g. digital literacy or vocational readiness), this suggests a gap. Interviews might reveal which

life-skills are taught – likely basic hygiene, cooking – but perhaps not financial planning or communication skills. We will discuss aligning life skills training with formal programs like JAN SHIKSHAN or NSDC.

v) **Aftercare and Reintegration:** Older youths may report anxiety about leaving the CCI. We might find that few have concrete plans, indicating poor aftercare. If any administrators mention aftercare homes or sponsorship programmes, we will detail those, but we anticipate many CCIs lack structured follow-up. This would mirror reports that without aftercare, CCI graduates often drop out of education or face homelessness. Emphasizing this, we will highlight the policy vision (JJ Act up to age 21 support) versus practice reality.

vi) **Policy Gaps:** We will synthesize findings to identify critical gaps. For instance, if ICPs were found in name only, we will emphasize the literature's call for fully implemented ICPs. If CCIs lack community linkage, we will point to the global shift to non-institutional care[7]. Any disconnect between laws (like JJ Act mandates) and observed practice will be discussed as an implementation failure. We will relate our findings back to the broader developmental context: how can CCIs best transform a vulnerable child into a confident, skilled citizen? This will involve citing our literature (e.g. confirming Dutta's findings on education[9] or highlighting the persistent psychosocial issues noted by experts[2]).

We will acknowledge limitations: our cross-sectional design cannot prove causation, and findings from 4–5 CCIs may not generalize across all of Delhi. However, by combining surveys with deep interviews, we aim for a rich understanding. Ultimately, we aim to present CCIs as supportive yet improvable – capable of housing and educating children who would otherwise be unserved, but in need of targeted reforms to fulfill their rehabilitative mission.

V. Policy Implications

Our findings will guide practical reforms for Delhi (and by extension other Indian urban centers). Specific recommendations include:

i) **Individual Care Plans:** Enforce JJ Act rules that **every child's ICP be created and reviewed regularly**. CWCs and CCI staff should be held accountable for up-to-date ICPs, perhaps via digital records. Training CCI staff on how to develop and use ICPs will ensure children's unique needs are addressed.

ii) **Trauma Counseling:** Integrate routine psychological services. Each CCI should have at least one trained child counselor (or regular visits by a psychologist/psychiatrist). Implement standard mental health screening on admission and periodically. This aligns with "trauma-informed care"

principles[2]. The government could fund counselor positions or tie-up CCIs with local mental health institutions.

iii) **Enhanced Education/Vocational Training:** Update curricula in CCIs. For example, connect with the National Skill Development Mission to offer recognized certificates (e.g. ITI courses, digital literacy) rather than informal activities. Ensure all school-age children are in formal schools or bridge programs as per RTE. Encourage use of digital learning tools (with government support like PM eVIDYA).

iv) **Life Skills and Aftercare Programs:** Adopt formal life-skills curricula (e.g. those from NIPCCD or NGOs). Pair youths with mentors or apprenticeships as they near leaving age. Expand foster care, sponsorship and aftercare grants under Mission Vatsalya, and publicize these schemes widely among CCIs. For instance, assigning a caseworker to each youth for 1–2 years after exit could be piloted.

v) **Monitoring and Accountability:** Strengthen oversight: ensure CWCs document regular inspections, and outcomes (education, health, vocational achievements) are reported. Establish a state-level CCI management committee involving civil society and former residents, to review conditions. Collect and publish CCI statistics annually (building on the Minister's reports) to track progress.

These reforms should be communicated as part of Delhi's contribution to child development targets (e.g. SDGs, Vision 2047). Demonstrating that even children in institutions are receiving world-class support will underscore India's commitment to inclusive growth.

VI. Conclusion

Delhi's CCIs sit at the nexus of child welfare and human capital formation. Legally they are obliged to be "homes away from home," but practice gaps can limit their impact. Our proposed study – grounded in both data and human stories – aims to rigorously assess how well CCIs are preparing children to thrive. We will identify strengths (e.g. high school enrollment, life skills taught) and weaknesses (e.g. weak psychosocial support, poor aftercare), and translate these into policy directives. Ultimately, the goal is to ensure that institutional care becomes a stepping stone, not a trap: equipping vulnerable children with education, resilience and skills so they can become empowered, contributing citizens in a Viksit Bharat 2047 society.

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A PRELIMINARY STUDY ON EFFECT OF APPLICATION NON-IONIC POLYACRYLAMIDE ON THE TENSILE STRENGTH OF MULBERRY SILK FILAMENT

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Abstract—**This study investigates the influence of non-ionic polyacrylamide (NPAM) on the tensile strength of mulberry silk filaments. Silk,a natural protein fiber known for its strength and elasticity, can be modified using polymer treatments to enhance its mechanical properties. The preliminary results indicate that treatment with NPAM improves tensile strength due to better fiber cohesion and surface modification. However, excessive concentration may lead to stiffness and reduced flexibility.**

I. Introduction

Mulberry silk, produced by the silkworm *Bombyx mori*, is widely valued for its high tensile strength, luster, and biocompatibility. Enhancing its mechanical properties is important for applications in textiles, biomedical materials, and composites. Non-ionic polyacrylamide (NPAM) is a water-soluble polymer commonly used in textile finishing, paper processing, and wastewater treatment. Due to its neutral charge, NPAM interacts with fibers primarily through hydrogen bonding and physical adsorption, potentially improving fiber strength. This study aims to evaluate the effect of NPAM treatment on the tensile strength of mulberry silk filament.

II. Materials and Methods

Raw mulberry silk filaments were used as the primary material for this study, along with non-ionic polyacrylamide (NPAM) as the modifying agent. NPAM solutions of varying concentrations (0.5%, 1%, 1.5%, and 2%) were prepared by dissolving the required quantity of polymer in normal tap water under continuous stirring until a homogeneous solution was obtained. The silk filaments were then immersed in these solutions for a fixed duration of 10–15 minutes to ensure adequate interaction between the polymer and the fiber surface. After treatment, the filaments were removed and dried under controlled ambient conditions. The tensile properties of both untreated and treated silk filaments were evaluated using a universal testing machine, where parameters such as breaking force, elongation at break, and tensile strength were recorded

Tensile Strength Testing

Tensile strength was measured using a universal testing machine. Parameters recorded:

- Breaking force
- Elongation at break



Fig.2.1 Application of polyacrylamide on silk filaments and testing of treated silk filaments

III. Results and Discussion

1. **Effect on Tensile Strength**
   A moderate increase in tensile strength was observed with increasing NPAM concentration up to an optimum level (around 1–1.5%).
   The improvement is attributed to:

   - Formation of a thin polymer coating
   - Enhanced intermolecular bonding
   - Reduction in surface defects

2. **Effect on Elongation**
   - Slight reduction in elongation at higher NPAM concentrations
   - Indicates increased stiffness of the fiber

3. **Optimal Concentration**
   Optimum NPAM concentration balances strength and flexibility
   Beyond optimum levels:

   - Fiber becomes brittle
   - Excess polymer causes rigidity

4. **Mechanism**
   NPAM interacts with silk fibroin via:

   - Hydrogen bonding with amino acid residues
   - Physical entanglement on fibre surface leads to improved load distribution along the filament.

IV. Conclusion

The preliminary study suggests that non-ionic polyacrylamide treatment enhances the tensile strength of mulberry silk filaments. An optimal concentration exists where strength is maximized without compromising flexibility. Further studies involving microscopic analysis and long-term durability are recommended.

TaxMate-An AI-Powered Application for Simplified Tax Awareness and Salary-Based Tax Calculation

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***Abstract*—Tax consciousness and correct taxes estimation are necessary facets of financial planning to individuals especially the employees who are on payroll who need to abide by the rules of government taxes. But, due to the complexity of tax slabs, deductions, exemption and changing tax policies continuously some individuals are unable to follow the tax rules and determine the amount payable as taxes. The conventional ways of finding taxes, in general, contain manual computations or reliance on tax professionals that can be time consuming, costly and are liable to errors by humans. In order to overcome these problems, this project is going to suggest an AI-Powered Application of the simplified tax awareness and salary-based tax calculation. With the assistance of this system, there is an intelligent platform in which the user can key in the salary information, deductions, and financial information and with the help of it, he/she is supplied with an estimate of tax liability subject to the relevant tax regulations. The app combines the power of artificial intelligence with the ability to explain everything clearly, and an offer on how to save more money on taxes and automatic calculations. The system receives user input at the backend and implement slab tax algorithms, that are displayed at the front end. The proposed system will make tax awareness and dependency on manual means less critical as it will simplify the calculation of tax and increase access to financial information. The application will further enhance financial literacy in people as it will show the tax elements in a well-organized and accessible way.**

***Index Terms*—Artificial Intelligence, Tax Awareness, Tax Calculation based on salary, Financial Literacy, Automated Tax Estimation.**

I. Introduction

1. Problem Definition

Governments are highly reliant on taxation as a means of revenue and it is also vital to the development of the economy of a country. Nevertheless, most of these people have complications with the interpretation of the tax laws, and the ability to calculate their taxes correctly. Most taxpayers are confused with the calculations of the tax due to the complex nature of tax rules, several tax slabs, deductions, exemptions and changes in the policies.

Salaried workers are also known to have problems with the calculation of their tax since they lack knowledge on tax deductions and tax regulations which are available. The conventional tax computing procedures call on one to slice the tax brackets by hand on their earnings that can be tedious and subject to mistake. There are numerous people hired by tax advisors or financial consultants, and this makes tax estimation more expensive and demanding.

The other difficulty is non-user friendly platforms to make people perceive the concept of taxation in simplified form. There are numerous online tax materials that cannot be easily understood by use of technical jargon and complicated financial description. Consequently, taxpayers are not in a position to make good use of existing deductions and exemptions.

The suggested system will solve this issue by applying a tax calculation engine as a rule-based calculator based on official government tax rules instead of basing it on machine learning datasets.

To tackle the challenges, a smart and computerized system will be necessary which will not only facilitate calculation of taxes but also to educate people on the topic of taxes.

2. Objectives of the Project

The primary goal of the project is to create an AI-based application that will ease the process of tax awareness and calculating taxes based on the salary.

The particular health goals can be divided into:

- To develop a system that will enable entry of the salary details and the calculation of the tax automatically in the system.
- To ease tax calculation through the use of preset tax slab regulations.
- To give a clear break down on the tax payable, deductions and taxable income.
- To enhance financial awareness by users on taxation.
- In order to create a web interface that is easy to interact with.

3. Limitations of the Project

- The system might fail to cover all tax regulations of any country.
- Constant changes in tax policies can necessitate changes in the system.
- The application targets primarily those that are earning salaries.
- The current version does not have such advanced features of financial planning.

II. RELATED WORK

The growth of the complexity of taxing systems has promoted the emergence of digital technologies and intelligent platforms that help people learn more about the different tax regulations and calculate their taxes. Numerous automated networks, financial guidance platforms, and other artificial intelligence-based strategies have been suggested by researchers and creators to make the calculation of taxes effeasible and enhance the tax consciousness of people.

The initial effort in this field was drawn toward the creation of the rule-based tax calculators which utilize pre-coded tax regulations and tax slabs to calculate the tax liability. The user is able to provide income information, deductions, and exemptions through such systems and software used to compute all applicable tax rules and the amount of tax that one is expected to pay. The use of such platforms will save much manual work and will drastically minimize a couple of calculation error as compared to the conventional manual computation of taxes. Nevertheless, most of these systems are restricted with simple estimation of taxes and do not give the detailed information on tax-savings plans or on some financial planning opportunities [1].

As artificial intelligence and financial technology (FinTech) proceed, researchers have suggested applying intelligent decision-support systems to financial administration and tax obligation. Financial data can be analyzed using AI-based platforms that may find various trends and give personal financial advice. Such systems combine technologies: natural language processing, machine learning, conversational interfaces, and so forth to help users in simplified way of comprehending complex financial information. It has been revealed that AI-based financial advisory tools can be very beneficial in engaging users and accuracy in decision-making during financial planning [2], [3].

Another significant trend in this sphere is chatbots and conversational AI applications in the financial services. Financial chatbots provide customers to converse with the systems, and use natural language queries so that they get immediate answers to queries on tax laws, deductions and financial consultation. The studies of the financial service chatbots revealed that the systems are capable of assisting the users in gathering information about finances and enhancing financial literacy. Conversational systems have been built using deep learning and delivery automated answers to financial questions and help users comprehend tax and investment advice [4], [8].

The implementation of AI in improving the tax compliance process and the tax administration process has also been examined in several studies. Reportedly, as per digital transformation adoption in tax administration, artificial intelligence has the potential to assist the governments and organisations in enhancing the effectiveness of tax systems in automating tax system, identifying tax fraud, and extracting crucial insights concerning vast amounts of financial data. The technologies are capable of supporting not only taxpayers but also tax authorities as these technologies can streamline the information related to taxes and create more transparent financial services [6], [7].

Moreover, recent polls of large language models and the potentially applicable AI usage in the financial sector indicate the increasing significance of intelligent systems in the financial analysis, decision support, and automated advisory services. The technologies allow the systems to handle the intricate financial data and offer insights that aid users to make informed financial choices [5], [9], [10].

Although AI-based financial systems have advanced, most of the current tax calculation tools continue to be limited to flaws like adverse user interfaces, opportunity to lack transparency in their calculations, and lack of user-related education resources. In most instances, the users are simply provided with the net sum of the taxes, without knowing how the respective calculation was carried out, and the deductions envelope, which used to be applied.

In response to these shortcomings, the suggested system aims at the creation of a simplified tax awareness and incorporating a salary-based calculator of taxes that will combine both rule-based tax calculation and easy to understand explanations and financial understandings. The system will improve financial literacy and ensure that the accurate tax estimation is performed by providing clear and understandable results using the official tax slabs based on the concept of the structured rule engine.

III. PROPOSED METHODOLOGY

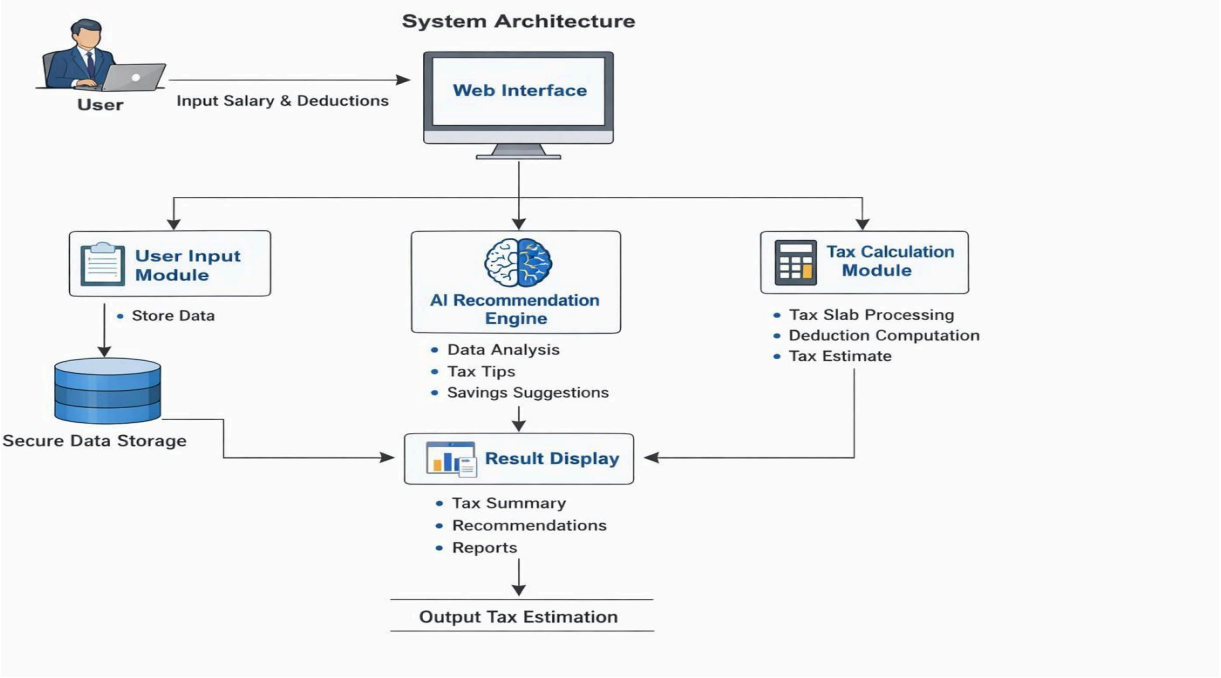


Fig 1: System Architecture

1. User Registration and Authentication Module.

Users can create an account and have safe access to the system with the help of this module. It captures unprotected data like user login details like user name, password, email and user details. Authors allow other users limited access to their financial information.

The functions of this module include:

- User account creation
- Https: Have a secure login and authentication.
- User profile management
- Protection of data security and privacy.

This module will make sure the data of the users are kept safely and will not be accessed by any other person unless he or she has the relevant authority.

2. User Input Module

The User Input Module gathers the financial data of the user needed in calculating the taxes. The user will key in the information that includes annual salary, bonuses, deductions and investments. Input parameters include:

- Annual salary
- Allowances and bonuses
- Standard deductions
- Investment deductions
- Insurance and home mortgage information.

This module authenticates data entered and passes it to calculation of tax module further processing.

3. **Tax Calculation Module**

The Tax Calculation Module executes the calculation of the system. It takes the input data and processes it to arrive at the rules of the tax slab against which the total tax is to be paid.
Activities undertaken by this module include:

- Sum total earnings every year.
- Less deductions and exemptions allowed.
- Determine taxable income.
- Tax the taxable income using the rates of tax slabs.
- Calculate the sum of tax to be paid.

This module will guarantee good estimates of tax by automatically enforcing preset tax rules.

4. **Data Acquisition Module**

The system suggested is not based on the use of a conventional dataset to train or make predictions. Rather it uses an engine based on rule computing logic that is based on governmental tax regulations. The official portal of the Income Tax Department of India and government publications on taxation were used to gather tax slabs, deductions, exemptions, and other taxation rules [15].

These tax rules were reviewed and transformed into organised conditional logic in the system. The rule engine will automatically consider the inputs entered by the user, including annual salary, deductions, and investments and implement the relevant taxable slab rules to compute the taxable income as well as the computed tax.

The rule-based system can be easily updated to reflect any modification in tax policies, as such changes can only be made by updating the variables of interest in the tax slab and the rules governing the deductions without having to retrain any machine learning models.

5. **AI Recommendation Module**

The smart AI Recommendation Module examine the finances of the user and will give smart recommendations on how to optimize the taxes. It assists users in determining the available tax-saving opportunities as well as bettering their financial planning.

Key functions include:

- Deduction usage analysis.
- Recommendation of investment choices.
- Recognition of opportunities of tax saving.
- Individual financial recommendations.

This module fosters the personal knowledge of taxation of the user and promotes superior financial decisions.

6. **Data Storage Module**

The Data Storage Module handles storage of user information, tax information and system information. It gives care to the fact that fiscal information is kept safe and can be accessed at the appropriate time.

Functions include:

- Secure database storage
- Calculations Data Retrieval.
- Tax report and result storage.

- Data backup and management

Through this module the integrity and confidentiality of the user's financial information is ensured.

7. Result Display Module

Result Display Module gives a clear and understandable format to the end user of the system. It presents the detailed information on calculation of tax process and gives a summary of the findings.

Outputs displayed include:

- Taxable income
- Total tax payable
- Deduction summary
- Tax-saving recommendations based on AI.
- Tax reports and summaries

To facilitate understanding of the results, the results are presented in a graph and tabular format as well as summaries.

100	1.6	96
200	2.4	95
500	3.9	93

IV. EXPERIMENTAL RESULTS

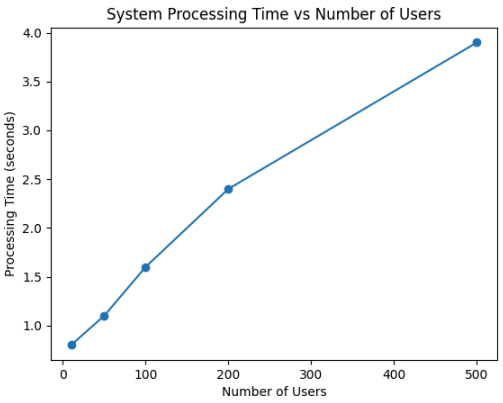
Experimental test of the suggested tax awareness and salary-based calculation of taxation system was conducted to test the accuracy, efficiency, and utility of the rule-based calculation engine of taxation. The system has not been based on any machine learning data thus the assessment was done by feeding to the system some simulated user inputs, various salary ranges, and deduction scenarios.

The system uses predetermined government tax slabs regulation and deduction regulations to calculate the taxable income and the overall tax due. Several test cases were run with alteration of parameters on annual salary, standard deductions, investment deductions, and insurance contributions. The calculations of the results were also checked with the manual calculation of the taxes applying to the official tax rules to identify whether the results were correct.

The experiments proved that the system is correct in calculating tax and giving comprehensible tax distributions such as taxable income, allowances, and all payments of taxes to be paid to the government. The automated method greatly saves time that should have been taken to estimate the tax rate using the manual calculation technique.

In order to measure the performance of a system, user requests ranging in numbers were simulated and the time it took to reply to those requests was recorded. Viewing the results, the system is highly efficient with low response time even in cases when there are several user requests.

Table 1:System Performance An

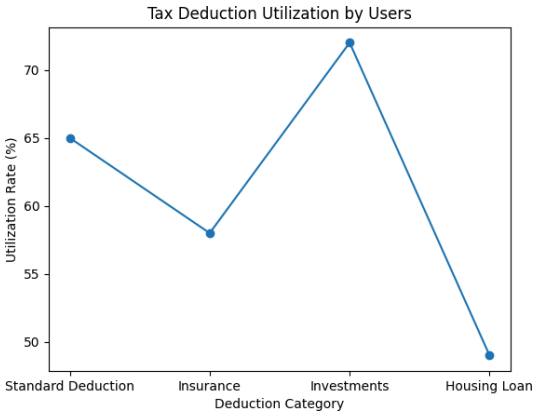


Deduction Type	Users Utilizing (%)
Standard Deduction	65
Health Insurance	58
Investment Schemes	72
Housing Loan	49

Fig 1:System Processing Time vs Number of Users

Table 2:Tax Deduction Utilizatio

Number of Users	Processing Time (seconds)	System Efficiency (%)
10	0.8	98
50	1.1	97



V. CONCLUSION

In this article, another AI-enabled solution to facilitate easier tax awareness and calculation of tax based on the salary was created, which allows people to learn and approximate their tax payment in an effective way. The proposed system is a comprehensive system that incorporates an engine, with rule based tax computation, which will use official tax slab regulations and deduction policies to compute automatically the rule based tax payable under specified circumstances that the user has provided. The system helps in giving the user a clear picture of the taxable income, deductions, and the resultant tax liability by enabling the user to input his or her annual salary, deductions, and investments.

In contrast to the traditional manual methods of tax calculation, the proposed application can make the process of taxation simpler as it allows automating the application of the tax rules and providing the results in the structured and easily comprehensible format. The system will also enhance financial awareness by clarifying the element of taxes and pointing out any deductions made available and possible savings on tax. The experimental analysis has shown that the system can make precise estimates of the tax with minimal processing time and high efficiency even when multiple user requests are being attended to. Comprehensively speaking, the proposed solution makes more financial information more accessible, minimizes the possibility of making mistakes in calculations, and helps people make better financial decisions regarding taxation.

Future Scope

Despite the fact the system proposed is an efficient and user-friendly solution to calculation of the taxes based on salary, a number of enhancements can be made in the future to have better capabilities. The inclusion of real-time updates of tax laws according to public government websites could be one of the potential improvements that would ensure the system automatically follows the policy changes. There is also an option of expanding the application to guarantee various income classes such as business income, capital gains, and other types of revenue than salaried income.

The further development of the system can also be based on the innovative methods of artificial intelligence, including machine-learning models and natural language processing, to make tax planning recommendations more personalized and engage the financial guidance. Connection with the conversational AI chatbots would enable users to pose questions about the taxes and be provided with the answer and the rest (natural language response) immediately.

The other valuable improvement would be the creation of mobile application and cloud based implementation where users can have access to tax calculation and financial advisory services 24 hours and using any device. Moreover, the system might be connected to the financial management

applications and digital banking solutions to offer a more holistic individual finance and tax planning ecosystem. These enhancements would make the system smarter, easier to scale and address the needs of a wider audience in the management of their taxation and financial planning issues.

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STUDY OF TOPOLOGICAL GAMES OVER SOME SPECIAL PRODUCTS AND ITS FUZZIFICATION

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***Abstract*—In this present paper, we study topological games over some special products and its fuzzification.**

***Index Terms*—Fuzzy Logic, Statistical Profiler, MATLAB.**

I. Introduction

By introducing the concept of topological game over an ideal of Hausdorff space, a game over some special product space is played. Fuzzy set theory has been applied to fuzzify some of the results obtained. Over an ideal of a topological space has played a topological game which is explained here in brief. Also by introducing the concept of rectangle in topological product spaces, some special types of products called D-Product and C-Product are studied and a game is played over such products. Lastly, it is explained how fuzzy set theory can be applied to obtain better results [1-2].

II. GAMES OVER AN IDEAL

Let G (I, X) be an infinite positional game of pursuit and evasion over I where X is a topological space and I $\subset$ P (X) s.t. (i) I am closed with respect to union (ii) I possess hereditary property [3].
Such collection I is called an ideal over X.
This game is played as follows: There are two players-P (Pursuer) and E (Evader). They choose alternately consecutive terms of a sequence < En/n$\in$N, Where N = {0,1,2,…n,….)}> of subsets of X s.t. each player knows I, E_0, E_1, ….,E_n when he is choosing E_{n+1}.

A sequence < En > of subset of X is said to be a play of the game if for all n N the following holds:

(i) $E_0 = X$ (ii) $E_1, E_3, E_5, \ldots\ldots, E_{2n+1}$ are the choice of P.
(iii) $E_1, E_3, E_5, \ldots\ldots, E_{2n+1} \in I$.
(iv) $E_2, E_4, E_6, \ldots\ldots, E_{2n+2}$ are the choice of E.
(v) $E_1, E_2, \subset E_0$, E3, $E_4 \subset E_2$; $\ldots\ldots, E_{2n+1}, E_{2n+2} \subset$ E2n
(vi) $E_1 \cap E_2 = \varphi$, $E_3 \cap$ E4 = , ……..$E_{2n+1} \cap E_{2n+2} = \varphi$.

If $\cap< E_{2n} >$ = then player P wins the play, otherwise Evader wins the play.
A finite sequence < E_m/ m $\leq$ n > is admissible for the game if the sequence < E_0, E_1, ……E_n, φ,φ,φ,…..φ > is a play of the game. For admissible sequence
< E_0,…..E_n> and even if s: < E_0,…..,E_n > P(X) and s (<E_0,…..,E_n) = E_{n+1} then s is a strategy for player P.
In case of odd n, s is said to be a strategy for evader E.

A strategy s is said to be wining for player P in the game G (I, X) if P wins each play of the game with the help of this s. Similarly, s is said to be winning for E if E wins each play of the game with the help of s [4].

We denote by P (I, X) the set of all winning strategies of P in the game G(I, X) and by E(I,X), the set of all winning strategies of E in the game G (I,X).

A topological space X is aid to be I-like if the set of all winning strategies of player is not empty i.e., if P (I, X) $\neq \varphi$.

Similarly, a space X is said to be determined, if P (I, X) $\neq\varphi$ or E (I, X) $\neq\varphi$ i.e., if X is I-like or X is anti I-like.

III. RECTANGULAR PRODUCTS

A subset A x B of a topological product space X x Y is called a rectangle. A rectangle E is said to be:

(i) Co-zero if E' & E" are co-zero in X x Y;
(ii) Zero if E' & E" are zero in X x Y;
(iii) Open if E' & E" are open in X x Y;
(iv) Closed if E' & E" are closed in X x Y;

where E' & E" are the projections of E into X and Y respectively so that E = E' x E".

A topological product X x Y is said to be strongly rectangular if each locally finite open cover of X x Y has a locally finite refinement by co-zero rectangles.

From above definitions the following conditions are seen to be equivalent:

(i) The product X x Y is strongly rectangular.
(ii) Each finite open cover of X x Y has a locally finite refinement by co-zero rectangles.
(iii) For each closed subset F and each open set U of X x Y with F U, there is a locally finite collection w by cozero rectangles s.t. F $\subset\cup$ W U.
(iv) X x Y is normal and for each zero-set F and each co-zero-set U of X x Y with FU, there is a locally finite collection W by co-zero rectangles such that F $\subset\cup$ W U.
(v) There exists a continuous map

f: X x Y [0,1] such that f (x,y) = $\sum_{tT} g_t(x)h_1(y)$

where g_t : X→ [0,1] and h_t : Y→ [0,1] are continuous.

IV. MODIFIED GAMES

We define the topological games G (I, X) with a slight change as follows: Each topological space considered in this paper is assumed to be a Hausdorff space. N denotes the set of all natural numbers and m denotes an infinite cardinal number. Also let L = {E_i | E_i is closed subsets of X}.

There are two players P and E. Player P chooses a closed set Et of X with E1 L and player E chooses an open set U_1 of X with $E_1 \subset U_1$ [5].

Again, player P chooses a closed set E_2 of X with E_2 L and player E chooses an open set U_2 of X with $E_2 \subset U_2$ and so on.

The infinite sequence < E_1, U_1, E_2, U_2……> is played by G (L, X). Player P wins the play < E_1, U_2, E_2, U_2,…> if {Un : n N} covers X, otherwise player E wins.

A finite sequence < E_1, U_1,…., E_n, U_n > of subsets in X is said to be admissible for G(L,X) if the infinite sequence < E_1, U_1, …E_n, U_n, φ,φ,…..> is a play of G (L,X).

A function s is said to be a strategy for player P in G (L, X) if the domain of S consists of the void sequence φ and the finite sequence < U1, …..,Un > of open sets in X and if s (φ) ad s (U_1,……,U_n) are closed in X an belong to L.

A strategy s for player P in the game G (L,X) is said to be winning if he wins each play $< E_1, U_1, E_2, U_2, \ldots$ in (L, X) such that $E_1 = S(\varphi)$ and $E_{n+1} = S(U_1, \ldots, U_n)$, for all $n \in N$.
We denote the following:
DL - The class of all spaces which have a discrete closed cover consisting of members of L.
FL - The class of all spaces which have a finite closed cover consisting opf members of L.
C - The class of all compact spaces.
C_m - The class of m-compact space.
I_1, I_2 - Arbitrary classes of spaces possessing hereditary property s.t.
$I_1 \times I_2 = \{X \times Y : X \in I_1 \text{ and } Y\ I_2\}$

V. GAMES OVER SOME SPECIAL PRODUCT SPACES

Firstly, we define the following two product spaces:
D- Product: A product space X x Y is said to be a D-product if for each closed set M of X x Y and each open set O of X x Y with $M \subset O$, there is a discrete collection J by closed rectangles in X x Y such that $M \subset \cup J \subset O$.
For a closed rectangle R in X x Y, R' and R" denote the projection of R into X and Y respectively. Thus, R is a closed rectangle in X x Y if R' and R" are closed in X & Y and R is an open rectangle in X x Y if R'R" are open in X and Y such that R = R' and R" [6].
C-Product: A product space X x Y is said to be a C-product if for each closed set M of X x Y and each open set O of X x Y with $M \subset O$ there is a countable collection J by closed rectangles in X x Y such that $M \subset \cup J \subset O$.
With the help of definition of D-product, we have,
Theorem: (1) Let X and Y be spaces such that X x Y is a D-Product. If player P has winning strategies in G (l_1, X) and (l_2, Y), then he has a winning strategy in G $(D(l_1 \times l_2), X \times Y)$.
Now we prove the following
Theorem: (2) Let X be a collection wise normal space and Y a subpar compact space with $\chi(Y) \leq m$. If player P has a winning strategy in G (DC_m, X), then every open cover of X x Y with power < m has a σ-discrete refinement by closed rectangles in X x Y.
Proof: Let s be a winning strategy of player P in G (DC_m, X). Let C be an arbitrary open cover of X x Y with $|C| \leq m$.
We construct:

(i) a sequence $\{J_n : n > 0\}$ collections of closed rectangles in X x Y;
(ii) sequence $\{< \Re_n, < \psi_n > : n \geq 0\}$ of the pairs of collections Rn by closed rectangles in X x Y;
(iii) the function $\psi_n : \Re_n \rightarrow \Re_{n-1}$; satisfying the following five conditions:
(a) J_n is σ-discrete in X x Y.
(b) Rn is σ-discrete in X x Y.
(c) Each $F \in J_n$ is contained in some $G \in C$.
(d) If $(x,y) \in R_{n-1} \in \Re_{n-1}$ and $(x,y) \in \cup J_n$.
Then there is $R_n \in \Re_n$ such that $(x,y) \in R_n$ and $\psi_n(R_n) = R_{n-1}$.
(e) for an $R \in \Re_n$, Let $U_n = X - R$ and $U_k = X - (\psi_{k+1}\ 0 \ldots\ldots 0\ \psi_n(R))'$, for $1 \leq k \leq n-1$.

Then the finite sequence $< E_1, U_1, \ldots, E_n, U_n >$ is admissible for G (DC_m, X).
Let $J_0 = \{\varphi\}$ and $\Re_0 = \{X \times Y\}$.
We suppose that the above $\{J_i : i < n\}$ and $\{< R_i, \psi_I > : I \leq n\}$ are already constructed. We pick an $R \in \Re_n$.
Let $< E_1, U_1, \ldots\ldots, E_n, U_n >$ be the admissible sequence in G (DC_m, X).
Hence there is a discrete collection $\{C\alpha : \alpha \in \Omega(R)\}$ by m-compact closed sets in R1 such that $s(U_1, \ldots\ldots, U_n)\ R' = \cup \{C\alpha : \alpha \in \Omega(R)\}$.
We can a choose discrete collection $\{W\alpha : \alpha \in \Omega(R)\}$ of open sets in R' s.t. $C\alpha \subset W\alpha$, for all $\alpha \in \Omega(R)$.
Since Cα is m-compact, $|C| < m$, $\chi(Y) \leq m$ and R" is subparacompact.
There is a collection $J_{n+1}^{\alpha} = \left\{Cl\ U^{\alpha,i} \times H : i = l, \ldots\ldots, K \text{ and } (k)\right\}$ and by closed rectangle in R, which satisfying the following four conditions:

(i) Each $U^{\alpha,i}$ is open in R'.

(2) $C \left\{U^{\alpha,i}: i = 1, \ldots..., K \right\} W$.

(3) Each CI $U^{\alpha,i} \times H_\lambda$ is contained in some G ∈ C.

(4) {H : ( )} is a σ-discrete closed cover of R". Then

$J^{\alpha}_{n+1}(R) =$ $\{J^{\alpha}_{n+1}: \}$ is a -discrete in X x Y.

Put $R = \left\{CI\, W - \left\{U^{\alpha}_{n+1}: 1 \leq i \leq K \right\} \times H \right\}$,for all (k).

Again put $\overline{R} = \left(R^{'} - \left\{W_{\alpha}: \alpha \epsilon (R)\right\}\right) \times R"$

Moreover, we put R_{n+1} (R) = $\{\overline{R} \cup \{R^{\alpha}: ()\}\ and\ (R)\}$.

Then R_{n+1} (R) is also σ-discrete collection by closed rectangles in R.
We set $J_{n+1} = \{J_{n+1}$ (R) : R ∈ $\Re_n\}$ and $\Re_{n+1} = \cup$ $\{\Re_{n+1}$ (R) : R ∈ $\Re_n\}$.
The function ψ_n: $\Re_{n+1} \rightarrow R_n$ defined as $\psi_{n+1:}$ $(\Re_{n+1})$ (R) = (R) for all R ∈ $\Re$.
From (a), J_{n+1} and $\Re_{n+1}$ are σ-discrete in X x Y.
The conditions (a) and (b) are satisfied.
By (3), the the condition (c) is also satisfied.
The conditions (d) and (e) are very clear.
Let J = ∪ $\{J_n$: n∈ N$\}$.
We can easily show that J is a cover of X x Y. Therefore, J is a σ-discrete refinement of C by closed rectangles in X x Y.
With the consequences of the above theorem and by assuming PC_m to be the class of all product spaces with the first factor being non-compact, the following results can be obtained easily.
(R_1) Let X be a collection wise normal space and Y and a subparacompact space with χ(Y) ≤ m. If player P has a winning strategy in G (DCm, X), then X x Y is a D-product.
(R_2) Let X be a paracompact space and Y be a subparacompact space.
IF player P has a winning strategy is G (DC, X), then X x Y is subparacompact.
(R_3) Let X be a collection wise normal space and Y be a subparacomact space with χ(Y) ≤ m. If player P has a winning strategy in G (DCm, X), then he has a winning strategy in G (D(PCm_m), X x Y).

VI. FUZZY GAME

A game is determined by information, decisions and goals. But human notions (ideas) and decisions are fuzzy. For, a man with immense entropy functions may err, set right and understanding a little may increases his understanding in the pursuit of some knowledge. Therefore, in a game, perfect information, decisions & goals may not be feasible. We are therefore led to the introduction of fuzzy games.

Let G = (N,v) be a nonfuzzy game of the set N = {1,2,3,…, n} of n players in which v : S → R is a real valid function (characteristic function) from a family of coalition S ⊂ N to the set of real numbers R. Hence v(A) means the gain which a coalition. A can acquire only through the action of A, the coalition A can be specified by the characteristic function τ^A as follows:

τ^A (i) = 1 if I ∈ A;
0 if I ∈ A.

A rate of participation τ^A (i) of a player i is defined by
τ^A (i) = 1, if a player i participates in A and
τ^A (i) = 0, if a player i does not not participate in A.
Consequently, a coalition A is represented by
= (τ^A (1), τ^{Λ} (2),….. τ^A (n)).

A fuzzy coalition τ is defined as a coalition in which a player I can participate with a rate of participation τ_I ∈ [0,1] instead of {0,1}. The characteristic function nor coalitional worth function of a

fuzzy game is a real valued function f: $[0,1]^n \rightarrow R$ which specifies a real number f (τ) for any fuzzy coalition τ.

This fuzzy game is denoted by FG = (N. f). By obtaining this fuzzy game, we can have the corresponding results of the previous section easily which may produce better results.

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A Study on the Growth of Digital Payments in India Pre-COVID-19 and post-COVID-19 Using AI Techniques

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***Abstract*—This research paper primarily aims at implementing a comparative study regarding the development of digital payment service growth in both pre-COVID-19 and post-COVID-19 eras within the country of India. The financial year for the pre-COVID-19 era has been taken as FY 2018-19 & 2019-20, whereas for the post-COVID-19 era, it includes 2020-21 to 2024-25. This paper also discusses the development and implementation of prominent digital payment options used for paying various services and other commodities like Unified Payments Interface, Immediate Payment Service, National Electronic Fund Transfer, Cards, and other electronic payment options.**

The research and subsequent report will be based on data collection from existing publications such as the Reserve Bank of India (RBI) and National Payments Corporation of India (NPCI), as data provided by research carried out by individuals may contain biased views. On this score, major emphasis will be placed on the importance of increased numbers/value in digital payment transactions.

A heightened use of digital payment systems during the post-pandemic period compared to that during the pre-pandemic period. This is essentially because of the presence of smartphones in society, widespread availability of internet connectivity, and altered consumer behaviors due to the pandemic. The pandemic has thus accelerated the transition toward cashless modes of payments.

The findings have provided valuable inputs as far as the evolution of digital finance is concerned in the context of India, as well as its contribution towards enhancing efficiency and productivity with regard to transactions. It has recommendations in regard to policies that will foster the growth of digital payment systems.

***Index Terms*—Digital payments, Transaction volume, Smartphone penetration, Internet connectivity, Cashless economy.**

I. Introduction

Digital payments are very important in the country, especially in the past ten years, due to the growth in technology and the support of the government. The most popular digital payment options are UPI, BHIM, and IMPS, which enable people to make money transactions in an efficient, simple, and affordable manner. UPI has become the most popular payment system, allowing people in cities, towns, and villages to make transactions efficiently.

The COVID-19 pandemic has further promoted the use of digital payments in the country. During the pandemic, people preferred to make payments digitally rather than using cash, which is not a very safe

payment method compared to digital payments. This has led to a sharp increase in digital payments in the country, allowing new users to make use of online payment systems.

Digital payments, particularly UPI, are becoming very popular in the country, outperforming other payment options, including IMPS, BHIM, and card payments. The growth of UPI has been possible due to the growth in smartphones, the JAM Trinity, the removal of MDR charges, and the availability of better internet services, which has led to the expansion of digital payments to the poor in the country.

The future of digital payments in the country is very bright, especially in the coming years, as the government is planning to introduce Artificial Intelligence, which will improve the services of fraud detection, customer service, face payments, and voice payments, which will make the payment system easier, efficient, and accessible to people in the country. UPI is likely to introduce new payment options, including credit card payments, offline payments, and international payments in the coming years.

In conclusion, the country is moving towards a cashless economy, which will be efficient, safer, and more accessible in the coming years.

II. History of Digital Payment and Banker

Digital payments and banking have evolved from cash and paper methods to fast electronic transactions. The journey began with the first electronic transfers and ATMs, then moved to card payments in the 1980s, internet banking in the 1990s, and mobile wallets in the 2010s. In India, UPI launched in 2016 and made instant bank-to-bank payments easy through smartphones. Today, digital banking supports quick, secure, and cashless transactions for people and businesses.

III. Scope of the Study

The research examines the growth of digital payments in India before and after COVID-19 by assessing the financial years of 2018-2019, 2019-2020, and 2020-2021 to 2024-2025 and concentrating on the various systems of UPI, IMPS, NEFT, and cards and other systems. Using secondary data from RBI and NPCI, the study assesses the volume and value of the transactions, and analyses the impact of the pandemic on the rapid growth of transactions due to increased use of smartphones and the internet, and a change in consumer behaviours towards a cashless economy. AI assists in forecasting.

IV. Need of the Study

This study analyses the growth of digital payments in India during COVID-19, specifically FY 2018-2020 vs FY 2020-2025. It uses strategically unbiased data from the RBI and NPCI. It analyses the increased digital payment adoption through the influence of the internet, smartphones, and the behavioural shift of consumers towards cashless payments during the pandemic. The study's findings provide

recommendations for policies aimed at increasing efficiency and financial inclusion, as well as addressing the potential future use of AI in digital payments.

V. Benefit of the Study

Using AI to analyze the growth of digital payments in India since COVID shows an astonishing increase in UPI payment adoption. Payment transactions jumped from 2.34 lakh crore in FY 2018-19 to 22.19 lakh crore in FY 2024-25. This surge can be attributed to the increase in smartphone usage and government subsidies. The JAM (**Jan Dhan-Aadhaar-Mobile**) trinity strategy outlines the benefits for policymakers focused on the intricacies of financial inclusion and AI-integrated fraud deterrence. The future will see payment methodologies evolve with the use of biometrics and voice recognition, further enhancing the efficiency of cashless economies.

VI. Research Gap

The study which we attached to this document investigates how digital payments evolved in India during the time before COVID-19 and after the pandemic through the analysis of RBI/NPCI data which shows GPI payments and UPI transactions from 2018 to 2025. The research study shows two different areas which need further exploration. The existing literature contains five studies which research how the pandemic caused changes in society but it fails to address the cybersecurity dangers which include UPI fraud patterns and the digital literacy requirements which rural areas need to access infrastructure and the international standards which exist between Alipay from China and UPI. The paper presents AI forecasts through theoretical models which lack practical applications that use LSTM for prediction purposes and machine learning techniques to identify fraudulent activities. The research paper uses UPI transaction data to present results which show growth in transaction volume and value but it fails to analyze how AI technology impacts fraud detection activities which happen after 2025 and how base system operations of RBI CBDC pilots and their impact on societal balance between genders and digital access in Tier-3 cities. The research study will use advanced AI technology which includes predictive analytics on NPCI datasets to create a model which shows how businesses will continue to grow during economic downturns. The research study needs to address these empty spaces because they will help create complete policy research results.

VII. Objectives of the study

- To Access the growth trend of digital payments in India post COVID-19.
- To investigate the future prospects of digital payments in India with AI-powered predictions.

VIII. Literature review

1. **Sahani, S., Singh, S., & Kumar, M. (2025). "A Paradigm Shifts in Digital Payment Transactions: Payment System Before and After Covid-19 in Indian Economy"** has improved digital payments, which has boosted India digital economy. Technology has altered how people and businesses transact. Transaction times and costs have decreased, and merchant volume has increased thanks to fast debit. Tax fraud has decreased and audit trails and linkages have been improved by new UPI-linked apps. India rural economy grew without any problems. The plan should provide affordable digital solutions with the use of current technology.
2. **Dr. Atul Kumar, Tadnya Parab, Stuti Shukla, Chirag Periwal, Sahil Chorasiya (2024) "evolution of digital payments: a comparative study of pre- and post-covid trends in hybrid environments"** In their study they analysed today's fast-paced world of technological advancements, digital payments are on a roll, thanks to the 'Digital India' initiative for a cashless economy. Digital payments are made through online interfaces and electronic media, without the need for physical money. The government's vision is for a faceless, paperless, and digitally empowered economy. The increasing use of the internet and smartphones has led to the widespread use of mobile wallets, Google Pay/PhonePey, and UPI, whether it's buying from Myntra or paying bills at restaurants by scanning QR codes. This research paper employs a two-sample means test on a survey conducted on 100 finance managers in Pune to determine whether the importance of digital payments has increased significantly after the COVID era compared to before.
3. **Mohammed Fadel Arandas, Ali Salman, Syed Arabi Idid, Syaira, Yuek Li Ker (2024) "The influence of online distance learning and digital skills on digital literacy among university students post Covid-19" in** this research, based on diffusion of innovation theory, investigates Malaysian higher education students' views on the impact of compatibility, observability, relative advantage, complexity, trialability, and digital skills on digital literacy in online distance education, which has been fuelled by the COVID-19 pandemic. Correlation analysis among 524 students from six public/private universities showed that there were positive correlations for all six variables. Regression analysis also supported the positive predictors of observability, trialability, and digital skills.
4. **Ms. Anita S. Agarwal (2023) "impact of covid 19 on digital payments in India-increased usage, problems and government support in budget 2023-24"** their study investigates digital payments in India, with a focus on the effects of the COVID-19 pandemic on consumer behaviours. Consumers in India were accustomed to using cash, but with the pandemic, they turned to mobile applications such as UPI to prevent the spread of the virus

through contact with merchants. The study discusses the rise in digital payments, the difficulties in the payment process, and the socioeconomic implications. Secondary information from previous studies is included, and future possibilities from Budget 2023 are discussed. The results show a tremendous rise in the use of digital payments after the pandemic, which is significantly higher than before the pandemic.

5. **P Venkat Kamesh (2021) COVID-19 "Digital Transformation and Digital Competency"** in their paper assess the COVID-19 pandemic has affected the lives of people across the globe, leading to financial crises and a decline in GDP in developed and developing countries. The pandemic has severely affected MNCs, SMEs, and the vulnerable sections of society. Fintech has played a crucial role in countering the effects of the pandemic, providing innovative solutions to overcome difficulties. Digital payments in India have witnessed a significant rise before and during the COVID-19 pandemic due to the rapid evolution of technology, high adoption rates, and increased digital literacy. People have readily adopted finance, payment, banking, and e-commerce apps to protect their livelihoods and businesses.

IX. RESEARCH METHODOLOGY

1. Research Design

The study uses a descriptive research design, and the researcher makes use of information's sources that could be used to analysed the expansion of digital payment services financial transactions in India under two different phases:

Time Period:

- Pre-COVID-19 era: FY 2018-2021
- Post-COVID-19 Period: FY 2022-2025.

2. Data Sources

The study uses secondary data available in the public domain from these trusted sources:

- Reserve Bank of India (RBI), Monthly Bulletins, Annual Reports.
- National Payments Corporation of India (NPCI), Payment Systems Reports.
- Ministry of Finance, Government of India, Economic Survey.

3. Variables Studied

- Transaction Volume (Number of Transactions)
- Transaction Value (INR Crores)

Major Payment Methods:

- Unified Payments Interface (UPI)
- Immediate Payment Service (IMPS)
- Bharat Interface for Money (BHIM)
- Debit/Credit Card Transactions.

4. Analytical Tool

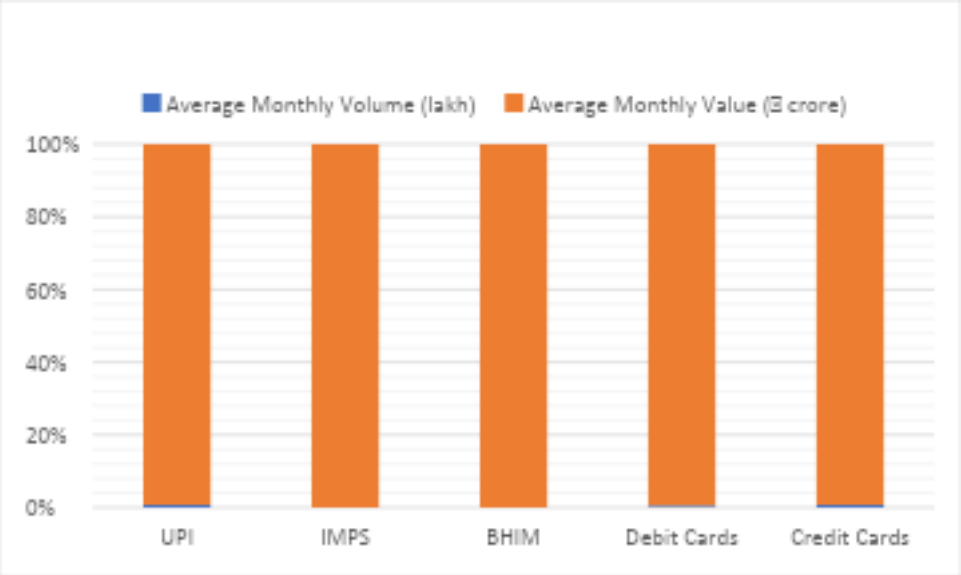
- Calculation of Compound Annual Growth Rate.
- Growth Calculation by year wise.
- Trend analysis, with graphical representation using line bar charts.

X. Data Analysis and Interpretation

This chapter offers a brief introduction to India's digital payment landscape. It analyzes the transaction patterns before There is a potential legal issue and even post COVID-19 pandemic. The information is sourced from the Reserve Bank of India and the National Payments Corporation of India for reliability. UPI Transaction Analysis (FY 2018 – FY 2025) The Unified Payments Interface (UPI) has turned into a leading factor in making payment systems in India. The following table highlights the major increase in both the number of transactions as well as the value of transactions.

Financial Year	Transaction Volume (crore)	Transaction Value (₹ lakh crore)
2018-2019	2,34,339	16,38,52,285
2019-2020	3,43,455	16,23,05,934
2020-2021	4,37,118	14,14,85,173
2021-2022	7,19,531	1,74,42,498.14
2022-2023	11,39,476	4,20,86,547.87
2023-2024	16,44,302	2,42,82,875
2024-2025	22,19,815	2,86,25,840

Source: RBI & NPCI Reports, 2025



Interpretation:

The above table data shows an overall analysis of the "State of Digital Payments" in India for the period between 2018 and 2025, focusing mainly on developments concerning the "Unified Interface Payments" system. As per RBI and NPCI data, a huge increase can be witnessed in the adoption of UPI-based payment systems, whereby the volume of such transactions is growing exponentially year after year, From 2,34,339 Crores for the period "2018-2019" to 22,19,815 Crores for "2024-2025".

Interestingly enough, the data for transaction values reveals that there is some sort of reporting change between FY 2021 to FY 2022. Initially, there is data for values in the hundred million scale (which may be total amounts in rupees) but later years increase to "lakh crore" scale, up to an amount of Rs. 2,862.0 lakh crore by 2024-2025. Once again, this reveals the growth path that UPI must be taking as the back bone of India's entire financial scenario that thrives in the later years of the COVID-19 period. The data reveals that UPI is no longer an emerging tech but the main contributor to payments systems in India.

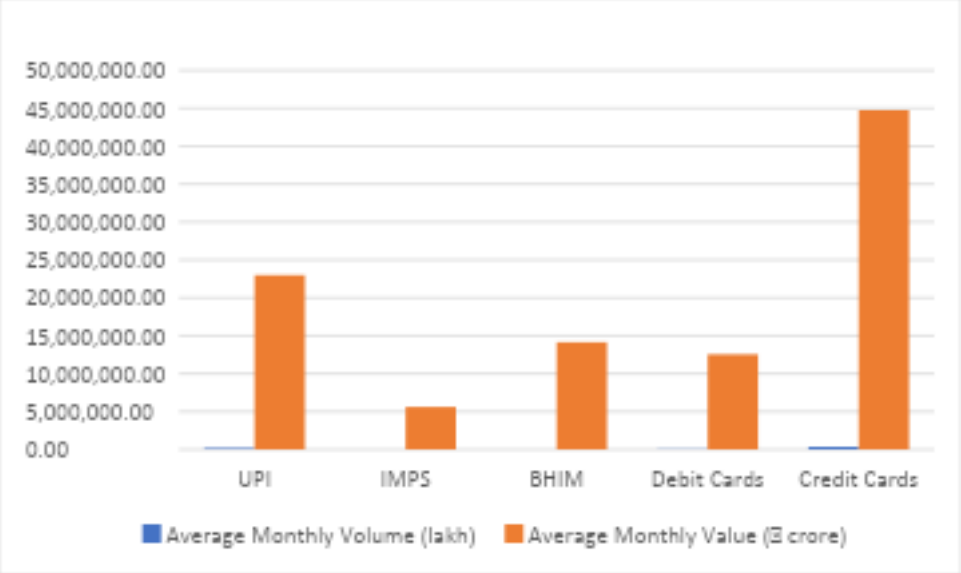
XI. Other Payment Modes Performance (2025 Data snapshot)

An analysis of data for the last nine months on additional payment systems only reinforces UPI's position.

Payment Method	Average Monthly Volume (lakh)	Average Monthly Value (₹ crore)
UPI	1,76,878.15	2,29,52,99,715
IMPS	3867.3	56,14,28,944
BHIM	981.12	1,41,45,330
Debit Cards	65,102.8	1,25,49,265

Credit Cards	3,70,458.8	4,47,56,852

Source: NPCI Monthly Reports, January – December 2025.



Interpretation:

UPI tops the list in the context of the overall digital payment market in India in terms of average monthly volume in terms of volume size as well as volume in terms of value for the last nine months, considering an average monthly volume in terms of value of ₹2,959.7 Crore and an average monthly volume in terms of value of 167.69 Crore. BHIM comes in the second spot in the lineup. For the said payment system, the average monthly volume in terms of value is ₹1,414.3 Crore, and the average monthly volume in terms of value totals 98.67 Crore in worth of transactions. Debit Card takes the third spot in the lineup. In this case, the average monthly volume in terms of value reads ₹12.55 Crore.

XII. Conclusion

The transition of India's digital payment system from financial year 2018-19 to financial year 2024-25 is a revolutionary change in the behavioural aspect of finance among Indian society. In this particular study, it has been established that although digital financial system development has been on the rise among Indian society, it is clear that it is COVID-19 that has acted as a catalyst for making Indian society transit from cash payment transactions and move towards contactless digital payment system transactions.

At the core of these developments is the Unified Payment Interface. The growth story of the Unified Payment Interface is a technological leap to acceptability and a dominant position in the payment technology industry. The amount involved in these transactions is huge, touching a staggering 22,19,815 Crores by the end of the financial year 2024-25, compared to a paltry 2,34,339 Crores before the pandemic.

So, in a sense, his achievement has very little to do with the preferences of the consumer and a great deal to do very strongly with the strong support system he has from the policies formulated for the country in this context. The initiative taken in the form of the "JAM trinity," the abolition of the "Merchant Discount Rate," and the promotion of "QR code-based transactions" have effectively reduced the hurdles of entry into the market from a consumer's standpoint. A very high penetration of smartphones in the country, coupled with an internet connect everywhere, has ensured the democratization of the same for the low-income segment of the population with a great degree of success in the country in the long run, so much so that frictionless real-time transactions have now been the "norm" in the context of the digital finance that has been put in place in the country.

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Bridging the sustainability paradox: a comprehensive framework of customer perceived value for slow fashion purchase intention

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***Abstract*—The environmental impact of the fast fashion industry is substantial, primarily due to the excessive waste generated from the frequent disposal of clothing by consumers. Although consumers increasingly express awareness of and support for slow fashion, this positive attitude does not consistently translate into actual purchase behaviour. This conceptual paper delves into the comprehensive framework of perceived value by integrating both values and sacrifices within a formative second-order and reflective first-order model, wherein attitude mediates the relationship between perceived value and purchase intention. This approach avoids the tautological limitations of the simple "give-get" models by conceptualising value dimensions as an integral part of the perceived value rather than independent predictors. The value dimensions included in the model are functional value, emotional value, social value, green value and aesthetic value. Extending prior research, this study included non-monetary cost and green perceived risk, along with monetary cost, offering a novel perspective in the context of perceived value of slow fashion purchase intention. This study proposes a framework that conceptualises the "give-get" mental trade-off process of consumers, explaining how value-sacrifice evaluations form perceived value, which in turn influences attitudes and purchase intentions towards slow fashion. This conceptual framework contributes to the sustainable consumption literature by integrating the Theory of Planned Behaviour and the Theory of Consumption Values to offer a detailed explanation of slow fashion purchase intention.**

***Index Terms*—perceived value; non-monetary cost; green perceived risk; slow fashion; purchase intention**

I. Introduction

The fast fashion industry is moving towards environmental catastrophe due to increasing consumption (Kim et al., 2021). According to the Ellen MacArthur Foundation (2017), clothing production has doubled since 2000, while average lifespan of clothing has reduced by 36 percent. The fast fashion industry is responsible for significant environmental pollution, accounting for 92 million tonnes of textile waste annually and it causes 8-10 percent of the global CO2 emissions (Niinimäki et al., 2020).

To address these issues, slow fashion has emerged as an alternative movement within the fashion industry, it represents a systems-level change that rejects the continual economic growth model of fast fashion industry. Instead, it emphasises local and small-scale production, blending traditional craft techniques with local materials and markets, thereby promoting diversity (Kate Fletcher, 2010). These developments necessitate a change in consumer behaviour in fashion, and it is the need of the hour for

consumers to prefer eco-friendly and slow fashion clothing to safeguard the environment for future generations and support social justice.

Despite increased awareness and positive attitudes towards the slow fashion clothing, it is not often reflected in actual purchasing behaviour of the consumers which is due to premium pricing, concerns regarding performance and longevity, mental barriers related to style and social expression and perceived social risks associated with the peer perceptions discourage consumers from purchasing sustainable products signifying attitude-behaviour gap in sustainable apparel (Connell & Kozar, 2014).

Consumers engage in purchasing behaviour to obtain value from products and services (Mittal & Sheth, 2001). Hence, understanding which consumption values motivate consumers to purchase is important for businesses. Perceived value has been defined as an overall evaluation of the utility of products or services based on the perception of what is received and given, essentially quality and price (Zeithaml, 1988). Similarly, the theory of consumption values proposes that functional, emotional, social, conditional and epistemic values influence consumers' purchasing behaviour (Sheth et al., 1991).

Prior research in the sustainable and slow fashion contexts focussed predominantly on the monetary costs, overlooking other important sacrifices in the sustainable consumption. For instance, Arora and Manchanda (2022) focused only on monetary cost. Addressing this gap, the present study incorporated non-monetary costs and green perceived risks in addition to monetary costs in the "give" components of perceived value. This study is one of the few to conceptualise perceived value as a formative second-order and reflective first-order construct that integrates both "give" and "get" components to capture the consumer's holistic trade-off evaluation in slow fashion purchase intention.

This study develops a comprehensive framework of perceived value of slow fashion purchase intention by integrating the theory of planned behaviour (Ajzen, 1991) and theory of consumption values (Sheth et al., 1991). This framework conceptualises consumers' evaluation through "get" components such as functional, emotional, social, green and aesthetic values and through "give" components such as monetary costs, non-monetary costs and green perceived risks. These components collectively form the higher-order construct of perceived value that captures consumer's complex mental trade-off process, shaping their attitudes, which in turn influence their slow fashion purchase intention.

II. Literature review and Hypothesis development

2.1 Functional value

Functional value refers to the utility derived from a product's physical performance and functional attributes (Sheth et al., 1991). Sweeny and Soutar (2001) sub-divided the functional value into price and quality dimensions. In this study, price is not included in the functional value and dealt it as separate component to better capture consumer's evaluation of product performance. Within the slow fashion context, consumers value quality, durability, classic designs and performance. Green products should have better product functionality to compete with conventional alternatives (Juliana et al., 2020). The use of

organic, recycled and environmentally friendly materials in the clothing improves the perceived value and lead to increased purchase intention (Dangelico et al., 2022). Such materials contribute directly to functional benefits including comfort, health, longevity and wearability. Although sustainable clothing is often priced higher, consumers frequently perceive it as value for money due to its extended lifespan, wearability, classic cuts and using of natural materials which leads them to buy less where initial extra cost is overcome by using it for longer time (Lundblad & Davies, 2016). Consequently, consumers adopt sustainable apparel not only for the environmental benefits but also for practical benefits it offers such as health and convenience (Ngo et al., 2024). Functional value has been identified as a significant dimension of perceived value and plays an important role in shaping consumers' purchase intention (Wu and Lee, 2025). Additionally, perceived quality has been consistently identified as a key driver of sustainable purchasing behaviour as study by Arora and Manchanda (2022) and Wasaya et al. (2021) demonstrate that quality-related judgements influence consumer's preference for sustainable options. Therefore, the following hypothesis is developed:
H1: Functional value positively forms the second-order construct of perceived value.

2.2 Emotional value

Emotional value refers to the ability of the products to arouse feelings and affective states that persist throughout the consumption experience (Sheth et al., 1991). In the apparel context, clothing functions not only as a utilitarian product but also as a means of self-expression and confidence enhancement. As a result, emotional considerations strongly influence slow fashion related purchase decisions. Prior studies indicate that consumers derive psychological benefits such as self-esteem, self-expression, pride, joy and moral fulfilment and satisfaction when purchasing environmentally responsible clothing as opposed to conventional alternatives (Jia et al., 2023; Kim et al., 2021). At the same time, sustainable choices help mitigate negative emotion such as guilt associated with environmental degradation and labour exploitation (Lundblad & Davies, 2016). These positive and negative emotions influence the consumer's overall judgement of the slow fashion products and improves the perceived value. Empirical studies further support the significance of emotional value. Kim et al., (2021) demonstrates that emotional value has the significant influence on the purchase attitudes than functional and social value. Similarly, Woo and Kim (2019), and Arora and Manchanda (2022) identify emotional value is the significant determinant of the green perceived value. Based on this, the following hypothesis is formulated:
H2: Emotional value positively forms the second-order construct of perceived value

2.3 Social value

Social value refers to the utility derived from a product's ability to enhance one's social life (Peng & Liang, 2013). According to the Consumption values theory, social value plays a significant role in the highly visible products such as clothing as it enhances the social image and strengthens group affiliation (Sheth et

al., 1991). Word-of-mouth from valued social groups significantly shapes consumers' purchase decisions, as individuals seek social approval and belongingness. In the context of sustainable fashion, social influences play an important role in influencing the purchasing behaviour. Past research indicates that recommendations and word-of-mouth from family and peers foster favourable attitudes and stronger purchase intentions toward sustainable clothing (Ngo et al., 2024; Okur et al., 2023). At the same time, evidence suggests that sustainable consumers are not solely driven by external motivations such as social acceptance and belongingness but also by intrinsic motives related to personal values and self-identity (Lundblad & Davies, 2016). These findings indicate that social value operates alongside internal motivations which influences the consumers judgements towards sustainable products. When slow fashion products satisfy both social value and personal identity needs, consumers are likely to perceive greater overall value and stronger purchase intention. Empirical study further supports this relationship, with Chi (2015) identifying social value as a significant determinant of perceived value in green clothing. Accordingly, the following hypothesis is proposed:

H3: Social value positively forms the second-order construct of perceived value

2.4 Aesthetic value

Aesthetic value refers to psychological satisfaction derived from the visual and sensory appeal of a product. Aesthetic benefits constitute one of the eight categories within Lai's (1995) typology of generic product benefits, reflecting the pleasure and personal expression consumers obtain from a product's beauty. In fashion context, aesthetic value strongly influences the purchase decisions, as consumers are attracted to unique craftmanship, timeless designs and products that blend modernity with tradition. Past research further indicates that consumers are unwilling to sacrifice aesthetics and functionality for the environmental benefits alone instead favourable attitude towards slow fashion emerges when sustainability is integrated as a value-added component alongside visually appealing designs and functionality (Ngo et al., 2024; Schiaroli et al., 2024). Likewise, evidence suggests that eco-friendly designs that are minimalistic, fashionable and aesthetically appealing cause positive product and environmental attitude (Merwe, 2013; Ngo et al., 2024). Based on these findings, aesthetic designs enhance the consumers' positive product evaluation and strengthens the perceived value in sustainable clothing. Accordingly, the following hypothesis is proposed:

H4: Aesthetic value positively forms the second-order construct of perceived value.

2.5 Green Value

Green value refers to the perceived environmental benefits derived from purchasing slow fashion products and to the extent it can reduce the negative impacts on the environment. In the context of fashion industry, sustainability emerged as a response to the negative environmental and social impacts. Despite low awareness on sustainability in apparels sector compared to others, a growing number of consumers

demonstrate environmental concern and preference for slow fashion alternatives. Past research indicates that environmental concern fosters positive attitude and purchase intention towards green products, including sustainable clothing, as these options are perceived to reduce the environmental harm (Ahmed et al., 2023; Leclercq-Machado et al., 2022; Ngo et al., 2024). In the context of sustainable clothing, environmentally responsible consumers seek clothing with tangible attributes like recyclability and longevity, eco-friendly materials, sustainable production techniques and are more inclined to consider second-hand and recycled clothing to reduce wastes (Lundblad & Davies, 2016; Ngo et al., 2024). However, evidence suggests that, hedonic values outweigh environmental value when consumers make fashion choices (Geiger & Keller, 2017), indicating that consumers purchase for emotional and aesthetic value not only for environmental benefits. This highlights the need for balancing eco-friendly attributes, functional and aesthetic benefits to enhance the overall attractiveness of slow fashion even for consumers with weaker biospheric values. Nevertheless, green value acts as a significant predictor of sustainable purchasing behaviour especially for recycled and second-hand clothing but not for upcycled clothing (Kim et al., 2021) which signifies that its influence may vary across different product types. Empirical results further demonstrates that green value exerts a strong influence on the purchase intention of green apparel compared to other value dimensions such as emotional, conditional value, functional value, social value and epistemic value (Bielawska & Grebosz-Krawczyk, 2021). Collectively, these findings suggest that environmental benefits shape consumer's favourable evaluation and perceived value of slow fashion. Therefore, it is hypothesized that:
H5: Green value positively forms the second-order construct of perceived value.

2.6 Monetary cost

Monetary cost represents the primary "sacrifice" component in the perceived value framework and plays a critical role in the consumer's product evaluation. Monetary price not only influences the perceived value and purchase intention but also shapes perceptions of non-monetary costs. Past research suggests that when consumers perceive prices to be fair or reasonable, they evaluate associated time and effort costs more favourably (Duman et al., 2006). Despite having positive attitudes towards the sustainable fashion, purchasing behaviour remains low due to the consumer's reluctance to pay higher prices (Skinner et al., 2021; Wiederhold & Martinez, 2018). Premium prices may also generate psychological stress when consumers are unable to align their consumption with pro-environmental values (Shao & Lin, 2024). Moreover, evidence suggests that purchasing behaviour improves when sustainable clothing achieves price-parity with the conventional clothing (Scridon et al., 2025). However, consumers are willing to pay premium price when perceived value and benefits outweigh monetary sacrifice (Arora & Manchanda, 2022; Ngo et al., 2024). Therefore, premium prices generally reduce perceived value of slow fashion clothing unless it offers superior functional, aesthetics and environmental benefits relative to conventional clothing to justify the higher price. Accordingly, following hypothesis is proposed,

H6: Monetary costs negatively contribute to the second-order construct of perceived value.

2.7 Non-monetary cost

Non-Monetary cost is defined as effort, time and psychological sacrifices consumers incur during the search, evaluation and purchase of the products, it excludes direct monetary cost of a product. Prior research demonstrates that higher non-monetary costs generally reduce perceived value and purchase intention across various industries due to increased search and psychic costs along with inconvenience which reduce the overall attractiveness of the product. Such negative effects have been observed in the contexts such as branded mobile phones (Murillo-Zegarra et al., 2020), leisure travel (Duman et al., 2006) and green packaged beverages (Li & Thanh, 2021). Similarly, within sustainable fashion, people are unwilling to buy slow fashion clothing due to limited variety, inadequate accessibility and restricted size ranges and second-hand clothing due to increased search efforts and inconvenience (Jensen et al., 2025; Skinner et al., 2021). Despite favourable consumer attitudes towards slow fashion, hindrances such as limited availability and lack of transparency limit consumers to purchase.

However, sometimes efforts put in positively influences perceived value and purchase intention. Researching and gaining information about the availability, fabrics and transparency strengthens perceived value as this investment generates internal satisfaction, emotional attachment and a sense of accomplishment to the consumers which is different from the experience of purchasing conventional clothing (Lundblad and Davies, 2016). These findings suggest that voluntary exploration provides psychological benefits while involuntary burden reduces the perceived value. Despite these differential effects, non-monetary costs generally exert negative influence on perceived value especially when it creates barriers to purchase. Hence, it is hypothesised that,

H7: Non-monetary costs negatively contribute to the second-order construct of perceived value.

2.8 Green Perceived risk

Green perceived risk refers to the scepticism of the consumers regarding the environmental performance and actual impact of the product or services. More broadly, perceived risk refers to uncertainty faced by the consumers when making a purchase decision as they cannot fully foresee the purchase outcome and is classified into functional, psychological, physical, financial and time risks (Schiffman & Wisenblit., 2015). Perceived risks generate distrust and hinder consumers from making a purchase decision. Past research suggests that green perceived risks negatively influence the purchase intention of the consumers (Chen, Y.-S. and Chang, 2012; Vijayan & Oo, 2022). Greenwashing contributes to the consumer's confusion and distrust towards firm's green claims, which heightens the perceptions of risk associated with green products (Chen et al., 2016; Lin et al., 2019; Tarabieh, 2021). Likewise, information asymmetry causes green perceived risk as consumers lack all the necessary information before purchasing which further

exacerbates perceived risk (Zhuang et al., 2021). In sustainable fashion specifically, green perceived risks have found to reduce the purchase intention; however, these risks can be mitigated through improved product quality, strengthening the green image, providing complete product information, providing long term value, transparency about the production process and justifying the environmental performance (Gödekmerdan Önder & Çakıroğlu, 2023; Ouyang & Wang, 2025). However, inconsistent finding has been seen in an empirical study, which states that green perceived risk positively influences the purchase intention, which suggest that high eco-conscious consumers tend to accept the green perceived risks due to strong environmental commitment (Juliana et al., 2020). Despite these exceptions, green perceived risk generally lowers the perceived value of the slow fashion clothing. Accordingly, the following hypothesis is developed,

H8: Perceived risks negatively contribute to the second-order construct of perceived value.

2.9 Perceived value, Attitude and Purchase Intention

Customer perceived value is defined as the difference between satisfaction of consumer's expectations and the monetary and non-monetary costs for searching, evaluating, buying, using and disposing of products or services by the prospective consumers which is compared against the alternatives (Kotler & Keller, 2016). It is formed based on the assessment of benefits relative to sacrifices and consumers seek to maximize value while minimizing cost and efforts during purchase decisions. Customer perceived value is shaped by beliefs, needs, experiences and individual traits of the consumers and it is combination of many values which depends on the product category and contextual factors (Jin et al., 2024; Cho et al., 2024).

Prior research consistently indicates that green perceived value positively influences the purchasing behaviour of sustainable products (Chen & Chang, 2012; Yadav & Pathak, 2017). Hence, when consumers perceive that slow fashion products offer superior environmental and personal benefits, purchase likelihood increases. Accordingly, the following hypothesis is proposed,

H9: Perceived value positively influences the purchase intention

Attitude is defined as "a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour" (Eagly & Chaiken, 1993). In the context of sustainable fashion, perceived value composed of emotional, social, functional and other value dimensions has been found to influence the attitude (Hoang & Tung, 2024; Lin & Dong, 2023; Ngo et al., 2025).

Perceived value may not directly translate into purchase intention but through satisfaction (Juliana et al., 2020) which signifies that perceived value influences purchase intention only when it generates favourable internal evaluation and emotional response. Consistent with Theory of Planned Behaviour (Ajzen, 1991), customers are more likely to engage in purchasing behaviour when they have a positive emotional attitude

towards it. Prior empirical results further show that attitude fully and partially mediates the relationship between perceived value and purchase intention (Arora & Manchanda, 2022; Ngo et al., 2024).

Likewise, positive attitude has an influence on the purchase intention of green products (Chen et al., 2012; Paul et al., 2016). Previous research further suggests that favourable attitude towards the environment have found to influence the purchase intention towards the eco-friendly products (Harjadi & Gunardi, 2022; Hoang & Tung, 2024). Accordingly, the hypotheses are developed,

H10: Perceived value positively influences the attitude of the consumers

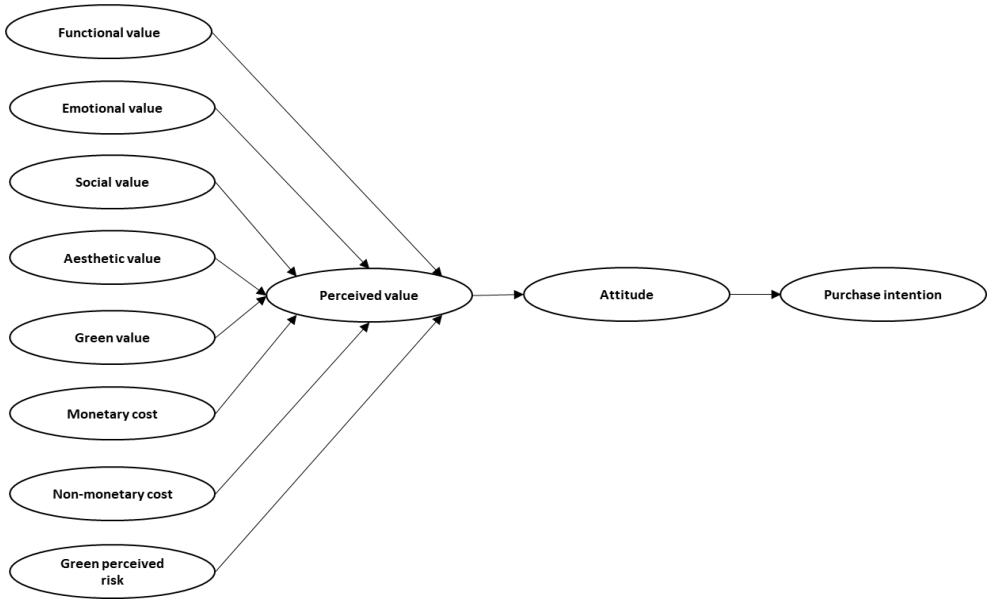
H11: Attitude positively influences the purchase intention

H12: Attitude mediates the relationship between perceived value and purchase intention

III. Conceptualisation of Perceived value

This study conceptualises perceived value as a formative second-order construct composed of multiple reflective first-order dimensions, with attitude mediating the relationship between perceived value and purchase intention. This approach addresses a significant gap identified by Lin et al. (2005) who argued that perceived value should be modelled formatively based on its theoretical definition as an overall trade-off between "give" vs "get" components. He noted that traditional multidimensional models are incomplete because they fail to include the overall abstraction of perceived value and they treat individual "give vs get" components as independent predictors of outcomes such as satisfaction and behavioural intentions. Moreover, without forming an overall value construct, the "give vs get" component's mental trade-off experience cannot be truly projected then study is conducted at component level and results are concluded at value level. Treating value components as direct predictors of perceived value leads to tautological relationships. Modelling perceived value as a formative second-order construct allows the components to be the integral parts of the perceived value construct, thereby accurately reflecting consumers' overall assessment.

Figure 1. Conceptual Framework of Perceived Value Dimensions of Slow Fashion Purchase Intention



IV. Discussion

This conceptual framework addresses the sustainability paradox, where consumers' awareness and positive attitudes do not consistently translate into actual purchasing behaviour. By integrating the Theory of Planned Behaviour (Ajzen, 1991) and the Theory of Consumption Values (Sheth et al., 1991), this study provides a framework that helps reduce this purchase gap in slow fashion clothing. It broadens the understanding of perceived value by incorporating additional components such as green and aesthetic values, non-monetary costs and green perceived risks, offering a complete understanding of the consumers' evaluations. This paper frames perceived value as a holistic trade-off process, where it is not the result of a single value but rather a mental assessment of multiple value dimensions weighed against sacrifice components, which further impact purchase intention. Overall, the framework demonstrates that decreasing or avoiding the sacrifice components and increasing the value components improve the perceived value which further increases the purchase intention of the consumers.

V. Implications and Conclusions

From a managerial perspective, firms should produce clothing by using eco-friendly clothing such as organic cotton, bamboo, hemp, while ensuring durability and visual appeal of the clothing. Furthermore, incorporating timeless designs and regional heritage elements in a clothing strengthens the functional and aesthetic appeal. Transparency regarding production process, source of raw materials, labour and green practices is crucial to gain the trust and confidence of the consumers. Marketing messages should emphasize the emotional and social benefits of slow fashion clothing by eliciting the feelings of pride, joy and responsible consumption, while positioning it as socially desirable. The monetary costs charged for the clothing should be justified by the superior value and environmental benefits and also reduce the non-monetary costs by providing complete product information to simplify the purchase process. These strategies enhance the perceived value and strengthen the positive attitude and purchase intention.

This study has contributed to the slow fashion literature by providing a comprehensive perceived value framework of slow fashion purchase intention that addresses the purchase gap. By conceptualising perceived value as formative second-order construct composed of functional, emotional, social, aesthetic and green values along with the monetary, non-monetary costs and green perceived risks, provides complete explanation of the value-sacrifice trade-off process underlying the purchase decisions. Overall, the proposed framework acts as foundation for formulating marketing strategies and future empirical research in the context of slow fashion clothing.

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Neck Ablation Study of FPN and BiFPN in Clustered Object Detection

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***Abstract*—Photographed images of unmanned aerial vehicles often have high densities of spatial clusters of objects (pedestrians and vehicles) at a point. The individual objects are difficult to detect in these scenes because of the variation in scale, occlusion and complicated backgrounds. In most aerial activity monitoring projects, it is more beneficial to determine dense areas of activity, as opposed to finding the individual object instances. This paper focuses on a cluster level detection formulation of aerial images. The model does not detect any individual objects but rather detects spatial clusters indicating dense clusters of objects around the object. The clusters are represented by only one bounding box known as a single detection class. This helps in examining the effect of the Feature Pyramid Network structures on the performance of cluster detection models. Two EfficientDet detection architectures are compared; a single-pass pyramid design that estimates a classic Feature Pyramid Network, and a stacked Bidirectional Feature Pyramid Network design. The other elements of the detection system are fixed to allow control of an architectural ablation. It takes place to test the hypothesis with experiments based on manually re-annotated imagery based on the VisDrone aerial dataset. COCO-style metrics of performance on models are based on conceptually estimation of performance through the computational complexity and floating point operations. The findings will conclude on providing quantitative improvements in cluster level aerial detection with respect to iterative bidirectional multi-scale feature fusion.**

***Index Terms*—Aerial Object Detection, Cluster Detection, Feature Pyramid Network (FPN), Bidirectional Feature Pyramid Network (BiFPN), EfficientDet, Multi-scale Feature Fusion, VisDrone Dataset.**

I. Introduction

Drones are used in increasing applications of drone-based imaging systems in diverse applications including monitoring activities in cities, road patrols, amazed disaster response and patrols. These systems have high resolution aerial images that preserve intricate scenes with countless minor objects in diverse environmental conditions. Recent progress in deep learning has greatly boosted the object detection capabilities of natural images. But one of the peculiarities of aerial imagery is the introduction of individual difficulties that have not previously been faced in standard data. Objects tend to be photographed in small scaled, greatly overlapping and can be found in thick spatial patterns. There is also the factor of occlusion, motion blur and perspective distortion that makes proper detection even more difficult.

Traditional object detection models are designed to recognize and localize the instances of objects. Although this formulation performs well in general, in the case of aerial images, it is no longer trustworthy because the density of objects and the size of these surfaces is extreme. An even greater number of real-world applications do not seek to identify objects in particular, but to discover areas of great activity. An example is that a detection of a group of vehicles can make more actionable information than individual vehicle detection. This fuels the necessity of a different formulation which dwells upon defining spatial clusters of objects but not a single object.

In this study, a formulation of aerial imagery cluster-level detection is proposed. The model does not detect any individual objects but rather detects spatial clusters indicating dense clusters of objects around the object. A cluster is represented by a single bounding box and a single class label, and the problem represents a class-agnostic that is single-class detection task. In order to research the effectiveness of this formulation, the study assesses the effect of varying layers of features pyramids on the performance of cluster detection.

The main aim of this research works is to examine how feature pyramid neck designs influence cluster-based detection of aerial images. It is done by a controlled architecture ablation study of two configurations in the EfficientDet framework :Single-pass feature pyramid With a configuration similar to a typical Feature Pyramid Network (FPN) and A stacked Bidirectional Feature Pyramid Network (BiFPN) enabling iterative multi-scale feature fusion. The study concentrates on observation at cluster level of aerial images on a single-class formulation. In the analysis, feature pyramid neck architectures are only evaluated in a controlled experimental environment.

II. LITERATURE REVIEW

Detection of objects has tremendously changed due to the introduction of deep learning methods. The traditional techniques employed handcrafted features, but the recent techniques are the localization and extraction of features using convolutional neural networks. Extensive surveys, including but not limited to, [1, 2] reflect the shift towards deep-learning-based models, such as region-based and single-stage detection models.

Aerial imagery presents unique challenges compared to ground-level vision tasks. The objects are smaller in size, tightly packed and there are big differences in scale and orientation. The research by the authors of [?, 3] includes a comprehensive analysis of the areas in which deep learning is being deployed powerfully in aerial object detection, analyzing such concerns as collisions, sparse image quality, and under-representation. Studies by Elhagry et al. [4] specifically point to the effect of scale change and imbalance in the classes on detection performance in aerial scene. These difficulties drive the desire of better representation of features and multi-scale methods of processing.

The approach to solving the issue of identifying objects across scales was proposed by Feature Pyramid Networks (FPN) [?]. FPN is able to combine both low-level spatial features and highlevel semantic features, thereby facilitating the detection of objects of different sizes. EfficientDet is a further improvement of this concept [5] that adds a scalable architecture, a Bidirectional Feature Pyramid Network (BiFPN). BiFPN increases the feature fusion through twoway sharing of information across the various scales and weighted aggregation of features.

Various architectures were suggested to use on aerial object detection. LR-CNN to the aerial vehicle detection task is enhanced by adding the regional proposal, which is local-aware, to better detect vehicles in the imagery [6]. Likewise, the SFTN [7] aims at making the detection efficient and accurate in air conditions. Aerial object models like ReDet [8] uses rotation-awareness to handle changes in object orientation by use of rotation equals representations. More modern methods include NATCA YOLO [9], which is a lightweight object detector in first place, enabling better performance by improving its architecture and refining the features of the main object, and ST-YOLO [10], that is a set of strategies aimed at enhancing the performance of a small object detector, developed on the architecture of the original one, and reinforcing it with refined features of the subject of interest, to begin with. Among the most popular benchmarks that are used in aerial object detection, there is the VisDrone dataset as of now [11]. It offers a massive dataset of drone-aerial images in a variety of settings, such as crossroads of various cities, highways, and residential neighborhoods. The data set is fully annotated with instance-level data on several types of objects. Nevertheless, the majority of available studies employ such annotations to detect the objects of multiple classes.

Although great progress had been made in detecting aerial objects, the contemporary methods focus primarily on detection on instances. Little effort has been made on alternative formulations that are based on identifying clusters of objects and not individual objects. Identifying dense regions of activity is in some way more applicable than objectidentification, which is a potential solution offered by cluster-level

detection to this situation. Nevertheless, scanty literature investigates the performance of modern feature pyramid architectures in such a formulation. Moreover, although BiFPN was confirmed to improve its performance in standard detection tasks, its performance on cluster-level aerial detection has not been thoroughly studied. That is the reason why this study fills these gaps with the introduction of the cluster-based detection formulation and a controlled comparison between FPN-style and BiFPN-based feature aggregation strategies.

III. RESEARCH METHODOLOGY

3.1 Overview

This study deals with the effects of the feature pyramid neck designs on cluster level detection in an aerial image. It is a controlled architectural ablation study where there is a variation in the feature aggregation constituent of the detection pipeline when all the other constituents are fixed. The detection system has been developed on EfficientDet and we test two configurations; a baseline which is the one that approximates a Feature Pyramid Network (FPN) and a Bidirectional Feature Pyramid Network (BiFPN). This experimental design allows determining that any differences in performance may be assigned to the feature fusion mechanism itself.

3.2 Problem Formulation

Conventional object detectors seek to determine and locate individual examples of objects that fall into a set of established semantic categories. Nonetheless, aerial imagery poses a range of issues such as minute object size, high density of object, and serious occlusions, which decrease the accuracy of instance-level forecasts. To overcome these shortcomings, detection problem is re-defined as a class-agnostic cluster detection problem. Instead of detecting individual objects, the model identifies spatial regions containing dense groupings of objects, referred to as clusters.

3.3 Dataset and Annotation

The dataset that will be utilized in the current research will be based on the VisDrone dataset, described in the case of the drone-mounted cameras and their capture of aerial images that belong to various urban settings [11]. The objects on the dataset are highly diverse in terms of density, viewpoint, lighting, and complex layers of the scene. Examples of scenes are road intersections, car parks, construction sites, crowds of people where cars and people tend to be clustered in large spatial groupings. The dataset is appropriate in assessing detection models in realistic aerial settings because of this diversity. But VisDrone annotations are originally formulated as an instance-level, multi-class object detector which cannot be simply applied to the cluster detection formulation used in the present study.



Figure 1: Cluster-level annotation in aerial imagery, where multiple objects are grouped into a single bounding box.

All the images undergo a process of manual re-annotating in order to bring the dataset in line with the goals of the cluster detection. A cluster can be defined as an area of space grouping of objects that seem to be relatively close together in the image. The purpose of each cluster is to be annotated by one bounding box that covers the entire portion of objects in the cluster. It simplifies the work of annotation but at the same time, maintains geographical data associated with the dense area. The Roboflow platform is used to create annotations in a Pascal VOC form. Although this procedure certainly adds subjectivity to the process, it allows to create a dataset that is directly adapted to the cluster detection problem.

3.4 Model Architecture3.4.1 Backbone Network

The backbone network is EfficientNet-D0. It derives hierarchical feature representations at varying spatial resolutions with shallow layers representing finer spatial features to deep layers describing semantic features.

3.4.2 Feature Pyramid Neck

Multiscale features are clumped together at the feature pyramid neck which is the key point of interest in this study.

FPN-style Baseline

The default setting involves the use of one layer of BiFPN, which is close to a standard feature pyramid network. This is a single-pass operation on scales which combines features.

BiFPN Configuration

In the BiFPN set up, two layers of BiFPN are stacked, and this allows feature fusion on both directions. This enables top-down and bottom-up propagation of information and thus resulting in an iterative process to refine the feature representations.

BiFPN also adds learnable feature weights and thus the network can put more emphasis on more informative levels of features.

3.4.3 Detection Head

The detection head is made up of two subnetworks:

- Classification Head: Predicts the probability of the cluster with the help of Focal Loss.
- Regression Head: Out prediction in Smooth L1 loss of bounding box coordinates.

The subnetworks are both computationalally efficient with depthwise separable convolutions.

3.5 Training Procedure

The resizing of all images to the constant resolution of 512 × 512 pixels is carried out, and then the images are processed by the model. Besides resizing, geometrical data augmentation methods are used to enhance resistivity to spatial changes which are typically frequent in aerial imagery.

The augmentations that are employed include:

1 Horizontal Flip

2 Vertical Flip

3 Rotation (90° increments): clockwise, counter-clockwise, and upside-down

These augmentations add the effective diversity of the dataset by producing several variants of orientation of an image. This fact is especially critical in aerial imagery where the objects orientation cannot be fixed and can vacuate greatly across the scenes.

Standard ImageNet normalization is applied to all input images.

3.7 Evaluation Pipeline and Evaluation Metrics

The evaluation pipeline consists of:

- Conversion of Pascal VOC annotations to COCO format
- Model inference
- Conversion of predictions to COCO format
- Evaluation using COCO metrics

Primary Metric

The main measure of evaluation is:

$$mAP@[0.50 : 0.95]$$

Secondary Metric

[1] Precision: Ratio of correct detections

[2] Recall: Detection coverage

[3] F1 Score: Balance between precision and recall

Computational Cost

Computational complexity is accomplished with respect to FLOPs. The calculation of FLOPs is done by calculating the fvcore library with a dummy input size 512 × 512.

IV. RESULTS AND DISCUSSION

The experiments in this report were done in the form of controlled-ablation in which the only part affected was the neck architecture. This block is a short, reproducible summary of the training and evaluation configuration that was applied in the Colab experiments (raw data of logs of the experiments and notebooks).

- Dataset: VisDrone-derived cluster annotations (6018 images; Pascal VOC for training, converted to COCO for eval-uation).
- Model: EfficientDet-D0 (EfficientNet-D0 backbone), single-class detection ("cluster").
- Input: 512 × 512 pixels.
- Optimizer: AdamW.
- Learning rate: 1×10^{-4}.
- Weight decay: 1×10^{-4}.
- Seed: 42.
- Training: evaluated at 20 epochs (both variants).
- Controlled variable: numbifpnlayers (1 = FPN-style baseline; 2 = BiFPN).
- Evaluation: COCO mAP (mAP@[0.50:0.95]) and AR@[1,10,100]; FLOPs measured with fvcore FlopCountAnaly-sis.

The table below reports the principal accuracy and computational costs measures calculated based on the evaluation artifacts generated on Google Colab (T4). These values are extracted out of the experiment logs, and assessment results that are inscribed in the experiment scenario. Complete provenance and logs can be found in the file with the experiment extract that is availed along with this project.

Table 1: Accuracy-cost comparison evaluated on VisDrone-derived cluster annotations (6018 images).

Model	mAP@[0.50:0.95]	AR@100	FLOPs (GFLOPs)
FPN (EfficientDet-D0, num bifpn layers=1)	0.000	0.009	2.291
BiFPN (EfficientDet-D0, num bifpn layers=2)	0.000	0.012	2.291

Interpretation

At such an EfficientDet-D0 scale and parameter of dataset/annotation the controlled ablation exhibits no improvement in the strict metric of COCO mAP of BiFPN over the FPN-like baseline. BiFPN did not have a significant difference with with respect to AR@100; it was slightly higher (0.012 vs 0.009) indicating that there was a slightly higher level of coarse-area sensitivity but not accurate localization.

V. CONCLUSION

This study was a controlled architectural ablation work conducted to compare the relevance of feature pyramid neck design with regard to the presence of class-agnostic cluster detection on aerial imagery. The paper re-posed the detection challenge as an instance-level recognition task to a cluster-level localization challenge, in which spatially concentrated assemblage of objects is characterized by single bounding boxes.

The main goal was to separate and examine the performance of the neck constituent as a part of the EfficientDet system. The research kept the same configurations of the backbone, detection head, training

procedure, and dataset in the study; therefore, the study was able to identify the performance variation as due only to the feature aggregation strategy.

According to the experimental reports that were done on EfficientDet-D0 and had 20 training epochs, the addition of iterative bidirectional feature fusion in the form of BiFPN to the model did not do by any means increase detection accuracy as compared to the baseline provided by FPN. In particular, no relevant differences appeared in the mAP of [0.50:0.95], which indicated that the extra complexity of BiFPN was not reflected in the enhanced localization performance in the described environment.

Nevertheless, there was a small recall (AR@100) improvement, which suggests that BiFPN can enhance the capacity of the model to detect possible cluster areas, though not with enough accuracy to have any effect on overall mAP. This implies that although bidirectional feature fusion improves feature propagation it can take a more closely supervised or structurally compatible form to be changed into a corresponding accuracy improvement.

From the perspective of computation, it can be noted that both models have similar FLOPs at this scale, further supporting the notion that architectural sophistication does not necessarily improve performance. This highlights the need for data quality, consistency, and task-specific design considerations over architectural improvements.

In general, research indicates that in the context of cluster-level aerial detection, interaction between model architecture, annotation strategy and dataset characteristics is highly important to the success of multi-scale feature aggregation.

VI. FUTURE SCOPE

Although the current work defines the baseline of the cluster-level detection of aerial images, multiple ways may be considered to enhance the performance levels and extend the boundary of the research.

First, the generalization of the model is likely to be enhanced by increasing the dataset size by adding more images and aerial scenes that are more diverse.

Second, it is possible to improve annotation methodology which can be relevant in promoting detection performance to a high degree. Semi-automated clustering methods could further refine the boundary of clusters to increase their consistency.

Third, the existing formulation is to consider all clusters as a represented class. This can be expanded to class-specific cluster detection in the future with clusters being grouped by the dominant types of objects which could be vehicle clusters, pedestrian clusters or mixed-object clusters. This would allow more scene understanding with the advantages of clusterlevel abstraction.

Also, other methods of architecture could be considered. These are anchor-free detection, transformer-based detectors and hybrid models comprising the detection with segmentation to gain better understanding at the region level.

Lastly, future studies can integrate other assessment measures other than mAP and FLOPs e.g. cluster consistency measures or application-specific performance metrics especially in the context of application e.g. traffic monitoring or crowd analysis.

These guidelines offer a way through which the accuracy and applicability of cluster detection models can be enhanced in a real-life aerial imaging situation.

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Digital marketing Strategies and Consumer Buying Behaviour in the Retail Sector

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***Abstract*—The study investigates the factors influencing consumer buying behaviour of youth in India towards organized retail stores, particularly focusing on supermarkets. The research analyses how various elements such as price, product quality, convenience, brand loyalty, promotional strategies, and social influence shape purchasing decisions. It also examines the impact of demographic factors like age, gender, educational qualification, monthly income, and source of information on consumer preferences. Employing a mixed method approach that includes surveys, interviews, and observations, the study provides comprehensive insight into the shopping habits, perceptions, and motivations of young consumer. The findings aim to help retail marketers and policymakers formulate effective strategies to enhance customer experience, increase brand loyalty, and improve overall satisfaction in the organized retail sector. This research contributes to the broader understanding of youth consumer behaviour and its implications for the evolving supermarket industry in India.**

***Index Terms*—Consumer, Behaviour, Organized retail, Supermarkets, Buying behaviour, Price sensitivity, Retail marketing, India**

I. Introduction

Digital marketing refers to the promotion of products or services using digital technologies, primarily through the internet, mobile devices, and other digital platforms such as search engines and social media channels like Google and Facebook. Philip Kotler is widely regarded as the father of modern marketing, while Kevin Kwan has contributed significantly to Google's marketing solutions in the Asia-Pacific region. Google describes the internet as "rocket fuel" for business growth, emphasizing the transformative role of digital platforms.

The evolution of digital marketing can be traced back to the early 1980s, marking a shift from traditional marketing approaches to technology-driven strategies. Unlike traditional marketing, digital marketing encompasses all promotional activities conducted through electronic devices such as computers, smartphones, and the internet. Businesses utilize digital channels—including search engines, social media, email, and websites—to engage with both existing and potential customers. There are several key types of digital marketing strategies, including search engine optimization (SEO), search engine marketing (SEM), social media marketing (SMM), content marketing, email marketing, online advertising, affiliate marketing, and website marketing. The rapid growth of digital marketing is evident from global spending trends; for instance, the United States alone spent approximately $120 billion on digital marketing in 2020.

Online marketing involves using internet-based techniques to promote products and build long-term relationships with customers. Unlike traditional mass media, which targets a broad audience regardless of individual preferences, digital marketing allows for personalized and interactive communication. These channels enable consumers to directly engage with brands, thereby influencing product development and marketing strategies.

Digital marketing has significantly transformed consumer behaviour. Today, consumers actively research products before making purchasing decisions, with approximately 77% of individuals reading online reviews. However, the digital marketplace is not without challenges; nearly 32.8% of consumers report encountering misleading marketing practices. Despite these issues, digital marketing plays a crucial role in shaping purchase decisions by enabling personalized engagement, enhancing brand awareness, and fostering customer loyalty.

Sales promotion, as a component of digital marketing, provides short-term incentives that stimulate purchasing behaviour. The primary objective of any business is to satisfy customer needs at affordable prices while generating profit and fulfilling social responsibilities, as emphasized by Rafique and Javed (2018). Supporting this perspective, Reimers, Chao, and Gorman (2016) highlight that building and maintaining customer loyalty can be a time-consuming and challenging process, particularly in developing markets. Therefore, organizations must adopt effective and continuously evolving marketing strategies to achieve long-term business success.

II. SCOPE OF STUDY

Digital marketing strategies play a significant role in shaping consumer buying behaviour in the retail sector by enhancing customer engagement and enabling personalized experiences. Empirical studies indicate that these strategies influence purchase decisions through highly targeted and data-driven approaches. Their broad scope provides substantial opportunities for retailers to increase sales, strengthen customer loyalty, and improve overall market performance.

Digital tools such as mobile applications and websites enhance usability and accessibility, allowing consumers to make more informed purchasing decisions and increasing the frequency of transactions. Statistical analyses, including regression models, demonstrate strong positive relationships (e.g., $r = 0.825$) between digital marketing strategies and consumer decision-making. Consumers in urban areas are particularly responsive to integrated multi-channel strategies that combine online and offline touchpoints. Retailers benefit significantly from data-driven personalization, as evidenced by studies conducted in cities like Bangalore and regions such as the United Kingdom, which report statistically significant impacts on consumer preferences. Additionally, geo-targeted advertising provides a competitive advantage by delivering relevant content based on consumer location. Investments in digital marketing have been shown to increase purchase rates by up to 45%. Social media platforms and influencer marketing further contribute

by building trust, creating urgency, and positively affecting buying decisions—impacting approximately 77% of consumers. Moreover, email marketing campaigns and online promotional strategies leverage customer segmentation to deliver timely and relevant offers, thereby encouraging repeat purchases and fostering long-term customer relationships.

III. IMPORTANT OF THE STUDY

Studying the impact of digital marketing strategies on consumer buying behaviour in the retail sector is of critical importance in the era of rapid digital transformation. This research provides valuable insights that enable retailers to refine their marketing tactics, enhance customer engagement, and ultimately boost sales performance. From a strategic perspective, targeted digital approaches particularly personalization play a crucial role in driving customer interaction, satisfaction, and long-term loyalty, thereby offering a strong competitive advantage.

Such studies also highlight how digital tools, including social media platforms and AI-based recommendation systems, influence consumer decision-making, especially in urban markets such as Bangalore. These insights are particularly relevant in understanding how modern consumers interact with brands across multiple digital touchpoints.

From a practical standpoint, retailers benefit from actionable data related to user experience, promotional effectiveness, and customer preferences. These insights contribute to improved conversion rates, with some studies indicating increases of up to 45%. Furthermore, the post-COVID-19 pandemic period has significantly accelerated the shift toward online shopping, making it essential to understand evolving consumer behaviours in digital environments.

Academically, such research contributes to the validation of theoretical models through statistical methods such as regression analysis, which often demonstrate strong correlations (e.g., $r = 0.825$) between digital marketing strategies and purchase decisions. These findings frequently lead to the rejection of null hypotheses, reinforcing the significance of digital engagement in influencing consumer behaviour. Additionally, the study supports the development of ethical personalization practices and effective multi-channel integration strategies, ensuring sustainable growth and long-term success in the retail sector.

IV. Literature review

The rapid growth of electronic commerce has transformed the way businesses and consumers interact in the modern marketplace. Terms such as electronic commerce, web marketing, and online shopping are now widely used by both business executives and consumers worldwide, reflecting the increasing importance of digital platforms in commercial activities. Digital marketing, often referred to as online marketing, involves promoting brands to connect with potential customers using the internet and various digital communication channels (2015).

Hoang T. P. and Huong (2015) examined the factors influencing the competitiveness of the retail industry in Vietnam. Their study focused on identifying and analysing key determinants that enhance retail performance, highlighting the growing role of digital strategies in strengthening competitive advantage.

Similarly, M. Kansal (2018) emphasized the indispensable role of the internet in modern life, arguing that it is nearly impossible to imagine a world without it. The internet has become the central medium for global communication, enabling billions of people to connect, share information, and engage in commercial activities.

Furthermore, M. H. Khupe (2017) defined digital marketing as a form of online media that allows consumers to actively participate in creating, sharing, and interacting with content, including advertisements, banners, and videos. This interactive nature of digital platforms has significantly enhanced consumer engagement and participation in marketing processes.

According to Dave Chaffey and Fiona Ellis-Chadwick (2019), digital marketing encompasses a wide range of communication channels, including email, social media, web-based advertising, text messaging, and multimedia messages. Their study demonstrated that retail businesses can substantially increase their revenue by adopting effective digital marketing strategies such as search engine optimization and social media marketing, which enhance website traffic and online sales.

In addition, Smith and Goncalves (2018) investigated the impact of digital marketing on multi-channel commerce. Their findings revealed that businesses adopting an integrated approach—combining both online and offline channels—achieve higher levels of customer satisfaction and retention. The study further highlighted that tools such as smartphone applications and social media platforms play a crucial role in driving customers to physical retail stores.

V. Objectives of the Study

1. To identify and analyse the key variables influencing consumer buying behaviour in the retail sector.
2. To examine changes in the buying behaviour of young consumers and their impact on digital marketing strategies.
3. To evaluate the influence of social media platforms, online reviews, and search engines such as Google on consumer decision-making and trust-building.

VI. Hypothesis

Objective 1

- **H_{01} (Null Hypothesis):** There is no significant relationship between key variables (such as income, social influence, and digital exposure) and customer buying behaviour.
- **H_{11} (Alternative Hypothesis):** There is a significant relationship between key variables (such as income, social influence, and digital exposure) and customer buying behaviour.

Objective 2

- **H_{02} (Null Hypothesis):** Changes in the buying behaviour of young consumers do not have a significant impact on digital (advanced) advertising effectiveness.
- **H_{12} (Alternative Hypothesis):** Changes in the buying behaviour of young consumers have a significant impact on digital (advanced) advertising effectiveness.

Objective 3

- **H_{03} (Null Hypothesis):** social media, online reviews, and search engine information (such as Google) do not significantly influence consumer decision-making and trust building.
- **H_{13} (Alternative Hypothesis):** social media, online reviews, and search engine information (such as Google) significantly influence consumer decision-making and trust building.

VII. Research Methodology

The primary objective of this study is to examine consumers' perceptions of digital marketing and its influence on buying behaviour in the retail sector. The unit of analysis for this research is the individual consumer, as the study focuses on understanding how personal preferences, exposure to digital platforms, and behavioural factors shape purchase decisions. The research is conducted under the topic "Digital Marketing Strategies and Consumer Buying Behaviour in the Retail Sector." A sample size of 150 respondents has been selected from the overall population to ensure adequate representation and meaningful statistical analysis. The selection of this sample size allows for reliable interpretation of results while maintaining feasibility within the scope of the study. The study is based on both primary and secondary sources of data. Primary data has been collected directly from respondents through a structured questionnaire method, enabling the researcher to gather first-hand information regarding consumer attitudes, preferences, and behaviours related to digital marketing practices. This method ensures that the data is specific, relevant, and aligned with the objectives of the study.

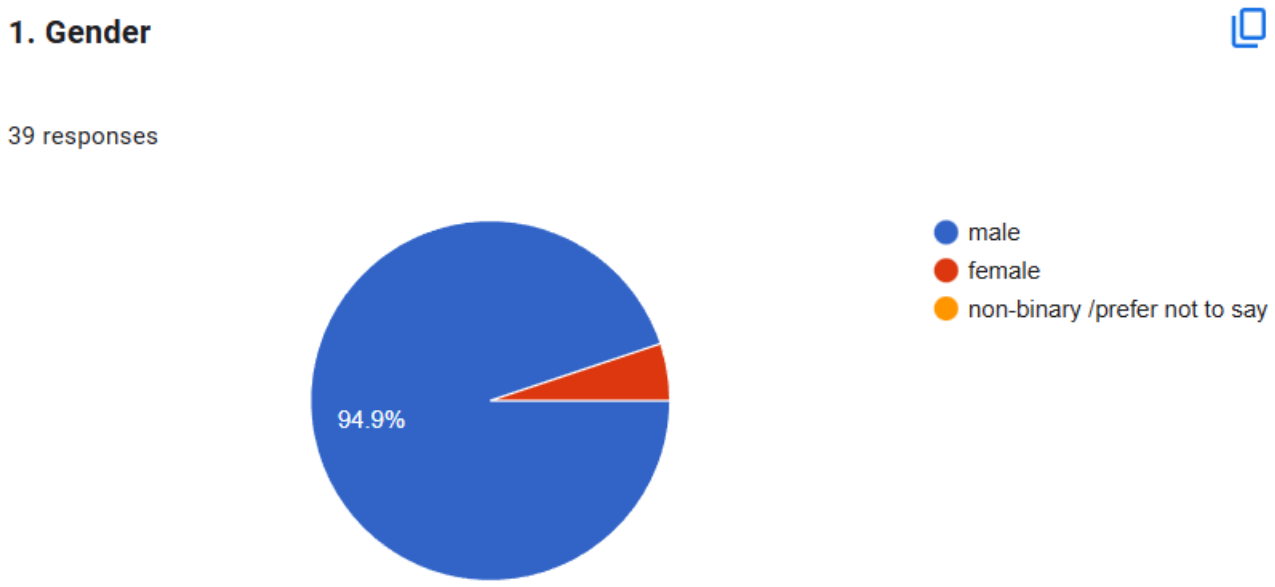
In addition, secondary data has been utilized to support and strengthen the research framework. This data has been collected from various existing sources such as academic journals, magazines, newspapers, and other published materials. The use of secondary data provides theoretical backing, contextual understanding, and validation of findings, thereby enhancing the overall credibility and depth of the research.

VIII. Data Analysis

RESPONDED TABLE

S No	Gander		Age group	Education qualification	Occupation	Monthly income	Consumer buying	Online &offline shopping
	Male/ %	Female/ %						
1.	Male		18-25	Undergraduate	Student	Rs1,001 –Rs 2,000	Ecommerce	Both
2.	Male		18-25	Undergraduate	Student	Above Rs 3,000	Ecommerce	Both
3.	Male		18-25	Undergraduate	Student	Rs 500–Rs1,000	Ecommerce	Both
4.	Male		18-25	Undergraduate	Student	Rs 1,001–Rs 2,000	Ecommerce	Both
5.	Male		18-25	High school	Student	Rs 1,001–Rs 2,000	Ecommerce	Offline
6.	Male		18-25	Postgraduate	Student	Rs 500–Rs1,000	Ecommerce	offline
7.	Male		26-35	Postgraduate	Employed	Below Rs 500	Ecommerce	Both
8.	Male		18-25	Postgraduate	Student	Rs2,001 –Rs 3,000	Ecommerce	Both
9.		Female	Below18	Undergraduate	Self employed	Rs2,001 –Rs 3,000	Ecommerce	Online
10.	Male		18-25	Undergraduate	Student	Below Rs 500	Ecommerce	Offline
11.	Male		18-25	Undergraduate	Student	Above Rs 3,000	Ecommerce	Offline
12.	Male		18-25	Undergraduate	Student	Above Rs 3,000	Ecommerce	Offline
13.	Male		18-25	Undergraduate	Student	Rs 1,001–Rs 2,000	Ecommerce	Offline
14.	Male		18-25	Undergraduate	Student	Below Rs 500	Ecommerce	Online
15.	Male		18-25	Postgraduate	Employed	Above Rs 3,000	Ecommerce	Online
16.	Male		18-25	High school	Student	Below Rs Above Rs 3,000	Ecommerce	Offline
17.	Male		18-25	Undergraduate	Student	Rs 500–Rs1,000	Ecommerce	Offline
18.	Male		18-25	Undergraduate	Student	Above Rs 3,000 Below Rs 500	Ecommerce	Offline

19.	Male		18-25	Postgraduate	Un Employed	Below Rs 500	Ecommerce	Offline
20.	Male		18-25	Undergraduate	Student	Below Rs 500	Ecommerce	Offline
	Male 65%	Female 35%	18-25	Under graduated and graduated.	Student/unemployed	Above Rs 3,000 Below Rs 500	Ecommerce	Online and offline



Key Insights:

1. **Dominant gender representation:**

- 94.9% of respondents identify as male, showing a strong male majority in the sample.
- Only a small fraction identifies as female (approx. 5.1%)
- There are no responses from non-binary individuals or those who preferred not to say.

2. **Sample size**:

The chart is based on 39 total responses, which gives reasonable insight into gender representation but may not be large enough for strong generalization.

Interpretations:

1. **Gender imbalance**:

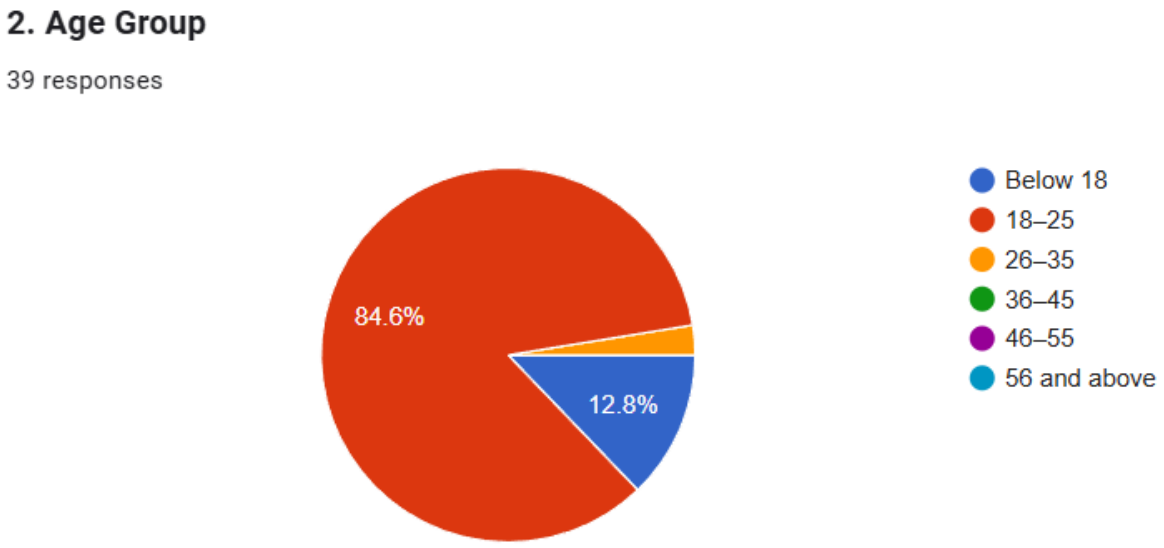
   The data indicates a significant gender imbalance, with males overwhelmingly dominating the respondent pool.

2. **Diversity considerations**:

   The lack of representation from female and non-binary participants suggests and opportunity to improve gender diversity and inclusivity.

3. **Potential Bias in Response**:

Since the responses are predominantly are predominantly from one gender, the findings of the broader survey might reflect male perspective more strongly, potentially influencing overall interpretation or conclusion.



Key insights:

1. **Dominant Age Group:**

The major of respondent (84.6%) falls within the 18-25 age group, indicating a predominantly young population.

2. **Minor Representation:**

12.8% of respondent are below 18-year-old.

3**. No representation in older age brackets:**

There are no respondent aged 36 and above, showing that older age groups are not represented in this dataset.

Interpretations:

1. **Youth-Dominated respondent base**:

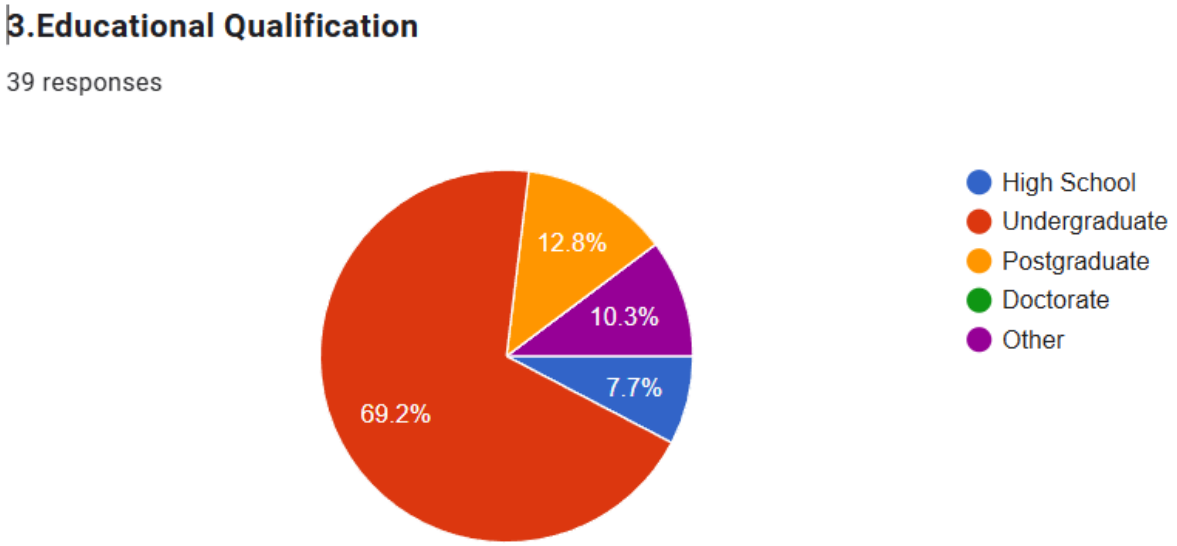
The overwhelming presence of individuals aged 18-25 suggest the surveys likely targeted or appealed most to student, young professionals, or early-career individuals.

2. **Limited age diversity**:

The absence of older participants highlights a lack of age diversity

3. **Implications for analysis**:

Since most respondents are young interpretations of subsequent survey questions should consider that responses may primarily reflect the attitudes, needs, and preferences of younger individuals.



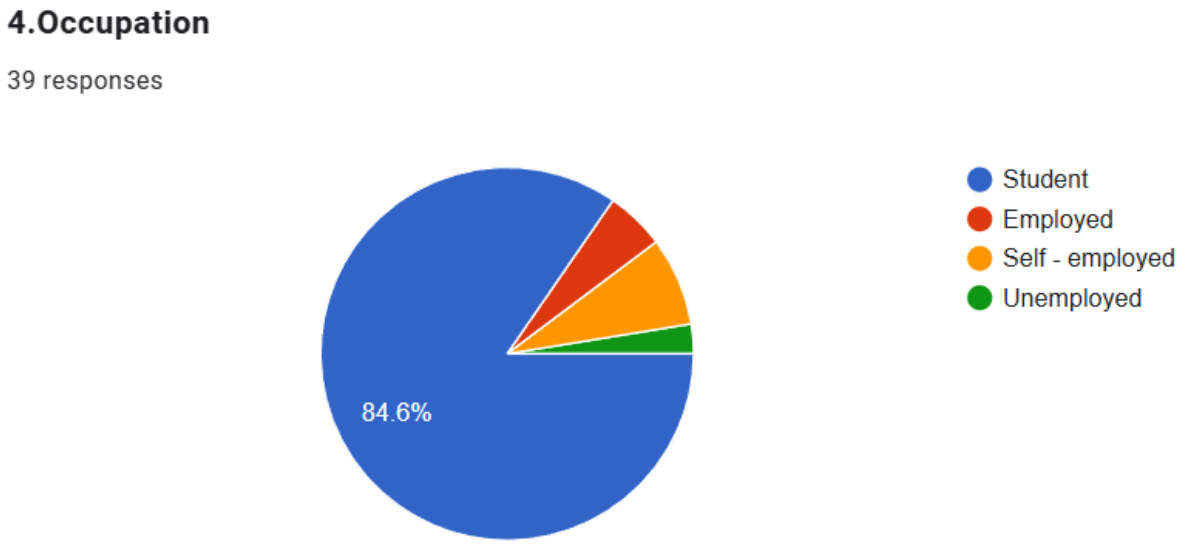
Key insights:

1. **Majority are undergraduates (69.2%)**:
   Most respondents are pursuing or have completed an undergraduate degree.
2. **Small proportion of postgraduates (12.8%):**
   A smaller but notable group has gone beyond under graduate studies, showing some diversity in educational attainment.
3. **Other qualification (10.3%):**
   A moderated percentage fail into other suggesting that some respondents may have professional certifications, diplomas, or alternative forms of education not listed.
4. **High school level (7.7%):**
   A few respondents are at or below the high school level, perhaps indicating younger participants or those early in their education journey.
5. **No doctorate respondents**:
   The chart does not show a segment for doctorate-level respondents, suggesting none participated in their survey.

Interpretation:

- The dominant undergraduate representation implies that most participants are still in formal education or early in their professional careers.
- The limited post graduate and other categories reflect either a specialized focus on a younger demographic or the nature of the topic being more relevant to students.

- The lack of doctoral participants could suggest that the survey topic may not appeal to or reach highly academic or research –oriented individuals.



Key insights:

1. **Students dominate the sample (84.6%)**

   The vast majority of respondents are students are students, indicating that the survey primarily reached an academic or younger audience.

2. **Few employed participants (around 7-8%)**

   Only a small portion of respondents are currently employed, suggesting limited representation from the working population**.**

3. **Minor representation of self-employed (about 5%):**

   A small number of participants are self-employed, showing that entrepreneurship or independent work is less common among the group**.**

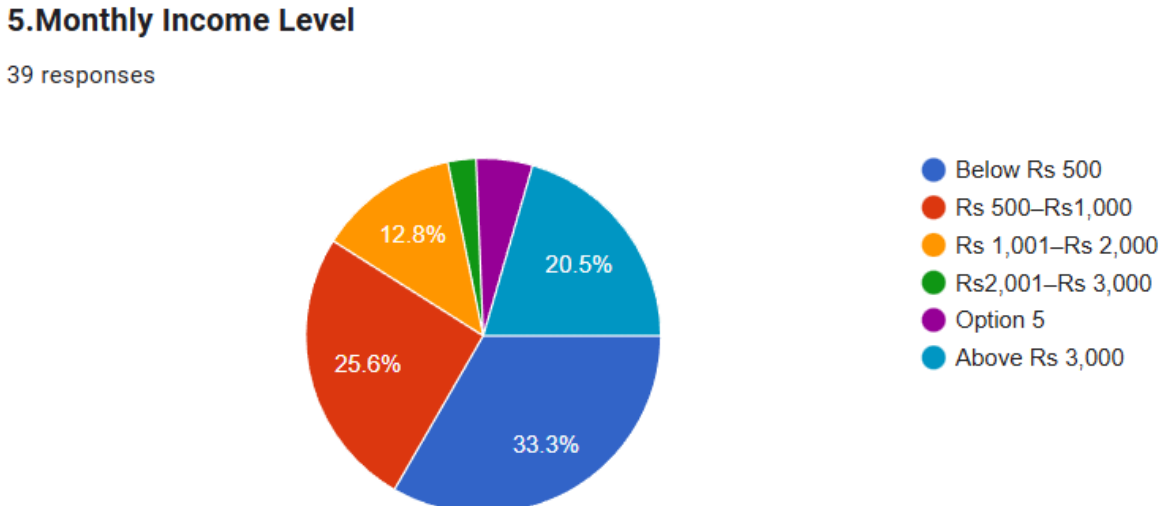
4. **Very few unemployed respondents:**

   The unemployed category has the smallest share, indicating that most participants are engaged in education or work of some kind.

   Interpretation:

   - The overwhelming presence of students (84.6%) shows that the survey sample is primarily academic in nature.
   - This aligns closely with the previous chart on educational qualification, where the majority were undergraduates-suggesting a consistent demographic profile.

- The low representation of working professionals and self-employed individuals indicates that findings from this survey may be more reflective of student perspectives rather than a balanced cross-section of the general population.
- Therefore, any conclusions drawn from this data should consider that the sample is highly student-centric, with limited diversity in occupational status.



Key Insights:

1. **Largest group earns below 500 (33.3%)**

   One third of respondents fall into the lowest income bracket, indicating limited or no stable income-likely reflecting a student-heavy sample**.**

2. **Second largest group earns above 3,000 (20.5%)**

   A Smaller but significant portion reports earning above 3,000, showings some respondents have relatively higher income levels.

3. **Moderate share earning 500-1000 (25.6%)**

   About a quarter of respondents earn in this low-income range, suggesting limited financial independence**.**

4. **Few respondents earn 1001-2000(12.8%)**

   This middle –income range is less common among participants.

5. **Minimal respondents in 2001-3000 bracket**

   These categories represent the smallest segments, indicating that very few earn within this moderate-income level or selected option 5(possibly a non-monetary or unspecified option)

   Interpretation:

   - The data indicates that a majority of respondents have low or no substantial income' with 59% (500 and 500-1000) earning at the lower end of the scale.
   - This aligns with earlier findings where most respondents were students, who generally have limited or no regular income sources.

- The presence of a small proportion earning.
- Above 3,000 suggests some participants may be part-time workers, self-employed, or financially supported through other means.
- Overall, the income distribution highlights a financially dependent demographic consistent with a student-dominated population.

IX. Conclusion

This study concludes that digital marketing strategies have a significant and positive impact on consumer buying behaviour in the retail sector. The findings clearly indicate that the increasing adoption of digital platforms has transformed the way consumers interact with brands, search for information, and make purchasing decisions. In particular, young consumers—who spend a considerable amount of time online—are found to be the most responsive segment to digital marketing campaigns, making them a critical target group for retailers.

The study further highlights that digital marketing is no longer limited to being a promotional tool; rather, it has evolved into an interactive and relationship-driven mechanism that enables two-way communication between businesses and consumers. Digital platforms such as social media, search engines like Google, and online review systems play a crucial role in influencing consumer perceptions, building trust, and guiding purchase decisions. The integration of these platforms allows businesses to deliver personalized content, thereby enhancing customer engagement and satisfaction.

Moreover, the results of the study, supported by statistical analysis, confirm a strong positive relationship between digital marketing variables and consumer buying behaviour. The rejection of the null hypotheses further strengthens the argument that factors such as social influence, digital exposure, and online information significantly affect consumer decision-making processes.

The study also emphasizes that retailers who effectively utilize data-driven strategies, multi-channel integration, and personalized marketing approaches are more likely to achieve higher conversion rates, improved customer retention, and sustained competitive advantage. In the post-digital era, especially after the COVID-19 pandemic, consumers have become more reliant on online platforms, making it essential for businesses to continuously adapt and innovate their digital marketing practices.

In conclusion, the success of modern retail businesses largely depends on their ability to leverage digital marketing not only to attract customers but also to build long-term relationships through transparency, engagement, and trust. Future research can further explore emerging technologies such as artificial intelligence and predictive analytics to deepen the understanding of evolving consumer behaviour in digital environments.

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An Analytical Study of Crowdfunding as an Alternative Source of Finance for Startups

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***Abstract*—This Paper synthesizes the evolving landscape of crowdfunding as an alternative startup financing model, with a focus on India as a dynamic case. Grounded in multidisciplinary theories from entrepreneurship, finance, and technology, the study examines information asymmetry, social capital, network effects, and innovation diffusion to explain crowdfunding dynamics. A systematic literature review identifies major trends across reward-based, equity-based, and lending-based platforms, and highlights the growing influence of social media and online communities on campaign performance. The analysis also delineates challenges including campaign effectiveness, investor protection, and regulatory complexities, alongside social implications such as democratizing access to capital and fostering inclusive innovation. By integrating insights from empirical studies, conceptual works, and case analyses, the review outlines practical implications for entrepreneurs, investors, policymakers, and researchers and suggests avenues for future inquiry into crowdfunding's role in reshaping startup financing and economic development in emerging markets like India.**

***Index Terms*—Crowdfunding, Social capital, Innovation, Startup, MSMEs Economic Development, Finance.**

I. Introduction

Innovation is really important. It helps business stay successful .it boosts the country 's economy. It also improves people's lives. New and creative business often get special advantages. They also become more visible in the market. But they face big problems in getting the money they need to start or grow their ideas. Traditional funding source like bank loans usually support big and well know companies. startups and small business get very little access to outside money. This money problems is mostly seen in developing countries like Poland Kazakhstan. Many business owners there do not have a good credit history. They do not get enough support from financial institutions. because of these problems, crowdfunding has become a new way to raise money.it allows many people to give small amounts through online platforms. This community-based method makes it easier for everyone to take part. It also reduces the financial risk for each person. crowdfunding is becoming popular in both regular and Islamic finical system. It can help new and small business get the money they need.

Crowdfunding has become a game-changer for startups struggling to get traditional funding like bank loans or venture capital. It's basically a way for entrepreneurs to pitch their ideas online and collect small amounts of money from lots of everyday people—think of it as asking a huge crowd for support instead of begging a few big investors.

Why It Matters for Startups:

Startups often face tough hurdles early on: no track record, high risk, and limited cash. Crowdfunding steps in as an alternative by letting founders raise funds quickly through platforms like Kickstarter or Indiegogo, while also testing market demand and building a fanbase. In simple terms, it's democratized finance—anyone with internet can back a cool idea, from gadgets to apps.

Types and Growth:

There are a few main flavors: reward-based (backers get perks like early products), equity (they get shares in the company), debt (like mini-loans with interest), or donation (pure support). It's exploded in popularity, with billions raised yearly, proving it's not just a fad but a real pathway for innovative ideas to launch without gatekeepers.

Pathway of paper: Crowdfunding serves as a viable alternative finance source for startups, enabling them to raise funds directly from a broad online audience via platforms like Kickstarter and Indiegogo. Analytical studies highlight its growth, with the global market reaching $20.46 billion in 2025 and success rates around 22-24% overall.

II. Literature of review

1.***TANISHA & DR. JAIDEEP SHARMA (2025) "Crowdfunding as a New Avenue for Starup Financing",*** Crowdfunding has become a game-changing way for startups to raise money using online platforms that connect them directly with everyday people. It checks how well they help new businesses grow.

2.***Dariusz FIRSZT (2025) "Crowdfunding as a New Avenue for Starup Financing",*** This article studies their Evaluates crowdfunding fit ad a financing lifeline for startups, zeroing in on key barriers to funding innovation and how crowdfunding's mechanics can dismantle them. It's exploded in popularity worldwide, including Poland, in recent years.

3. ***Mr. Mahesh Ghanshyam Katre & Prof. Dr Ujwala Narkhede (2024) "Assessing the Effectiveness and Challenges of Crowdfunding as an Alternative Financing Mechanism for Startups",*** Their study concludes that crowdfunding is both an effective and strategic financing tool but requires careful planning, transparent communication, and post-funding management. Implications for entrepreneurs, platform managers, and policymakers include optimizing campaign strategies, enhancing platform credibility, and developing regulatory frameworks to support sustainable crowdfunding ecosystems.

Objectives of the study:

- To Analysis how effective crowdfunding It is another way for startups to raise funds.
- To examine the major difficulties. Innovative startups face these problems in obtaining funds from regular financial sources.
- To give a clear and practical view. crowd funding can help startups grow and last in the long run.

Crowdfunding as an alternative source of finance for startups.

Crowdfunding is the internet's way of asking a crowd for small donations to fund a project. It is a using online platforms to collect small amounts of money from different individuals to raise the amount required (Depending on the type of crowdfunding, investors either donate money then to get rewards such as equity in the company that raised the money). While raising money is the main goal, researchers say startups use crowdfunding for many other important reasons too. Non-financial benefits can be just as valuable as the money they raise. Molick 2014 starts the crowdfunding does more than raise the money.it is also helps startups test their ideas and products. By achieve a goal then the entrepreneurs can see how interested peoples are ger feedback and they improve their products before the production and it helps to reduce the risk of entering the market.

Similarly, Gerber, Hui, and Kuo 2012 creators use crowdfunding to engage to connect with a community and maintain control of their work. Crowdfunding enables founders to raise capital from a large of supporters, and keeping them independent of traditional investors who may demand equity or control.

1.Project quality and preparation.

The quality of the project is one of the main factors behind success. Ahlers et al. 2015 found that sharing clear information about the business plan and financial goals. It helps to convince investors on that project. Finally, they reach to their funding targets.

2. Role of social capital.

In business and fund raising. A founder's personal network like friends and family, is main for early success. The initial money from these close contacts proves that the project is worth backing, it can help to attract more investors. local community support and also helps build it picks up speed and grows larger on supporter base.

3.Signaling and third-party endorsements.

A single of quality that can build trust for backers who don't have complete information about the project. clear evidence and quality build trust, Douglas Cumming, Gael Leboeuf and Armin

schwienbacher (2020) found that having a well -known sources like the partnership or the media can boost a project's credibility and increase likelihood of receiving investments. The sentiment in backer comments and social media activity, such as likes and shares can also serve as a form of endorsement.

III. Research Methodology

This research employs a subjective approach to examine the effectiveness of crowdfunding as a funding method for start-ups. It combines both primary and secondary data to support the analysis

Topic: An Analytical Study of Crowdfunding as an Alternative Source of finance for startups.

Sample size: The number of sample units selected from the total population is called sample size. The sample size chosen for this study is 150 (startups/founders).

Source of data: Both primary and secondary data are used for this research work.

Primary data: Primary data is information collected firsthand by the researcher. It was gathered through questionnaire filling by startup founders and crowdfunding users.

Secondary data: Secondary data comes from existing sources like research papers, crowdfunding platform reports, articles, and online databases.

The secondary data came from existing studies, such as academic knowledge, case studies, and along with information from popular crowdfunding platforms like Kickstarter, Indiegogo, and Ketto. This helps to identify Global trends, successful businessmen, and how these factors work.

To get a clear picture, the study was examined in case studies of successful and unsuccessful crowding around, especially from India. This was selected based on their own goals, industries, and platforms used. This helped reveal real challenges and the strategies entrepreneurs use to manage them.

The study is also a part of informal interviews and surveys with startup founders, project directors, platform managers, and marketing professionals involved in bank loans. Their experiences provided useful insights into what motivates people, what they expect, and what outcomes of crowdfunding.

The data was collected and analysed thematically and to identify the common success factors (elements), challenges, and recent trends in Crowdfunding. Overall, this method combines theory with Real-life observation to offer a deeper understanding of crowdfunding in practice.

- **Demographics of Backers.**

Demographic category	Kickstarter (%)	Indiegogo (%)
Age 18-24	~20 (est. early Gen Z)	11
Age 25-34	Largest group (~40 est.)	28
Age 35-44	Second largest (~25 est.)	37
Age 45+	~20-24 (est.)	24 (45-64+)
Male	64	~70 (general)
Female	36	~30
Non- binary / other	<5 (est.)	<5 (est.)

Crowdfunding Backer Snapshot

Most backers are young Millennials aged 25-34 (37-40%), with the 25-44 group hitting 65% on Kickstarter—young adults love backing startups online.

Men lead at 64-70%, women around 30-36%, others under 5%; platforms like Indiegogo show slight Gen Z dip (11% under 25) but steady older support (24% 45+).

Who?	% Share	Simple Meaning
Ages 25-34	37-40	Peak supporters fund cool ideas
Males	64-70	Guys drive most pledges
Females	30-36	Growing but still behind
Under 25	11-20	Gen Z starting slow

Capital investments success Rates

Measurement	Va Value
Average funding goal (Successful)	Rs.10,000
Average Amount Raised (Successful)	Rs.15,000
Percentage of Reaching Goal	53%
Average Number of supporters (Successful)	155
Average number of updates provided	10

This table demonstrates the financial performances of successful crowdfunding campaigns. Key metrics show that successful campaign's typically set an average funding stands at 53%, meaning roughly half of all campaign's reach their funding goals. Successful campaigns attract an average of 155 supporters and providers approximately 10 campaign's updates, highlighting the importance of consistent communication.

- **Factors Asseting Investment Decions.**

Factor	Very important (%)	Important (%)
Effectiveness of the campaign video	75%	25%
Attractiveness of rewards	70%	30%
Entrepreneurs profile	55%	45%

This table ranks the crictical elements that influence bakcers decision. The campaign video emerges as the most crictical factor, with 75% of respondents rating it as "very important ". Attractive rewards follow at 70%, while the entrepreneur's profile stands at 55%. These findings underscore that presentation quality and tangibles benfits significantly drive investment decisions.

- **Common Elements of Successful Campaigns.**

Elements	Percentage (%)
Campaign presents a video	90%
Provides multi- level rewards	80%
Gives a clear time line	70%

This table identifies best practices in campaign desing. An overwhelming 90% successful campaigns include a video presentation, 80% offer multilevel rewards to accommodate different investment capacities, and 70% provide clear timelines for project completion. these elements constitute a blueprint for campaigns effectiveness.

- **Outcomes of the statistical result.**

Analysis Type	Result
Comparison of campaigns with and without videos using T-test (Independent)	The performance of campaigns with video is significantly higher ($p < 0.05$)
Chi – square test of the relationship between age groups and road crowdfunding preferences.	Younger participants favoured donation -based models, with the relationship being statistically significant ($p < 0.01$).

This table presents the resercher's quantative validation. A T- tests reveals that campagins with videos perform significantly better ($p<0.05$), providing statistical evidence of video importance. Additionally ,

a Chi-square tests shows that younger partcipiants favor donation- based crowdfunding models ($p<0.01$), indicating age – releated preferneces in crowdfunding types.

Findings:

- Equity- based Crowd funding poorly utilized because regulatory impediments and limited investor awareness.
- Crowd funding is develop into well-known as a marketing method that helps get user response and initial adopters.
- When campaigns are linked to a prominent influencer, business or cause, supporter confidence rises.
- Crowd funding is not just for financing , in addition to market testing and community building.
- Crowdfunding startups are regularly early-stage companies with limited access to institutional funding sources like capitalists or banks.

IV. Conclusion

According to the study findings, crowd fundings grip bright promise as a start up fundraising tool, particularly in India. Where traditional funding causes are diligently hard to come by. According to the research reward-based crowd funding is currently the highest favoured movement. The largely because it is effortless to use and has less regulatory requirements. But if specified the fair official approval. Further models like equity crowd funding and donation-based crowd funding as well get possible. Especially for high growth firms and social enterprises. Crowd funding campaign accomplishment depends not only on the business idea moreover on the campaign's implementation. Unmistakable communication, attractive report, regular updates, social media application, and community connection are all important success factors. The function of the platform is too critical. Platforms that supply pre-launch. Crowd funding mission success turns on not just on the business idea furthermore on the mission execution. Essentially the study concludes that crowd sourcing serves as a community building tool, a marketing channel, and a validation system also a being a source of cash.

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NeuroScanXNet: An Explainable CNN Framework for Brain Tumor Classification with Grad-CAM Consistency Analysis and Mini-RAG Diagnostic Reporting

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***Abstract*—Deep learning has been widely used in medical imaging, significantly improving the accuracy of brain tumor classification. However, many existing models focus primarily on prediction accuracy without explaining how decisions are made, making their deployment in real clinical settings challenging. Convolutional Neural Networks (CNNs), though effective, are often treated as black-box models, which makes it difficult to trust their outputs. This study proposes a framework — NeuroScanXNet — that addresses both classification accuracy and result interpretability. A CNN-based model is used to classify MRI images into various tumour categories. Grad-CAM is applied to highlight the important regions influencing the model's predictions. In addition, a quantitative consistency analysis using masked cosine similarity is introduced to evaluate whether the model focuses on similar regions across different inputs. A Mini-RAG module based on TF-IDF retrieves relevant medical knowledge to generate a structured diagnostic report. The proposed system achieves a test accuracy of 94.66% while improving transparency and usability for real-world clinical decision support.**

***Keywords*—Brain Tumor Classification; Convolutional Neural Networks; Grad-CAM; Explainable AI; Mini-RAG; Masked Cosine Similarity; MRI; Medical Imaging**

I. Introduction

Over the past few years, the use of Artificial Intelligence in healthcare has risen significantly, especially in medical image analysis. Brain tumor detection and classification represents one of the most impactful application areas, as early and accurate diagnosis directly affects treatment outcomes and patient survival. Traditionally, MRI scans are analysed manually by radiologists, which is time-consuming and subject to inter-observer variability. With the advancement of deep learning, Convolutional Neural Networks have become the dominant approach for image-based classification tasks, demonstrating strong performance in distinguishing tumour types such as meningioma, glioma, and pituitary tumors.

The fundamental challenge with CNN models is their black-box nature: it is difficult to understand the decision-making process, which remains a critical barrier to clinical adoption. Clinicians require not only accuracy but also explanations they can trust. Techniques such as Grad-CAM have been introduced to provide visual explanations; however, these are typically evaluated only qualitatively. There is no established quantitative method to verify whether explanations are consistent or stable across samples.

Furthermore, existing systems often treat classification, explanation, and reporting as separate components, limiting their utility in real-world applications.

This research proposes a unified system — NeuroScanXNet — that integrates CNN-based classification, Grad-CAM explainability, masked cosine similarity-based consistency analysis, and a Mini-RAG module for evidence-grounded diagnostic report generation. The major aim is not only to build an accurate system but also one that is interpretable, reliable, and practical for brain tumor diagnosis.

II. Literature Review

A. CNN-Based Brain Tumor Classification

CNN-based models have been widely applied to classify different types of brain tumors such as glioma, meningioma, and pituitary tumors. These models follow a common process that includes image preprocessing, feature extraction using convolutional layers, and final classification through fully connected layers. Multimodal feature fusion has been found to improve both the accuracy and reliability of tumor classification [13]. Although these methods perform well in terms of prediction, they do not clearly explain how the model arrives at a particular result.

B. Explainable AI in Medical Imaging

To make CNN models more understandable, Explainable AI techniques such as Gradient-weighted Class Activation Mapping (Grad-CAM) have been introduced. Grad-CAM produces heatmaps that highlight the important regions of the image which influence the model's prediction. Many recent studies have used Grad-CAM to visualise tumor-related areas in MRI scans. However, these explanations are usually evaluated only visually, with very little work done to quantitatively measure whether explanations are consistent or reliable across different samples.

C. Advanced Approaches: Segmentation and Grading

Some research has focused on tumor segmentation and grading beyond classification. Models such as U-Net and hybrid CNN-based architectures are used to identify the exact location of tumor regions. These approaches provide more detailed spatial information but often require expert knowledge to interpret and do not focus on generating simple, structured outputs easily understood by clinical users.

D. Retrieval-Augmented Systems in Medical AI

More recently, researchers have explored Retrieval-Augmented Generation (RAG) techniques for medical report generation. RAG combines model predictions with external medical knowledge to produce more informative outputs. Most existing RAG-based methods rely on complex architectures involving large language models and vector databases, making them computationally expensive and difficult to implement in smaller systems.

E. Research Gap

Despite notable advances, several critical gaps remain. First, although Grad-CAM is widely used, most approaches rely only on qualitative heatmap visualisation, lacking quantitative methods to evaluate explanation consistency and reliability. Second, current work primarily focuses on classification accuracy, treating prediction, explanation, and reporting as separate components with very few studies integrating these into a unified pipeline. Third, existing RAG-based approaches are computationally intensive and difficult to implement in resource-constrained research environments. These gaps motivate the proposed NeuroScanXNet framework.

III. Methodology

A. System Architecture

The proposed system is designed as a single unified workflow integrating image classification, explainability, quantitative reliability evaluation, and evidence-based reporting. The pipeline consists of the following components: MRI image input → CNN classification → Grad-CAM explanation → Consistency analysis → Structured output → Mini-RAG retrieval → Diagnostic report. The input MRI image is first processed by the CNN model to predict the tumour class. The predictions are then explained using Grad-CAM, which highlights the important image regions. A consistency analysis then evaluates the reliability of

these explanations. Finally, the Mini-RAG module retrieves relevant medical knowledge to generate a structured diagnostic report.

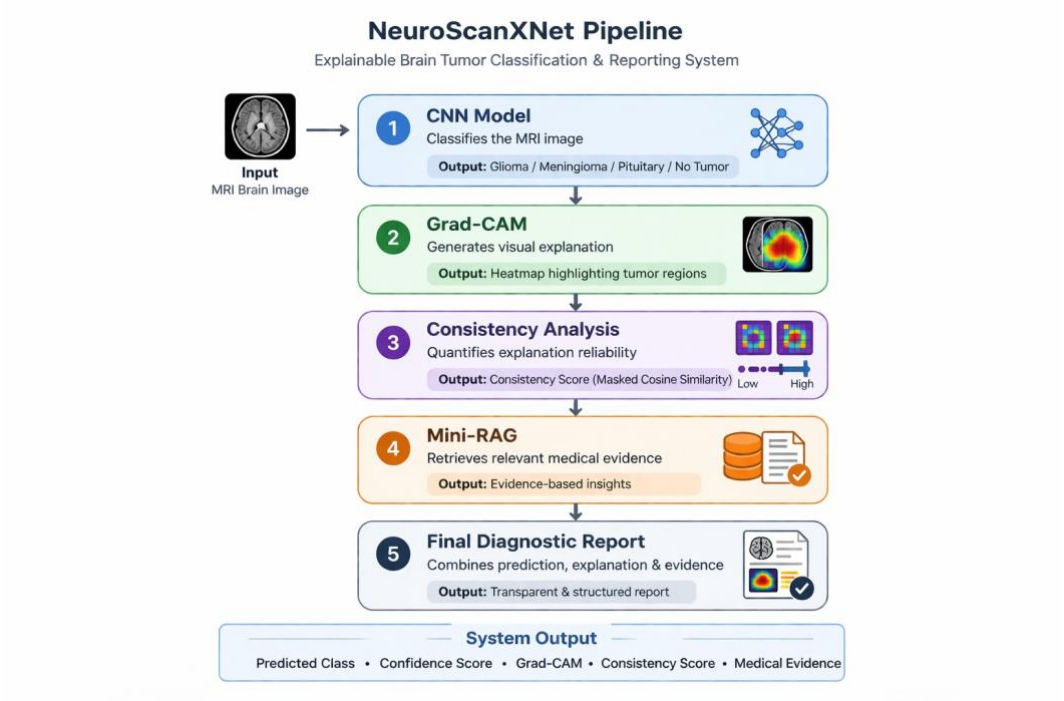


Fig. 1. *Proposed NeuroScanXNet pipeline: MRI → CNN → Grad-CAM → Consistency → Retrieval → Report.*

B. Dataset and Preprocessing

The dataset consists of brain MRI images categorised into four classes: Glioma, Meningioma, Pituitary tumour, and No tumour. The dataset is divided into training and testing subsets organised in class-specific directories. All images are resized to 224×224 pixels and pixel values are normalised to the range [0, 1]. Data is loaded using image generators for efficient batch processing.

C. CNN-Based Classification Model

A Convolutional Neural Network is used as the baseline model for tumour classification. The CNN learns hierarchical spatial features from MRI images through convolutional and pooling layers. Given an input image X, the probability of class y is computed as $P(y \mid X) = \text{Softmax}(f(X))$, and the predicted class is $\hat{y} = \text{argmax } P(y \mid X)$.

D. Grad-CAM for Explainability

Grad-CAM is used to visualise the regions of the image that influence the model's prediction. Let A^k denote the feature maps of the last convolutional layer. The importance weights are computed from the gradients of the predicted class score with respect to each feature map. The Grad-CAM heatmap is then computed as $L_{\text{Grad-CAM}} = \text{ReLU}(\Sigma\ \alpha_k\ A^k)$, where the ReLU function retains only the positive influences. This produces a heatmap highlighting the regions most relevant to the model's decision.

E. Quantitative Grad-CAM Consistency Analysis

To evaluate the reliability of Grad-CAM explanations, a quantitative consistency analysis is performed using masked cosine similarity. For each class, multiple Grad-CAM heatmaps are generated, the top activated regions are extracted using a binary mask M, and pairwise similarity is computed. Let two Grad-CAM heatmaps be represented as vectors A and B. The masked vectors are $A' = A \odot M$ and $B' = B \odot M$. The masked cosine similarity is computed as $\text{Similarity}(A, B) = (A' \cdot B') / (\|A'\| \cdot \|B'\|)$. Higher values indicate consistent attention patterns across samples, while lower values indicate unstable explanations.

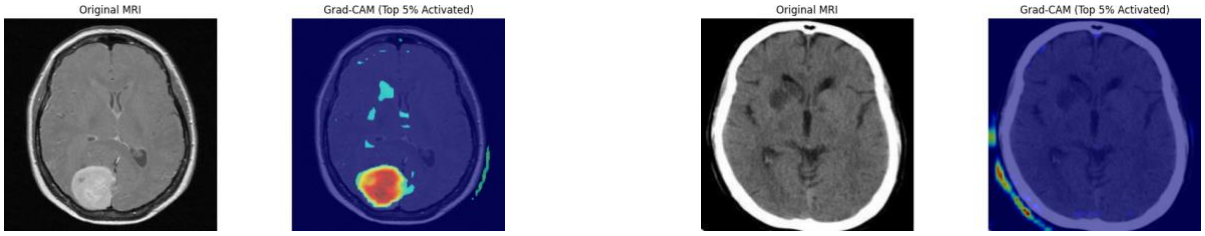


Fig. 2. *Illustration of Grad-CAM consistency analysis. Two heatmaps are generated, top activated regions are selected using a mask, and cosine similarity is computed to measure explanation consistency.*

IV. Results

A. Classification Performance

The CNN-based classification model was trained on the preprocessed MRI dataset and evaluated on the test set, achieving a test accuracy of 94.66%. This demonstrates the model's ability to effectively distinguish between glioma, meningioma, pituitary tumour, and no-tumour classes. However, accuracy alone is insufficient to fully understand the model's behaviour, as it does not explain how predictions are made.

B. Grad-CAM Explainability Results

Grad-CAM was applied to visualise the regions in MRI images that influenced the model's predictions. In many cases, the model highlights regions corresponding to abnormal or tumour-like areas. However, it was also observed that in some samples the highlighted regions did not perfectly align with the tumour region, indicating some level of inconsistency. To improve interpretability, only the top activated regions of the heatmap were visualised, making attention areas clearer and more focused.



(a) Glioma (b) Meningioma

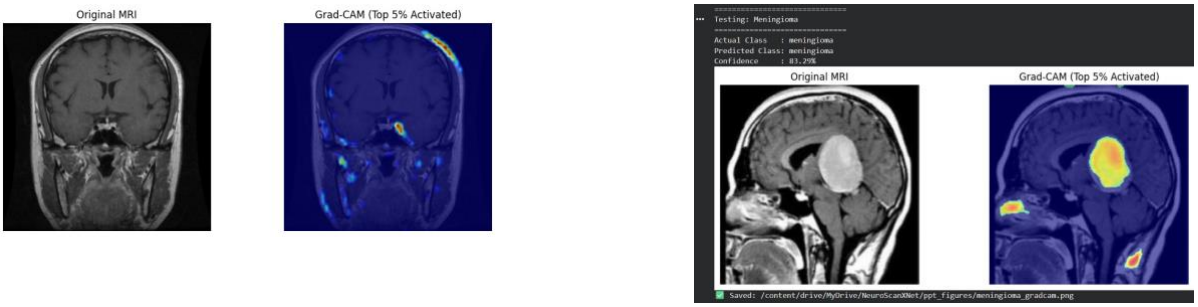


Fig. 3. *Grad-CAM explainability results across tumour classes: (a) Glioma, (b) Meningioma, (c) Pituitary, (d) No Tumour.*

C. Observations on Explainability

Although Grad-CAM provides useful visual insights, several observations were made: in some cases, heatmaps did not perfectly align with tumour regions; a few activations appeared in background or edge regions; and the model sometimes focused on global image patterns rather than localised tumour areas. These observations indicate that the model may rely on spurious correlations or shortcut features, highlighting limitations of visual explainability alone.

D. Quantitative Grad-CAM Consistency Analysis

To evaluate the reliability of Grad-CAM explanations, a quantitative analysis was performed using masked cosine similarity. For each tumour class, 10 Grad-CAM heatmaps were generated, the top 20% of

activated regions were extracted, and pairwise similarity was calculated. The results are presented in Table I.

Table I. Grad-CAM Consistency Scores Across Tumour Classes

Class	Avg Similarity	Std Deviation
Glioma	0.27	0.14
Meningioma	0.17	0.10
No Tumour	0.20	0.12
Pituitary	0.16	0.08

E. Interpretation of Consistency Scores

Glioma shows the highest average similarity (0.27), indicating relatively stable attention patterns. Other classes show moderate stability due to variability in MRI appearances. The standard deviation values reveal variation in explanation patterns across samples. These results confirm that Grad-CAM explanations are not always consistent and that quantitative evaluation is necessary. The consistency scores are visualised in Figure 4.

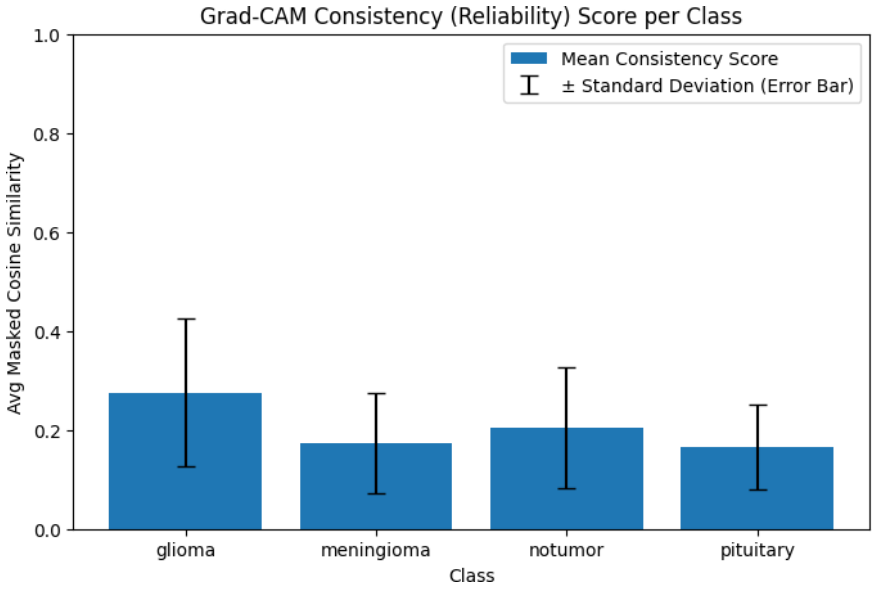


Fig. 4. *Grad-CAM consistency scores across tumour classes (bar chart). Height represents average similarity; error bars indicate variation across samples.*

F. Structured Pipeline Output and Mini-RAG Diagnostic Report

The system generates a structured prediction output summarising the predicted tumour class, actual class label, confidence score, and Grad-CAM visualisation. This is followed by the Mini-RAG diagnostic report, which uses a TF-IDF-based retrieval system to obtain relevant medical knowledge from a predefined knowledge base. The final report includes the predicted class, confidence score, Grad-CAM visualisation, an explanation summary, retrieved supporting medical evidence with similarity scores, and non-prescriptive clinical guidance. This converts the system from a simple classifier into an evidence-assisted diagnostic support framework.

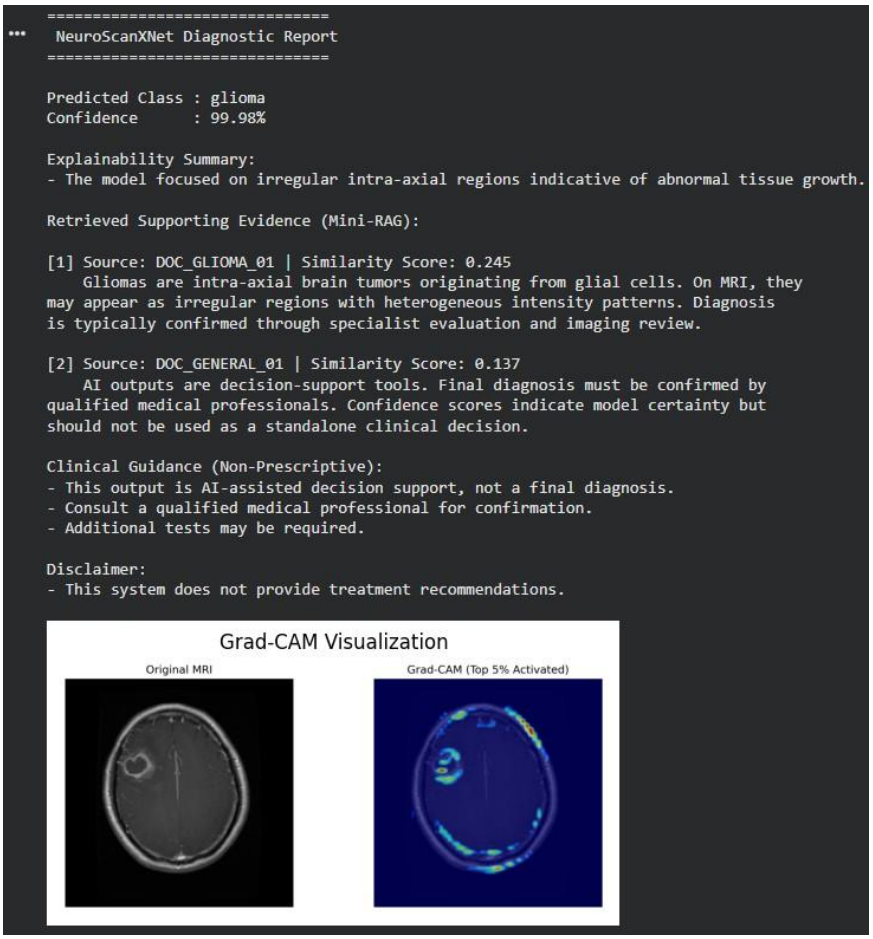


Fig. 5. *Generated diagnostic report combining prediction, Grad-CAM visualisation, and retrieved medical evidence.*

V. Conclusion and Future Scope

A. Conclusion

In this work, NeuroScanXNet — an explainable, system-focused framework for brain tumour classification — was developed using MRI images. A CNN model classifies MRI images into four categories (glioma, meningioma, pituitary tumour, no tumour) with a test accuracy of 94.66%. Grad-CAM provides visual explanations of the model's predictions. A masked cosine similarity consistency analysis quantifies the stability of these explanations. A structured output and a Mini-RAG module using TF-IDF generate an evidence-assisted diagnostic report. Overall, the system combines prediction, explanation, reliability analysis, and report generation into a single framework, improving transparency and practical usability.

B. Limitations

Several limitations were observed. Grad-CAM visualisations did not always align perfectly with actual tumour areas; the model sometimes focused on irrelevant surroundings or background regions. The consistency analysis showed that Grad-CAM outputs were not always stable across similar cases. The Mini-RAG module uses a small, manually created knowledge base, limiting diversity and detail of retrieved evidence. The system does not perform detailed tumour localisation or segmentation, which is often required in clinical settings. Finally, the model was tested on a relatively limited dataset, and performance on real-world clinical data under varying image quality, scanning conditions, and patient variation remains uncertain.

C. Future Scope

Several directions can improve this system: (1) integration of advanced deep learning models such as Vision Transformers for better classification; (2) incorporation of tumour segmentation models such as U-Net to identify tumour boundaries; (3) use of additional explainability techniques such as SHAP and Integrated Gradients alongside Grad-CAM; (4) enhancement of the retrieval mechanism through

embedding-based models and vector databases; (5) multimodal data integration incorporating clinical reports and patient histories; (6) clinical validation and deployment on real clinical datasets; and (7) development of a user-friendly interface for practical medical use. This research demonstrates that high accuracy alone is insufficient for real-world medical AI — transparency, consistency, and evidence-grounding are equally essential.

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TRANSLATING IMPLICATURE SENTENCES FROM TAMI TO ENGLISH IN VAIRAMUTHU'S KARUVACHI KAVIYAM AND COMPARING WITH AI TOOL

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Abstract—**Implicature is an indirect meaning that depends more on the meaning of the utterance and goes beyond its literal meaning. It is typically derived from the speaker or listener's context. The primary data of the research is taken from the novel Vairamuth's Karuvachi Kaviyam and it's examined, how the author has used implicature sentences in the novel The research paper's goal is to translate the implicature sentences from Tamil to English in to Vairamuthu's Karuvachi Kaviyam and compare with AI in order to analyse its cultural nuances and translation difficulties. Firstly, Conversational implicatures emerge from a set of more general and proper respective forms of conventions. And the next analysis of conversational context-based inferences, indirect requests, and irrelevant sentences. Conventional implicature, which is embedded in particles, discourse marker. Conventional implicature analysis of naturally occurring language through which Tamil speakers' proverbs, and idiomatic phrases are distinctive to Tamil. By contrasting hybrid approaches, the primary goal is to identify the obstacles between implicature translation from Tamil to English and the pragmatic overview. The research adopts Palmer and Grice theory framework and compared with both AI tool called Perplexity processing and qualitative analysis. The finding reveal is human translation may face the challenges on contextual and cultural meaning where areas the AI tool Perplexity cannot retain the implicature meaning which will translate only the syntax pattern rather than the depth of meaning or contextual thought also they give shallow out not the pragmatic thoughts.**

I. Introduction

Language is more than just a way for people to express their feelings to one another. Additionally, it serves as a primary instrument and useful component of language and translation. Language plays a major part in translation; it does more than simply translate ideas or meanings from one language to another; it also carries out cultural nuances and contextual concepts in the pragmatic overview. It takes more than just translating lexical and syntactical patterns to translate implicit meaning; one of the hardest things to do is translate an implication sentence. The literary work, which is probably referred to as a highly poetic, lyrical style narrative, depicts the struggles with resilience and a rural life, where the most difficult and challenging concepts require more precise contextual meaning and socio-cultural critical meaning for the implicature translation.

The majority of Tamil literature is based on rural works that are highly concerned with implicature

sentences, such as misery, gender inequality, and social hierarchy. These works are anchored in cultural nuances. Vairamuthu's *Karuvachi Kaviyam* is highly regarded for its narrative, poetic approach. This novel's profound significance, metaphor, smile, reduplication word, and cultural essence-loaded expression are all profoundly ingrained in it and serve as a more potent instrument for Tamil novels by replicating the lives of rural Tamilnadan people. Instead than directly conveying message, it can emotionally connect with the audience without undervaluing the metaphorical and contextual implications. The feature strengthens the novel's core and provides a challenging environment for analyzing the translation.

. Implicature sentences were built in a descriptive fashion throughout Vairamuth's *Karuvachi Kaviyam.* With the surface of common code phrases related to caste dynamics, gender oppression, poverty, and moral judgment, each speech holds deep meaning. For those who have already digested contextual meaning, such meaning is easier to understand.

Additionally, it presents greater difficulties for translators.

However, the implicature meaning is not captured by the conventional Tamil translation techniques, especially when it comes to literal or semantic meaning. For AI-based language translations, these problems become considerably more challenging. The neural translation is accurate in terms of grammar and literal meaning, but it is unable to replicate cultural inference and pragmatic meaning. AI systems typically provide more accurate word. For AI- based language translations, these problems become considerably more challenging. The neural translation is accurate in terms of grammar and literal meaning, but it is unable to replicate cultural inference and pragmatic meaning. AI systems typically provide more accurate word-for-word translations or prioritize surface-level translations over implicature interpretations.

Despite all, quick AI tools and AI translation are more practical and comfortable when it comes to accuracy for literal meaning as opposed to implicature words. However, the extent to which the AI technologies are translating the implicature sentences is the focus of this study. Furthermore, studies comparing AI and human translation have been conducted recently; however, these investigations have not yet been conducted. As a result, these findings emphasize the need for more research and the research gap. The pragmatic overview highlights the significance of implicature sentences. The study looks for trends in machine- assisted translation success and failure, especially in terms of cultural faithfulness and pragmatic preservation.

Instead than discrediting AI translation, the study aims to evaluate its present shortcomings and investigate the circumstances in which human participation is still necessary. This study promotes a more nuanced perspective of translation, emphasizing the importance of implicature in the formation of meaning and advocating for hybrid translation strategies that combine technical efficiency with human interpretative skill.

Research question:

1. How effectively are conversational implicatures in Vairamuthu's *Karuvachi Kaviyam* translated from Tamil into English by human translators compared to AI-based translation tools?
2. To what extent do human translators preserve culture-specific and context-dependent implicatures in the English translations of *Karuvachi Kaviyam*?
3. How do AI translation tools (e.g., neural MT and LLM-based systems) handle implicit meaning, indirectness, and pragmatic inference present in the source Tamil text?
4. Which types of conversational implicature (quantity, quality, relevance, manner) are most frequently lost, distorted, or explicated in AI translations compared to human Translations?
5. What translation strategies (explication, modulation, omission, adaptation) are adopted by human translators to render implicature, and how do these differ from AI outputs?

II. Methodology

Three steps were taken in the corpus selection process to prevent researcher bias. First, a close reading of the book revealed an initial pool of passages full of indirect speech acts, metaphorical language, and sociocultural allusions. Second, implicature markers including silence, metaphor, understatement, irony, culturally charged imagery, and elliptical expressions frequently seen in rural Tamil discourse were filtered out of these passages.

Third, an independent expert in Tamil literature verified that the final thirty sentences had pragmatic depth and non-explicit meaning. The corpus's validity and dependability are improved by this triangulated selection procedure.

III. Human Translation procedure

Two skilled translators with professional degrees in Tamil literature and translation studies performed the human translation, guaranteeing linguistic proficiency and cultural awareness. The translators were told to put pragmatic equivalency ahead of literal correspondence and to work alone to prevent mutual influence. They were urged to take into account the source text's inferred meanings, sociocultural ramifications, narrative context, and authorial intent. Functionalist and interpretive translation theories, which prioritize meaning transfer above word-for-word accuracy, are consistent with this method. This agreed-upon human translation served as the standard by which AI-generated translations were later compared. Instead of depending just on surface-level accuracy measurements, a principled assessment of AI performance is made possible by using professional human translation as a baseline.

IV. AI Translation Procedure

To investigate whether new developments in contextual modelling enhance implicature translation, the study used a contemporary large language model (LLM)-based translation system in addition to traditional NMT tools. LLMs may be more sensitive to context and suggested meaning than typical NMT systems since they are trained on large multilingual corpora that contain conversational data, literary texts, and narrative discourse. To prevent the output from being skewed toward interpretative or adaptive translation techniques, the LLM was given neutral translation instructions. In order to ascertain whether the LLM outperformed traditional AI tools in managing implicature, metaphorical language, and pragmatic nuance, the generated translations were examined. This comparison enables the study to determine if improvements in AI architecture result in significant improvements in the quality of literary translations or whether human interpretive skill is still indispensable.

V. Linguistic aspects of semantic features

Semantics is a discipline of linguistics that has been refined, and it can also refer to structured language. Semantics can also be analysed at various levels from the mirror of linguistics. Semantics is not a reliable concept in linguistics. since its meaning may varies depending on the speaker, listener, and context. The listener should not interpret the speaker's meaning in the same way. It will adjust in accordance with the context and may alter the corresponding listener. When an employee requests a raise, it is a real-world scenario.

We might conclude that each statement and word had a purpose. Additionally, the standard interpretation will alter based on the unique circumstances. When it comes to analysing "meaning" against "use," according to the philosopher and linguistics between pragmatic and semantics, this could be a significant issue. However, Lyron made a more deliberate distinction about the meaning of sentences. It has to do with the sentences' lexical and grammatical characteristics as well as the meaning of the utterance.

VI. Aspects of Utterance Meaning

From the perspective of utterance meaning, they are four main concepts: Prosodic and Paralinguistics second, speech act; third, presupposition; and fourth, implicature.

VII. Prosodic and Paralinguistic features

Spoken language uses prosodic and paralinguistic features, such as intonation, stress, rhythms, loudness, etc., to convey meaning. By altering the constituent word and structure, any of these characteristics can change the sentence's meaning.

VIII. Speech Act

Delas with the facial expression, gestures, is the paralinguistic feature. The term "speech acts" refers to speech acts that are distinct from "sentence meaning.". Sentence can be described as a warning, a declaration, a threat, a promise, etc.,

IX. Presupposition

Three steps were taken in the corpus selection process to prevent researcher bias. First, a close reading of the book revealed an initial pool of passages full of indirect speech acts, metaphorical

X. Implicature

meaning. This is known as implicature. The technical term "implicature" is derived from the "verb" infer and the corresponding noun "implicature." It originally surfaced in Latin between 1530 and 1540. The term "implicature" was first used by H.P. Grice. Additionally, the author claims that some implicature relies on a word's conversational meaning. The traditional meaning of words is the other. Grice definition for implies that unstated information is conveyed to an audience that is able to work out what is being said to references to cultural or linguistic maxims that are being flagrantly flouted.

XI. Conversational Implicature

According to Grice, implicature meaning is simply suggested meaning. (pragmatic deductions). Both the speaker and the hearer make the same assumptions in this conversational implicature. Conversational implicatures are associated with specific words and utterances, as well as the context of the people conversing with one another. As a result, this implicature—a sort of agreement between a speaker and a listener—can also be referred to as the cooperative principle.

XII. Co-Operative Principle

CP is the basis successful conversations, which can be essential while language user interact. It is expectations that the listener has towards the speaker. It is achieved that the speaker intended to communicate more than what the words means. In the earlier stage people, they communicate with each other they start to follow these four Cooperatives Principles (Four Maxims) which are Grice confirms that the conversational had four types of Maxims, which are Quantity of Maxim, Quality of Maxim, Relation of Maxim, Manner of Maxim.

XIII. Maxim of Quality

The quality of the information which means giving the true information. The speaker shouldbe more conscious about cutting down the information. Don’t say that which lack of evidence.

கல்லு மாதிரி இருந்தவ ஒடஞ்சு உருமாறிப்பபானாளப்பா . என்னபாடு

படுத்துநாபனா அந்த ஈனப்பய

AI Translation:
She was like a stone, but she melted away and changed completely, dad. What song is this that I'm singing? That disgusting guy.

Human Translation:

She then turned towards the hard stone, enduring internal pain that caused her suffering.

Analysis:

The speaker's literal interpretation is that a human being cannot be a stone. The implication here is that she was once resilient, robust, and healthy. The aforementioned statement suggested that she had experienced a serious physical or psychological trauma that had ruined her spiritual well-being. Because it is so contextual, it is impossible to fully comprehend this line without understanding the background of Karuvachi or Kattaiyan. Whereas the AI merely explains the text's literal meaning without taking into account its emotional or cultural context, human translators are able to comprehend the context and apply some cultural vocabulary words to clarify the text's correct scenario.

கல்லப் புழிங்சு கஞ்சி குடிக்கிற மக்க வவவசயம் பாக்கிற அங்சாறு

வபருந்தனக்காரங்களத் தவிர மத்தபடி எல்லாம் மழைழயக் கும்புடுற

மனுசங்க.

AI Translation:

People who squeezing stones to drink congee and do agriculture, they are courageous. Aside from the influential big-shots, the rest are humans who worship the rain.

Human Translation:

These are people who wring life out of barren lands just to survive. While the landlords pride themselves on their wealth, these humble souls know that only the rain is their true God.

Analysis:

Physically speaking, "squeezing stones to drink porridge" is not feasible. Since this is not literally true, it appears to violate the Maxim of Quality. The people's incredible tenacity is implied here. It suggests that they can pull life (food) from even the most desolate, rock-like environments since they are so industrious and needy. "Squeezing stones" could be taken literally by the AI. It may have trouble with the word, which is a regional colloquial term that

frequently refers to a lineage. A human understands that "squeezing stones" is a metaphor for labor. They recognize that "worshipping the rain" is an indication of complete reliance on nature rather than merely a ritual, either misinterpreting it or downplaying the significance of the idiom.

Maxim of Quantity:

Supplying the speakers with the appropriate amount of information. Don't provide further details. Make it more succinct. increase the content's depth

அவன் சத்தந்தான் வகாஞ்சத்துக்கதுக்வகாஞ்சம் தணிஞ்சிருக்பக தவிர உள்ள இருக்கிற மப்பு வகாழரயல

AI Translation:

"His anger has mellowed out just a tiny bit, but the inner fire—the real heat—is still burning strong, undiminished."

Human Translation:

The intensity in his voice has somewhat diminished, yet his inner indignation remains unyielding.

Analysis:

In this instance show the depth of anger , the sentence clarifies the extent to which the character maintains his conceit and intoxication. The phrases' underlying meaning conveys the entirety of a man's personality and state. How obstinate the character is. The person's exterior appears softer, but their inner self still harbors a lot of harmful traits and unaltered thoughts. Although AI translation is far quicker than human translation, it never provides implicature accuracy. The aforementioned sentences indicate how the man maintains his anger, and human translation is able to accurately convey cultural context through implicatures. Here, the human translation conveys the intensity of men's rage.

அரசமரம் ஒண்ணு – புளியமரம் ஆறு பூவரசு நாலு புங்கமரம் வரண்டு பவர் ல பதனா ஊத்துனாலும் இதுக்குபமல வளர என்னலகாதுன்னு நின்னுபபான குட்டிமரத்தச் பசத்து பவப்பமரம் ஒன்பது .

AI Translation:

One royal tree—six tamarind trees, four flower-rose apple trees, two oleander trees. Even if you pour honey at the roots, it won't grow beyond this—they stood there like dwarf saplings turned into nine bamboo trees.".

Human Translation:

The Pipal tree, Tamarin tree, and The Portia tree, also known as the Indian beech tree, encompass the small neem tree. If honey is poured onto their roots, it will no longer grow. These trees are considered sacred in the village.

Analysis:

The phrase makes it very obvious that the speaker should just provide the appropriate information and not be too or underly informative. Here, the author purposefully adds extra details by giving the precise numbers (1 peepal, 6 tramind, 4 portia, 2 pongame, and 9 neem trees), which imply a strong connection to the land. The author mentions and details the struggle of growing in addition to explaining the names of the trees. An emotional landscape is created from a dry list by the "excessive" information. In this case, the human translator comprehends the author's motivation. AI tools may be quicker than human translators, but they are unable to understand contextual and cultural aspects, regardless of the author's level of connection to the region. Thus, the human translator adds additional weight to the text.

Maxim of Manner:

Be clear, the speaker should also speak sincerely, relevant, while providing sufficient information. Avoid Ambiguity, expression, be orderly.

“வநறம் கறுப்பு. கறுப்புல பல கறுப்பு இருக்கு. அட்டக்கறுப்பு;
அடிச்சட்டிக் கறுப்பு; வகட்டிக்கறுப்பு; கரிக்கறுப்பு; கார்பமகக் கறுப்பு.
காக்காக் கறுப்பு, குயில் கறுப்பு... இப்படி எத்தழனபயா கறுப்பு.
கருவாச்சி ைஅகுகறுப்பு; அம்சமான கறுப்பு.”

AI – Translation:

Black is the colour. Within black, there are many blacks. Pitch black; beaten pitch black; spoiled black; charcoal black; storm-cloud black. Crow black, cuckoo black... and so on, countless blacks. Karuvachi beauty black; peerless black.

Human Translation:

She has a dark complexion, but there are various shades of black surrounding us, including pitch black, deep black, light black, and black like a crow, a cuckoo, or a storm cloud.

Analysis:

But Karuvachi's blackness is admirable. The statement illustrates that the speaker begins with the general black color of the main character and narrows it down to a specific "Asthetic black." Maxim of manner the speaker uses these comparisons to generate a specific meaning rather than just stating that she is dark-skinned and attractive. Here, the goal is to help the listener comprehend a particular kind of beauty that words like "dark" or "brown" are unable to convey. The speaker's thorough categorization of black is a pertinent refutation. Each comparison (crow, black, cuckoo black, cloud black) serves as a relevant argument for Karuvachi's "divine beauty." AI can only relate to literal meaning in this situation, while the human translator may analyse the implicit meaning.

வராம்ப உசரமில்ல கட்டழடயன். அதுக்காக அவன் குட்டழடயனு மில்ல. கருந்பதக்கங் கட்டழடய எைச்சு எைச்சுப் பண்னமாதிரி வநஞ்சுக்கூடு. எண்வெய அப்பிக் அப்பிக் கருங்கல்லுச் வசழலக்குக் கழடசியா ஒரு வநறம் வரும் பாருங்க...அந்தக் வகட்டிக்கறுப்பு கட்டழடயன் கறு

AI -Translation:

He's not short just because he's scrawny, that guy. But he puffs up his chest like a puffed-up rice cake rising in the pan. Rub oil on him over and over till the black stone shines smooth at the end—you'll see a streak appear... that's the black of that wretched dark-skinned runt."

Human Translation:

He is of average height, neither short nor tall. His chest resembles a dark, carved cloud. His skin is very dark in hue

In this instance, the sentence elucidates the skin tone of the character known as Kattaiyan. The author suggests that he is tough, resilient, and polished through hardship by using the phrase "chest reference like." The "Black stone idol coated in oil" is a metaphorical portrayal of the character. The idol is referred to as the "divinity structure" in Tamil culture. The listener cannot comprehend the metaphorical connection without understanding the cultural intensity. Because if they are familiar with the state's culture, only human translators are able

to relate Skin tone Temple Idole.AI is unable to replace human intelligence in certain areas. since they are limited to connecting data from vast amounts of information, but humans experience the moment. So they able to reproduce accurate translation.

Maxim of Relevance:

கறுச் கறுச்'சுன்னு வநஞ்சுல முள்ளுக்குத்துது. நான் வபாத்திப் வபாத்தி வளத்த புறாக் குஞ்சுக்கு அந்தப் வபராந்துப்பய ஒத்துவருவானா? அந்தக் பகாயில்மாடு கழடசிவழரக்கும் எம் மகளுக்குக்
கஞ்சி ஊத்துமா? ஏபதா சாகப்பபாற நாழளயில சழடயத்பதவருக்கு நல்ல புத்தி வந்திருச்பசன்னு நாழளக்கி மாலமாத்தி மறுவீடு பபானாலும் எம் பிள்ழள கழடசிவழரக்கும் அங்க ஒக்காந்து
ஒல ழவக்குமா?

AI Translation:

"My heart feels the sharp, jagged prick of thorns—*karuch, karuch*. Is that hawk-fellow really a match for the pigeon-chick I raised so tenderly? Will that temple-bull of a man actually provide for my daughter until the very end? Just because a bit of sense finally touched Sadaya Devar in his dying days... even if the wedding rituals and homecomings are done tomorrow, will my child be able to sit there and keep the hearth-fire burning for the rest of her life?"

Human Translation:

The jagged, stinging prick of thorns is felt in my heart heavy. Can that hawk-fellow truly compete with the pigeon-chick I so lovingly reared? Will my daughter truly be supported by that temple-bull of a guy till the very end? Will my child be able to sit there and keep the hearth-fire glowing for the rest of her life, even if the wedding ceremonies and homecomings are completed tomorrow, just because a little common sense finally struck Sadaya Devar in his latter days?"

Analysis:

In this case, the precise meaning is: Is marriage a good idea? The speaker compels the listener to search for a deeper meaning by departing from the straightforward response. The birds that were stated did not specifically refer to the birds, but rather to the groom's trait. The bride's kindness is symbolized by the pigeon. This suggests an imbalance of power. Here, the groom's predatory tendencies are demonstrated by the words "temple bull, eagle," but the phrase "temple bull wonders feely" is ineffective. Replicating the careless groom's nature won't result in financial equilibrium. In this case, the human translator will be able to analyze

the implicature meaning and comprehend the context. An AI may provide a preliminary translation; it may be useful to comprehend the immediate meaning but not the precise context. It may be difficult to communicate the metaphor and emotional weight.

இவன் காட்டுக்கு யாராச்சும் உழுகப் பபாறாகன்னு வச்சுக்குங்க
"வவளஞ்சா வீடு வந்து பசரும் �ைவு காசு"ன்னு கடன்
வசால்லி அனுப்பிருவான்.

AI Translation:

"Suppose someone goes to plow his forest land; he will send them away on credit, saying, 'If it yields a harvest, the plowing wages will reach your house."

Human Translation:

"Let's say someone goes to plow his forest land; he will give them credit and say, 'If it yields a harvest, the plowing wages will reach your house.'"

Analysis:

In this instance, the literal interpretation is that the speaker refrains from paying the plow. However, the suggested implication is that the speaker, Lier, will never fulfill the promise; instead, he will lie and send them away by stating, "Money will reach home later after the home harvesting." By comprehending the human material, they can identify irritation in the human translation. A frequent cultural attempt is that humans are able to translate the implied meaning of every farmer's payment after harvest. However, AI will use the likelihood with that data to determine the definition; it will undoubtedly fail to comprehend the implicature and will not provide the idiomatic and phrases.

Classification of Conversational Implicatures.

This Implicature are mainly classified into three major divisions which are PCI and GCI

Generalized Implicature:

"அழதயும் இழதயும் பகட்டு ஆசிங்கபடுதாந்தீங்க . சிலழதச்
வசால்லலாம் சிலழதச் வசால்ல முடியாது "

AI Translation:

"You keep getting annoyed asking this and that. Some things can be told, some cannot be said."

Human Translation:

Please do not embarrass me with inquiries. Not everything can be discussed here.

Analysis:

The speaker is not providing the audience with the necessary information, and I am purposefully withholding the more delicate truth. Rather than providing the audience with a direct response, the speaker utilized terms that are more generic than specific, such as "அழதயும் இழதயும்" and "சிலழதச்." Here, humans are able to relate the context because they have learned and comprehended rural cultural discourse, which allows them to translate with implied accuracy. In contrast, artificial intelligence (AI) can only translate the literal
meaning; it is unable to replicate the implied sense from the speaker's point of view.They are only able to replicate a specific degree of accuracy.

"புதுசா வந்த வபாம்பள இப்படாடியப்படி இருக்காதன் வசய்வா"

AI Translation:

"The woman who recently arrived (the newcomer) will obviously behave like this."

Human Translation:

The newly married women will behave in this manner.

Analysis:

In reality, the speaker is describing the newlywed girl's mindset. It concerns questionable, inappropriate, and unambiguous methods. Rather of criticizing the girl for being so haughty, flirting, and disobeying our standards. The speaker wants the audience to comprehend what they are attempting to say. The speaker used some ambiguity terms instead of providing a clear description of the girl's character, as evidenced by the word " இப்படாடியப்படி." The listener is able to comprehend the gravity of the situation because of the speaker's words .Because they are familiar with the cultural context, human translators are able to determine the degree to which a speaker conveys meaning to the listener; however, AI was unable to do so due to severe interpretation.

Particularized implicature.

ஆப்பபவ எம் புத்திக்குள்ள கவுளி கத்துச்சு

“Even back then, a lizard chirped within my mind."

AI Translation:

“At that moment, I realized my wisdom”. “Even back then, a lizard chirped within my mind."

Human Translation:

“At that moment, I realized my wisdom”.

Analysis:

"Palli Sound" is regarded as a negative omen in Tamil culture. Why is it implied? The novel will undoubtedly lose sense if a non-Tamil speaker reads it. Palli Sound is dependent on the cultural setting. The meaning depends on the surrounding cultural environment; without understanding the specific culture, they are unable to comprehend certain terminology relating to that culture. Additionally, the lizard's repeating chirp will symbolize the intuition's inner voice. The only method for analyzing the intrallactual component utilizing brain cells is the human transistor. In this instance, the sentence explains the power of human translation, yet it can only be replicated by AI

இந்த வகட்டசதிப் பயலக் வகஞ்சிக் கஞ்சி குடிக்காட்டி என்னா ஆம்பழளக்கு மூஞ்சியில மீழசன் வபாம்பழளக்கு வமைாங்கல்லா மீச .

AI Translation:

"If I don’t make this wicked plotter beg for his food, why should a man have a Mustache on his face? A woman might as well have one on her knees!"

Human Translation:

Why are you pleading with this unfeeling individual for furmenty? When a man sports a Mustache, women tend to be submissive

Analysis:

The speaker is perhaps using humour as a metaphor for a monk or to differentiate between gender roles and his extremely rustic behaviour. A Mustache is a sign of pride in one's masculinity. By utilizing the word "knee" to symbolize domestic chores, it is emphasized that

female portraits should also be powerful. In this instance, the word "Mustache" was used to particularize the Kattaiyna character. Because of the cultural background, the human translator is able to relate what the author is attempting to say. However, AI is also related to humans in a different way. because, according to the state's rural areas, men are always valued more than women. Human brains clearly prevail in this situation, as it can only be understood through cultural means.

XIV. Conventional Implicature

In linguistics, a conventional implicature is a meaning that isn't explicitly stated but is automatically understood because of the words used.

இப்படியாப்பட்ட கட்டழடயனுக்கும் கருவாச்சிக்கும் ஏணி வச்சாலும் எட்டுமா? வசாந்தம் பவணும்; ஆனா கல்யொம் பவொம்னு வசால்லுது ஒரு புத்தி. கல்யொம் பண்ொம வசாந்தம் கூடுமான்னு பகக்குது இன்வனாரு புத்தி. ஒண்ணுக்கு வரண்டா பயாசன பண்ணிக்க தாயி"ன்னு பகாளாறு வசால்லுது ஒரு கூட்டம்.

AI Translation:

Is a match between this 'Kattayan' and 'Karuvachi' even reachable, even with a ladder? One side of the mind says, 'I want the kinship, but not the marriage.' The other side asks, 'Can there be kinship without the knot of marriage?' Meanwhile, the meddling crowd stirs the pot, saying, 'Think it over once, no, think it over twice, woman!'"

Human Translation:

Is it even possible to reach a match between this "Kattayan" and "Karuvachi" ? "I want the kinship, but not the marriage," argues one part of the mind. "Can kinship exist without the knot of marriage?" argues the opposing viewpoint. "Think it over once, no, think it over twice, woman!" exclaims the interfering crowd as they stir the pot.

Analysis:

"Ladder" Metaphor: *"ஏணி வச்சாலும் எட்டுமா" ?*

Direct Meaning: A physical impossibility of height.

Emotional or social incompatibility. It implies that a "bridge" (marriage) could not be sufficient to bridge the gap between Kattayan and Karuvachi because they are from different worlds or have such profound defects. This stands for the "Social Conscience" or "Public Eye." They imply that any departure from the usual will result in disaster, so their advice to "think twice" goes beyond simple prudence. Understands the weight of the agony of longing and the scent of the ground in human translation. However, AI does not analyse implicature; instead, it analyses literary tropes, cultural information, and linguistic patterns. links the word "Kalyanam" to direct translation using "AI" cannot gathers the cultural norms that are stored in my training data. Consequently, the novel essences cannot be replicated by human translator.

வசாக்கத்பதவன்பட்டி வசாக்கத்பதவன்பட்டின்னு அந்த ஊருக்குப் பபரு. அந்த ஊரு இருந்தாலும் இல்லாமப் பபானாலும் இந்தியசர்க்காருக்கு ஒரு கவழலயுமில்ல

AI Translation:

"Chokkathevanpatti—that is the name of that village. Whether that village exists or ceases to exist, the Indian Government has no worry."

Human Translation:

"That village is called Chokkathevanpatti. The Indian government doesn't care if that village survives or disappears.

Analysis:

The author suggests the village has a soul, a history, and a strong sense of local identity by repeating the term, which makes the state's disregard for it all the more heartbreaking. This is an attack on centralized authority. The implication is that the hamlet doesn't even appear on the "radar" of growth because it is so little, so impoverished, or so ostracized. The human translator understands the soul connection with the text and the author by repeating words, implying a "State of Exception" where a nation's laws and advantages do not extend beyond its borders. However, when an author writes something with contextual structure, the AI cannot think or create like a human mind because it is already overloaded with data.

XV. Findings

The fact that human translators constantly maintain conversational implicature better than AI technologies is among the most important discoveries. Human translators are sensitive to

cultural presumptions, contextual signals, and pragmatic intent, which enables them to preserve the inferred meaning even when the sentence's surface structure shifts.
AI tools, on the other hand, frequently reflect the literal meaning precisely while neutralizing or eliminating the implicature present in the original Tamil text since they prioritize lexical and syntactic equivalency. Human translators, drawing on cultural competence, often reconstruct the implicature using functionally equivalent English expression. AI tools demonstrate high consistency in lexical choices and grammatical structure. However, this consistency comes at the cost of pragmatic sensitivity**.** The findings reveal that **c**urrent AI evaluation metrics (fluency and adequacy**)** are insufficient for literary texts rich in implicature. AI translations may score high in fluency while failing pragmatically.

Thus, implicature translation requires pragmatic evaluation criteria, not merely semantic accuracy.

XVI. Conclusion

This work unequivocally shows that conversational implicature and Conventional Implicature in Tamil literary discourse poses a structural and systemic difficulty to modern AI-based translation systems, especially when translating culturally rich books like Karuvachi Kaviyam by Vairamuthu. The results verify that implicature in Tamil is a fundamental mechanism for creating meaning rather than an ornamental style element. It is intricately linked to oral discourse patterns, sociocultural knowledge, and contextual inference.
Semantic adequacy and pragmatic integrity clearly have different functions, according to the comparison study. When it comes to presenting surface-level semantic content, such as lexical meaning and grammatical structure, AI translation technologies demonstrate a high level of skill. They are still severely limited in their ability to understand and replicate context-dependent, culturally unique conversational implicatures that rely on silence, indirectness, shared cultural presumptions, and evaluative understatement. Because of this, AI translations frequently result in texts that are pragmatically flattened but grammatically competent, which results in a loss of character voice, emotional depth, and narrative nuance.

Human translators, on the other hand, show the capacity to serve as cultural mediators as opposed to just language converters. They are able to reconstitute implicature through

functional equivalency, modulation, or strategic explication when needed since their translations demonstrate an awareness of the pragmatic goals behind Tamil statements. Even in situations when direct structural correspondence is not possible, human translators are able to maintain the interactional ethics of Tamil discourse—such as courtesy, hierarchy, and face-saving techniques—within the target language thanks to their interpretive ability. Practically speaking, the study warns against using AI techniques carelessly to translate Tamil literary works that contain a lot of conversational implicature. Artificial intelligence (AI) systems cannot yet take the role of human translators in activities requiring pragmatic interpretation and cultural negotiation, even if they may be used as preparatory or supplementary tools. The results also suggest that human-AI collaborative translation models, in which human interpretive judgment directs or post-edits AI output to restore pragmatic depth, may be useful.

In summary, this study confirms that translating conversational implicature from Tamil into English involves an act of interpretive and cultural translation rather than just a technical exercise in linguistic transfer, especially in a culturally complex work like Karuvachi Kaviyam. Human translators will continue to be essential in maintaining the implicit meanings that make up the literary and communicative core of Tamil discourse until AI systems are able to accurately simulate socio-pragmatic reasoning and cultural inference.

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Psychosocial Impacts of Marital Rape

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***Abstract*—From ancient world to today's modern society, women have been subjected to disparities and fell prey to abuses and it will not be surprising even in the institution like marriage which promises security and intimacy it engendered women to be raped by the person whom they have to face all their lives, the same face which stings them of the violence. The question is about why most women negate the actual incidence of rape by their husbands, while some who do stand against it are subjected to prejudice by their own family. Everything in marriage is seen as a private affair which should remain closed behind curtains but if the same privacy violates the safety of women shouldn't be questioned. Marital rape in present time is criminalized in more than 100 countries, while exception being countries like India, Pakistan, Saudi Arabia, Haiti, Tajikistan etc. In some instances, Indian courts have also given exceptional judgement as Karnataka HC says, rape is rape, be it by the husband. The rising instances of Marital rape time ground the acknowledgement for legislation of such crime. The paper highlights how marital rape affects women on all parameters be it physical, psychological and emotional leaving her pilfered from her sanity.**

***Index Terms*—Marital rape, Privacy, Sanity, Legal framework, Emotional dysfunction, trauma.**

I. Introduction

The subject of marital rape has always been a point of controversy and issue in various institutions of society be it religion, law and family. Rape; impacts a woman's both body and mind where she suffers the most destructive catastrophe in her life and later her suffering is seen as a taboo, a shame on her family and she is force to carry the burden of abiding fate for her whole life. The definition of rape and sexual violence have always been under the view of intense attention, centering on the question of how rape should be defined, whether the scope of its definition should be referred by the lack of consent of victim or the coercion and threat and force used by the offender. The ICC defines rape as 'The perpetrator invaded the body of a person by conduct resulting in penetration, however slight of any part of the body of victim or of the perpetrator with a sexual organ or of anal or genital opening of victim with any object or any parr of body. The invasion was committed by force or by threat of force or by fear of violence, duress, detention, psychological oppression or abuse of power, against such person or another person or by taking advantage of a coercive environment or the invasion was committed against a person incapable of giving genuine consent. However, our country legalization for rape as a crime has gone through dynamic changes where sec 375 of IPC defines Rape as an act committed by man without a woman's consent or will or by exerting hegemony over her will to reach the consent in her conscience and with a broadened definition in 2013 Amendment Act it also included rape beyond penile-vaginal penetration and included anus and mouth penetration. In the domestic spheres, the fight against violence saw a major shift with domestic violence act 2005, which defined the act in comprehensive manner in section of DNA, 2005 as

1. Physical, mental, verbal, emotional, sexual and economic abuse.
2. Harassment of dowry
3. Act of threatening to abuse the victim or any person related to her.

Thus, covering the abuse against women which were either excluded or not defined earlier laws.

1. GRISLY UMBRA OF MARITAL RAPE

Marriage as an institution is backed by anthropological, social and legal establishments across different discourse, marriage emerges out as a social obligation with rights and in various cultures, marriage is also acknowledged with recognition of sexual relationships. In Indian context, marriage is regarded as sacrosanct where not only individuals but families and values are also involved. However, in the depth of this institution, marital rape covers a grey area where forceful sexual intercourse between spouses without his/her partner's consent is not referred to as content of grave issue and it is often shut down as a subject of taboo, whereas on one hand rape is considered as a non-compoundable offence bringing severe punishment. Marital rape remains under ambiguity from both social and legal perspectives. According to NFHS- survey (2019-20), it has been reported that 29% of married woman have experienced some form of physical or sexual violence in their lives from their husbands. It has also been found that more than two thirds of married women in India aged 15-49 have been beaten or forced to provide sex. The report of the UN population fund questions the sanctity of the marriage institution which promises to give equal rights and respect to both sexes. The fundamental question which arises in the context of marital rape is the specifying marital rapists and the layers of the consequences woman bears in an abusive marriage.

Through the ages, writers have explored the graveness of marital rape through the lens of literature & pain of its character.

In Rosa Pared's *Australian Heroine*, she lays bare the brutalities of marriage. The story records how the antagonist *George Brand* justifies violence towards his wife by telling her "You are mine now, remember and I may do what I like with you".

It shows on a deeper lane that marital rape is not abuse of body but also her moral soul.

As *Esther* finds her marriage as "Nothing but a degrading prostitution from which she could not escape". And which has "Upon her the effect of slow moral suicide".

In *Rape in Marriage (1990*), Diana Russell attacks the passive and traditional doctrine of wife's implied consent in patriarchal marriage system.

She defines marital rape as any act of sexual intercourse or violence against her without *her consent.*

A husband in an institution of marriage is placed on the pedestal as owner of the property (*His wife).*

The intensity of rape in a marriage is virtually ignored because of the long-standing norms of the legality of sex in marriage which transcends the boundary of women's consent. Many women themselves don't see marital rape as an act of violation because of the sacrosanctity of husband's authority.

Even the society finds it hard to believe that there can be such a force in marriage which later manifests in the form of how cases of wife rape are swiped under the carpet because of long established prejudices.

Russell situates marital rape as an act of not only physical violence but emotional and psychological abuse which is compounded by isolation of women from her institutional support. The trauma gets intensified because it occurs within a relationship that is considered safe and legal.

2. PSYCHOSOCIAL IMPACT OF MARITAL RAPE

The social and psychological impact of marital rape extends beyond individual's physical memory. It damages identity, fractures the social relationships and a person is left only as *a breathing dead soul.*

These impacts are intensified by systematic norms of legal silence, social stigma attached to it and taboo of marital privacy.

Research by Campbell (2002) shows that how marital rape disrupts a victims' capacity to trust and understanding. The victim lives through emotional numbness and anxiety for intimacy. There are also instances where risk of depression and PTSD resulting from marital rape are even higher than childhood abuse.

And it creates a cycle of suffering of emotional dysfunction which also affects children. The anguish works on an ideological plane in the way women are told to focus on marital harmony which leads to silent suffering & suppression of trauma.

Brownmiller in her study conceptualizes the licensing of rape 'a conscious process of intimidation by which all men keep women in state of fear'. When the husband gets a legit license to control the wife's body which extends from sex to bearing child.

Bergen (1996) found that women going through marital abuse don't leave their husband until they notice the gravity of abuse is increasing and their husband might hurt someone else or they would hurt their husband. The way of such marriage is affected by numerous factors such as deprivation of health from family and fear of retaliation.

A study conducted by Ankita Banerjee reports an old woman who told the reporter about the violence she endured,

"*I didn't have enough strength to fight back" she said*

"After he would be done, I'd ask how could you do that, but in return he would silence me with a hard slap on my face".

The researchers on victims of abuse have found that how the impact of such an abuse go beyond the boundaries of broken bones and bruises and reaches the stage where victim start blaming themselves for their incapability & failure which caused husband to use coercive behavior, many times the insults used by partners escalates their guilt.

3. EXCUSES FOR CRIMINALIZING MARITAL RAPE

The excuses of male dominated society that are regulated as contentious against criminalizing marital rape

- For instance, there is no need for legislation to address marital rape because it is so rare.
- A dissatisfied, enraged and spiteful wives may accuse their innocent husbands of marital rape.
- When a woman marries a guy there is implied permission to have sexual relations.
- Many marriages would get destroyed if laws against marital rape are enabled

This shows how society trivializes the same act of violence committed against women not by any stranger but her husband.

II. CONCLUSION

Even in the 21st century where women are equal breadwinners for a family, their decisions are suppressed and conflicts arise; they sometimes escalate to abuse. Marital rape is the abuse committed towards one woman but her trauma follows through generations. Rape committed by the husband is nefarious materialization of jealousy, hatred and authority over her body. Thus, it is a crime of grave intensity but trivialized in both the social and legal arena. It questions the discreteness of society which promises women safety and equality but fails to provide her security in most intimate relationships.

III. METHODOLOGY

This research paper adopts the method of document analysis, qualitative and the study is guided by feminist criticism to analyze the power relations in the patriarchal social institution. The primary sources adopted for this study includes the literary text which portray marital rape and secondary sources includes journals, article, reports and studies related to marital rape.

The study of data includes close analysis of text and it focuses on the problems and impact caused on victims. The study doesn't include medical case studies and is limited to textual analysis.

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Redox Mediated and Decoupled Water Electrolysis Using Soluble Inorganic Mediators: A Comprehensive Review

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***Abstract*—The worldwide trend toward the green energy systems has enhanced academic research into the biological synthesis of green hydrogen through the electrolysis of water. Conventional electrolytic systems require simultaneous Hydrogen Evolution Reaction and Oxygen Evolution Reactions that are separated by ion-exchange membranes; such systems are prohibitively expensive, complex to operate, and their lifetime is limited.**

Decoupled and redox-, redox-, and electrolysis Redox can now be utilized as a promising paradigm, with redox couples being used as electron shuttles to either spatially or temporarily separate Hydrogen Evolution Reaction and Oxygen Evolution Reaction to allow membrane-free systems or scalable multi-reactor systems. This paper critically reviews the current developments in the field of mediated and decoupled water electrolysis with a focus on Ferri/ferrocyanide systems used in alkaline water and chromium-based mediators used in acidic water. Systematic analyses are made of rationalizations of reaction mechanisms, thermodynamic viabilities, kinetic profiles, material choices, performance metrics, safety considerations, and scalability issues.

Comparative evaluation with other possible mediator systems including iodine, cerium, and manganese couples is made, and the merits and limitations of each of the systems are brought to light. The discussion highlights the opportunities to achieve cost-efficient hydrogen production on a laboratory scale and outlines the relevant research gaps that should be filled to take these technologies to the next stage of practical and industry-deliverable application.

***Index Terms*—Decoupled water electrolysis, Redox mediated electrolysis, Hydrogen evolution reaction (HER), Membrane-less electrolysis, Ferri/Ferrocyanide redox couple, Electrochemical hydrogen production**

I. Introduction

Working on hydrogen is often seen by most as a component of future low-carbon energy systems because of its high gravimetric energy density and clean burning characteristics [1]. The renewable electricity-powered water electrolysis provides a long-term solution to hydrogen production; however, traditional alkaline, proton-exchange membrane (PEM), and anion-exchange membrane (AEM) electrolyzers face issues related to cost of the membrane, gas crossover, catalyst degradation, and complexity of the system engineering [2].Specifically, the oxygen evolution reaction (OER) is a reaction, which is slow, energetically active, and adds significantly to the overall cell overpotential [3].

Another potential emerging paradigm is redox-mediated and decoupled electrolysis where the OER is replaced or temporarily separated by a reversible redox couple that is able to store and release electrons [4]. In such setups hydrogen and oxygen do not necessarily have to be produced simultaneously or in the same reactor, dramatically reducing the risk of gas-crossover and allowing the use of membrane-free operation.

This concept has been gaining academic interest since the last ten years as one of the means to reduce system cost, increase safety and offer an opportunity to operate with flexibility [5].

This is a critical review of the recent experimental and conceptual developments in the redox-mediated electrolysis of water, but specifically focusing on two examples, namely,

1 Ferri/ferrocyanide-mediated membrane less water electrolysis in alkaline solution using stainless-steel electrodes
2 Ferri/ferrocyanide-mediated membrane less water electrolysis in alkaline solution using nanoparticle electrodes.
3 Dichromate-mediated decoupled electrolysis in an acidic system.The systems represent the potential and the constraints that are associated with soluble inorganic hydrogen generation mediators.

II. Fundamentals of Redox-Mediated and Decoupled Electrolysis

1. Conceptual Framework

In standard water electrolysis, both the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER) occur simultaneously at the anode and cathode respectively, thus, requiring a separator to preclude the interactions between hydrogen and oxygen [6]. The oxidation or reduction of a soluble redox species that can be faster kinetically and with lower over potential replaces the anodic OER in mediated electrolysis. In fully decoupled systems, HER and OER are conducted in two different reactors which are connected only by redox mediator cycle [7].

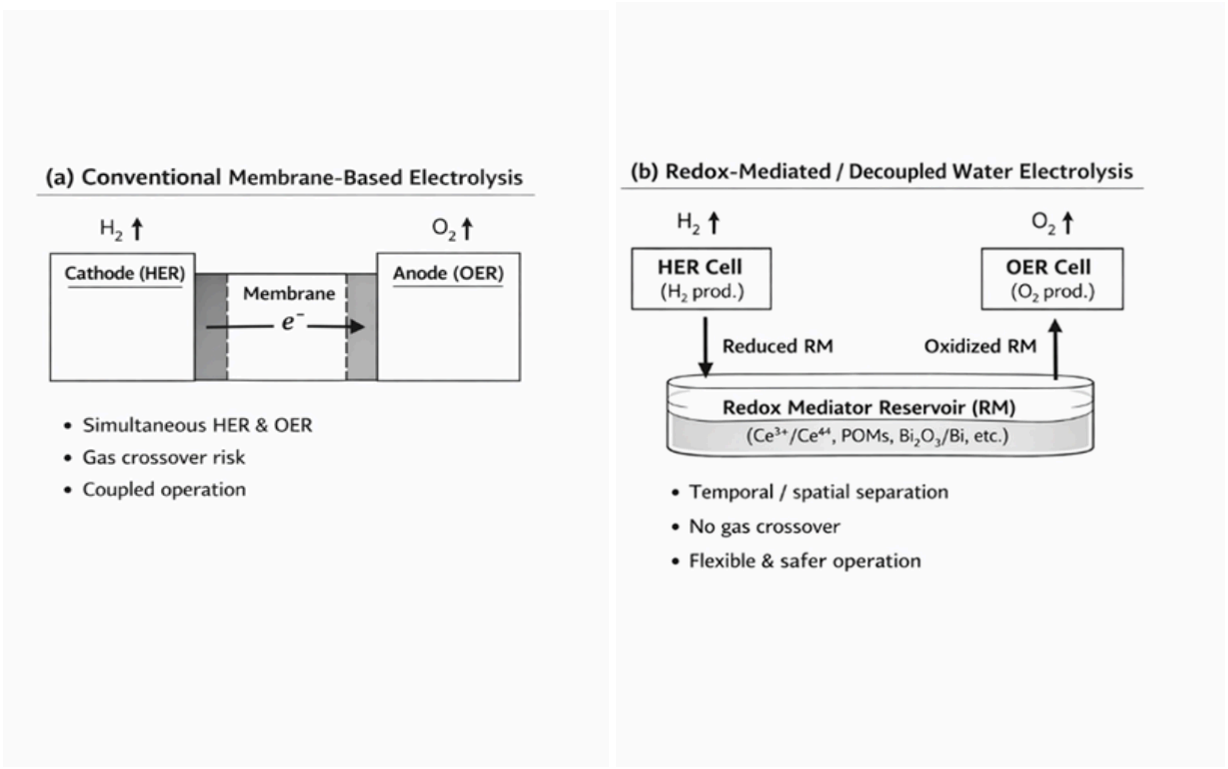


Figure 1: Schematic Comparison of Conventional Membrane Based and Redox-mediated (decoupled) water electrolysis

2. Thermodynamic Relations

Knowledge of the appropriateness of a redox mediator is dictated by its standard redox potential, stability window, solubility and reversibility. Preferably, the redox potential of the mediator must be between that of HER and that of OER to minimize the sum of the cell voltage and yet have enough driving energy [8]. Also the redox chemistry of the mediator should be matching to the pH that the electrolyte surroundings are supposed to be [9].

III. Ferri/Ferrocyanide mediated Membrane-less Electrolysis in Alkaline Media

1. The Redox chemistry and the Redox reaction mechanism

Ferri/Ferrocyanide redox couple Fe (CN)63-/Fe (CN)64- can replace the oxygen-evolution reaction (OER) at the anode in alkaline media and thus allows the operation of the membrane-free mode [10].

Cathodic reaction (HER, alkaline):

$2H_2O + 2\,e^- \rightarrow H_2 + 2OH^-$

Anodic reaction (mediator oxidation):

$Fe(CN)_6^{4-} \rightarrow Fe(CN)_6^{3-} + e^-$

Overall reaction (per 2 e^-):

$2H_2O + 2Fe(CN)_6^{3-} \rightarrow H_2 + 2OH^- + 2Fe(CN)_6^{4-}$

2. Materials and Cell Design

The stainless-steel electrodes (SS -304/316) are widely used due to low cost, resistance to corrosion in alkaline environment, and moderate hydrogen-evolution reaction. The use of a single-compartment cell bypasses the need to use ion-exchange membranes and hence simplifies the reactor architecture and reduces ohmic dissipation. Common electrolytes include 0.1–1.0M KOH with the presence of dissolved potassium ferricyanide.

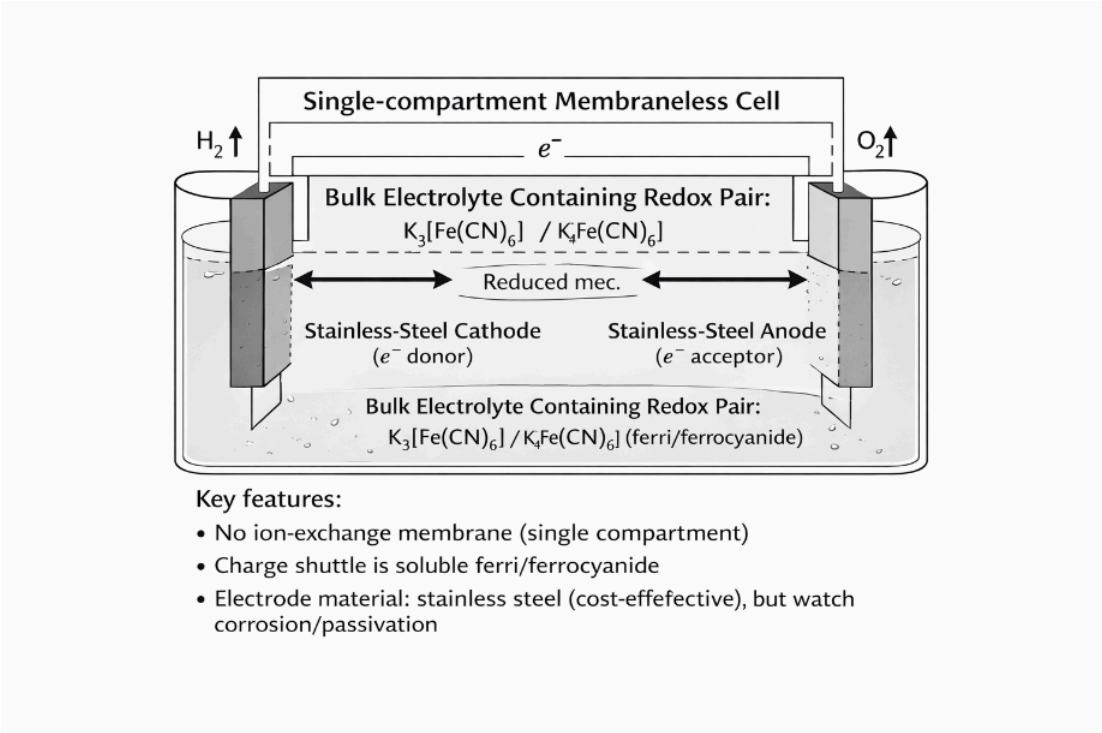


Figure 2: Membrane-less Redox Shuttle-Assisted Electrolysis for Decoupled H_2 and O_2 Evolution

3. Electrochemical Performance

It is an electrochemical performance that measures the capacity of the electrode in relation to the voltage and current of the cell case.

The recorded polarization characteristics have shown significantly low cell voltages as compared to traditional water electrolysis at the same current densities. The cathode generates hydrogen and, the anode is gas-free, and this increases safety. Laboratory Separate demons have identified Faradaic efficiencies virtually near to unitary [11].

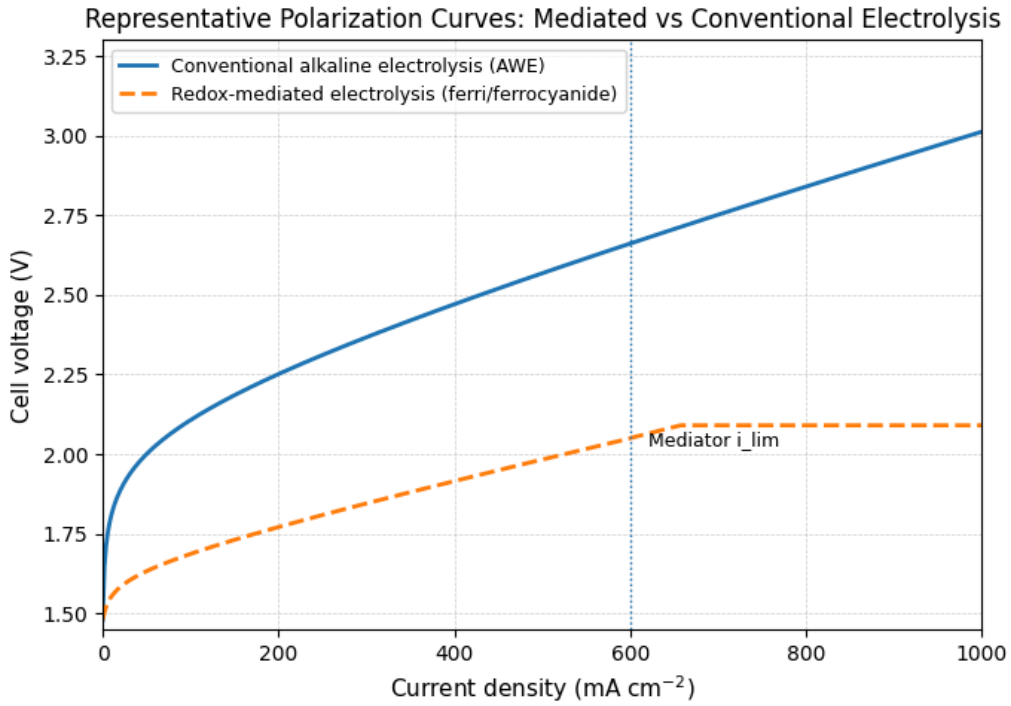


Figure 3: Representative Polarization Curves Comparing Conventional Alkaline Water Electrolysis and Ferri/Ferrocyanide-Mediated Electrolysis

4. Durability and Safety Assessment

Even though the Ferri/ferrocyanide systems exhibit good short-term reversibility, the stability of the system at longer distances might be compromised by photodecomposition and also by the degradation of the ligands. The alkaline media should be strictly kept to ensure that there is no emission of hydrogen cyanide when the environment is acidic. Thus, these restrictions limit scalability, but they are not the reason to deny the utilization of such systems in a laboratory or educational environment *(M. Stern et al.)*.

IV. Potassium Dichromate based Decoupled Electrolysis in Acidic Mediums

1. Chromium Redox Chemistry

Cr (VI)/Cr (III) redox pair possesses a fairly large standard potential (EO ≈ +1.33V vs. SHE), meaning that it can be thermodynamically compatible with the hydrogen evolution reaction (HER) in acidic conditions [13]. The dichromate-based systems are traditionally used in a full decoupled, two reactor system unlike ferricyanide such as the half-reaction [14-18].

$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$.

2. Decoupled Reactor Configuration

A common system comprises of an electrochemical reduction reactor (ERR) that produces hydrogen along with the reduction of Cr (VI) to Cr (III). Subsequently, the Cr (III) is re-oxidized in an electrochemical oxidation reactor (EOR) to Cr (VI) and oxygen is generated [19].Temporal separation enables independent optimization of the hydrogen evolution reaction (HER) and oxygen evolution reaction (OER).

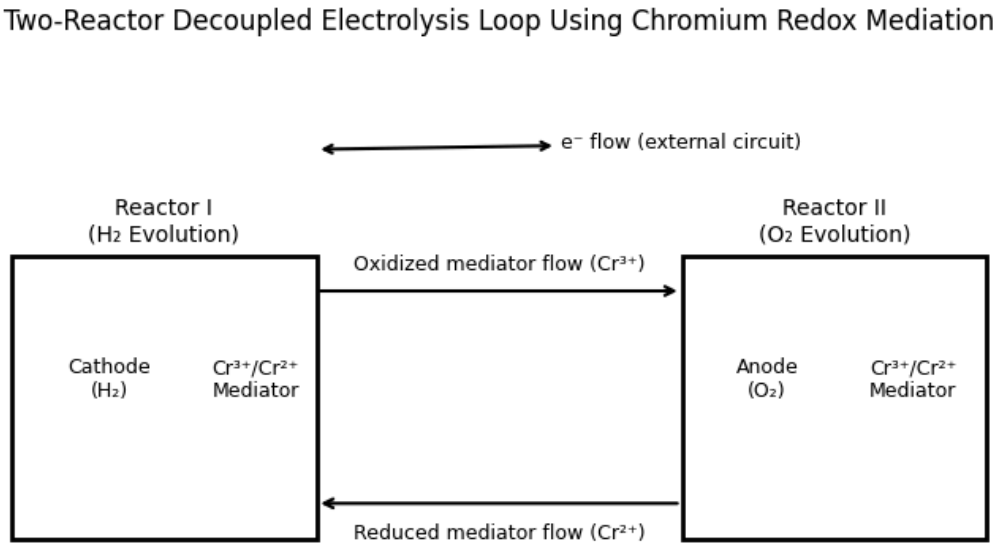


Figure 4:Schematic Representation of a Two-Reactor Decoupled Water Electrolysis System Employing a Cr^{+3}/Cr^{+2} Redox Mediator

3. Performance Metrics

An experimental study seems to show the hydrogen producing step to be conducted with relatively low cell voltages with the hydrogen produced being of high purity [20]. This does not mean that the energy consumption is any lower than that measured in present state-of-the-art PEM systems but, as such results do show, does support the fact that what is being proposed is conceptually possible as well.

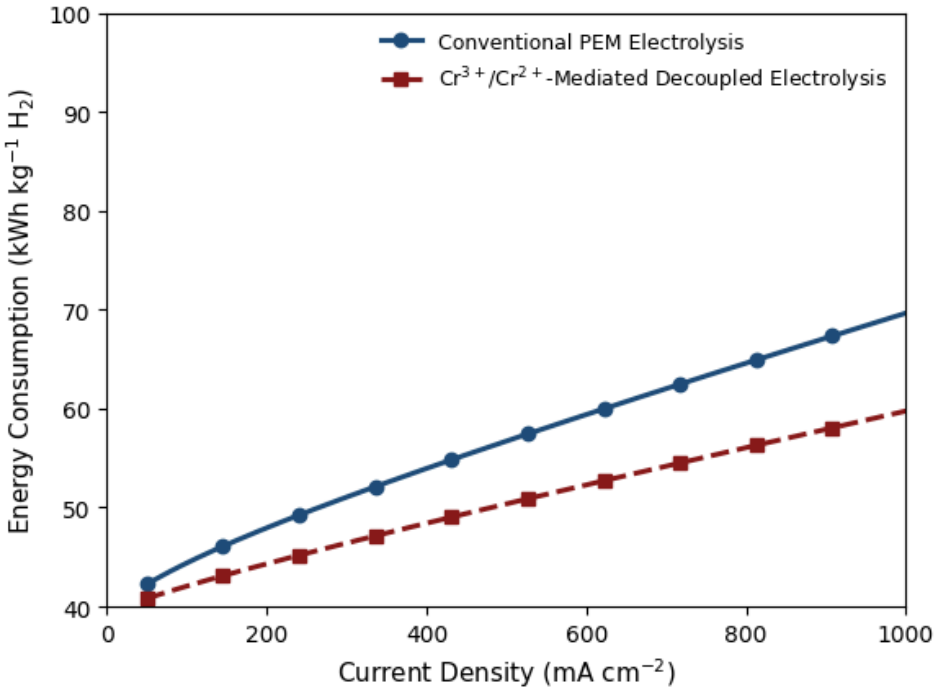


Figure 5: Comparative Energy Consumption of Conventional PEM Electrolysis and Cr^{+3}/Cr^{+2}-Mediated Decoupled Electrolysis as a Function of Current Density

4. Toxicity and Environmental Impact

Although the compounds of the Cr (VI) have favorable electrochemical properties, they are very toxic and carcinogenic [21]. As a result, their implementation requires strict containment and constant monitoring of their use, and full waste-treatment systems. In this regard, di-chromate based systems should be more applicable in mechanistic investigations than in large scale production of hydrogen [22].

V. Comparison to other Redox Mediator Systems

Other mediators have been explored such as I3-/I-, Ce4+/Ce3+, and MnO2/Mn2+. Mediators have unique trade-offs in redox potential, reaction kinetics, cost and environmental impact [23-26]. The ferricyanide is described as a safe, operationally simple chemical in alkaline environments and chromium as a high driving force in acidic systems although increased toxicity.

Table-1: Selected Redox Couples and Their Electrochemical Properties Relevant to Decoupled Water Electrolysis

Redox Couple	E°(V vs SHE)*	Typical Electrolyte / pH	Advantages	Primary Limitations
$Fe(CN)_6^{3-/4-}$	0.36	Neutral–mild alkaline aqueous media	Fast outer-sphere kinetics; high reversibility; well-characterized electrochemistry	Ligand instability under extreme pH; cyanide-related safety considerations

Fe^{3+}/Fe^{2+}	+0.77 (acidic)	Acidic to near-neutral aqueous media	Abundant; low cost; scalable redox chemistry	Hydrolysis and precipitation at elevated pH; corrosion concerns
V^{3+}/V^{2+}	System dependent	Acidic electrolytes	Multi-electron redox chemistry; compatibility with flow systems	Speciation complexity; air sensitivity; higher material cost
Cr^{3+}/Cr^{2+}	–0.41 (acidic)	Acidic media	High theoretical redox capacity; enables spatial decoupling concepts	Cr^{2+} instability; toxicity and environmental constraints
Quinones / TEMPO (organic mediators)	Tunable (0–1.0)	Neutral–acidic media	Molecular tunability; metal-free systems; adjustable redox potential	Chemical degradation; membrane crossover; long-term durability issues
Polyoxometalates (POMs)	System dependent	Acidic–neutral	Multi-electron storage capability; structural robustness	Cost; solubility limitations; electrolyte compatibility

VI. Challenges, Research Gaps and future Outlook

The key challenges for mediated and decoupled electrolysis include

1. Degradation of mediators
2. Crossover induced performance degradation in looped system
3. Energy efficiency concerns and environmental constraints

Future research should focus on finding benign, earth-abundant mediators that show quick kinetics and long-term stability, and, at the same time, search the way to integrate them with renewable sources of energy [7]. It can be the case that hybrid strategies that are synergistic in the fusion of solid and soluble mediators can offer promising prospects of progress.

VII. Conclusions

A promising alternative to more conventional membrane-based processes could be redox mediated and decoupled water electrolysis in terms of cost effective, flexible and safe hydrogen production at the laboratory and pilot scale. Paradigmatic cases such as Ferri/ferrocyanide and dichromate systems can be used to outline the benefits as well as the natural limitations of the soluble inorganic mediators. Current advances in mediator chemistry, reactor design and safety technology are essential to the realization of the potential of this new electrochemical paradigm [5].

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AI Powered Crypto Analytics Agent for Token Insights and Forecasting

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***Abstract*—The cryptocurrency market is highly volatile and keeps changing rapidly, which makes accurate prediction and decision-making quite difficult. To handle this, we developed an AI-driven crypto analytics agent by combining time-series forecasting models like ARIMA, LSTM, and GRU with NLP-based sentiment analysis to gain real-time market insights.ARIMA worked well for capturing linear trends but struggled with sudden market fluctuations. On the other hand, deep learning models such as LSTM and GRU performed better by learning nonlinear patterns and long-term dependencies. We also used sentiment analysis to understand public mood from social media and news, adding context to numerical predictions.Data was collected from DexScreener, CoinGecko, and social media APIs, and the results were displayed on an interactive dashboard with features like whale transaction tracking, portfolio risk analysis, and sentiment-driven forecasting. Our evaluation showed that combining deep learning with sentiment analysis improved predictive accuracy and provided more practical insights for investors and analysts.**

***Index Terms*—AI-Enabled, Cryptocurrency Analytics, Time-Series Forecasting, LSTM, GRU, ARIMA, Sentiment Analysis, FinTech, Market Prediction, Real-Time Insights**

I. Introduction

The cryptocurrency market is highly volatile, with sudden price swings and quick changes in investor sentiment, which makes it difficult for traders and analysts to make timely decisions. Unlike traditional markets that mostly react to economic indicators and long-term trends, crypto prices are heavily influenced by social media discussions, news updates, regulations, and overall market psychology. Because of this, traditional technical analysis tools often fail to fully capture the complex, non-linear patterns and sudden shifts in the market

To address these challenges, this project uses Artificial Intelligence and Machine Learning to build a smarter and more adaptive forecasting system for cryptocurrency trading. We combine time-series models like LSTM, ARIMA, and GRU with NLP-based sentiment analysis so that the system can learn from both historical price data and real-time public sentiment. By integrating numerical trends with market mood, the model improves prediction accuracy and provides a more practical, AI-powered solution compared to conventional technical methods.

II. Problem Identification

The cryptocurrency market is very unstable, and prices can change within minutes. It is influenced by rapid price movements, speculative trading, government regulations, and constant shifts in investor sentiment. Traditional forecasting models like ARIMA can identify basic linear trends, but they struggle with sudden fluctuations and complex non-linear patterns, which affects their accuracy. Also, many existing

systems do not properly include sentiment analysis, even though news and social media have a strong impact on market behavior.Another challenge is that data is spread across different exchanges, blockchain explorers, and online platforms, making it hard for investors to gather and analyze information in real time. Most available tools only show raw data or simple analysis and lack advanced decision-support features. Key functions like combined forecasting, whale transaction tracking, portfolio risk analysis, and personalized alerts are often missing. Because of these gaps, there is a clear need for an AI-based hybrid system that integrates LSTM, GRU, and ARIMA with NLP-based sentiment analysis, while collecting data from multiple APIs to provide accurate, timely, and practical insights for investors and analysts.

III. Related Work

Many researchers have studied how artificial intelligence and machine learning can help solve the challenges of cryptocurrency prediction and analysis. Traditional statistical models like ARIMA are often used for time-series forecasting, but they have difficulty handling the non-linear behavior and high volatility of crypto markets. To achieve better results, researchers have started using deep learning models such as LSTM and GRU, which are more capable of capturing long-term relationships and complex patterns in price movements. Several studies also stress the importance of sentiment analysis, where Natural Language Processing (NLP) is applied to news articles and social media posts to understand overall market mood and improve prediction accuracy. Hybrid methods that combine technical forecasting models with sentiment analysis have shown better performance than using a single approach.Additionally, integrating real-time data from platforms like DexScreener, CoinGecko, and Whale Alert is important for reliable market monitoring and quicker decision-making. Recent research has also examined reinforcement learning and multi-agent systems to develop more flexible and adaptive trading strategies. Transformer-based NLP models are being used to gather, analyze, and summarize cryptocurrency news more effectively. Overall, these studies highlight the value of combining time-series forecasting, sentiment analysis, and hybrid machine learning techniques to provide investors and analysts with timely and practical insights in the fast-changing cryptocurrency market.

IV. Dataset Details

The dataset used in this project is dynamic and is collected in real time through APIs from multiple reliable sources. These include CoinGecko for market prices and trading volumes, DexScreener for decentralized exchange liquidity data, Whale Alert for monitoring large transactions, and Twitter for capturing social media sentiment. The system regularly fetches this data and performs preprocessing and cleaning to maintain accuracy and consistency. The raw dataset initially contains millions of records covering various tokens and attributes. After proper cleaning and filtering, it is converted into well-structured, high-quality data that is suitable for training and testing the models. The main attributes selected for analysis are token prices, trading volumes, liquidity levels, whale transaction frequency, and sentiment scores. These features are used as inputs for the hybrid machine learning models such as LSTM, ARIMA, and GRU, along with NLP-based sentiment analysis. This approach enables the system to generate real-time insights and deliver more accurate predictions for cryptocurrency markets.

No of columns	No of columns used for train test	Total no of rows	Total no of rows after cleaning	Columns present in the table
5+	5	3,000,000 +	1,200,000+	price, volume, liquidity, whale_txn, sentiment_score

Table 1- Dataset Details

V. Methodology

The proposed system is designed to give investors, analysts, and traders clear insights and more reliable forecasts in the cryptocurrency market. It combines multiple machine learning models with real-time data collection to create a smart analytics platform. The main goal is to predict token price movements, track whale transactions, analyze market sentiment, and present useful insights through a simple and interactive dashboard.To achieve this, we use time-series forecasting models along with NLP-based sentiment analysis. This hybrid approach allows the system to learn from both historical price data and real-time market mood, improving overall prediction accuracy and performance.

Machine Learning Models: The system uses ARIMA to study basic linear trends from historical price data. To capture more complex patterns and long-term dependencies in price movements, it uses deep learning models like LSTM. In addition, NLP-based sentiment analysis is applied to understand overall market mood by analyzing Twitter posts and cryptocurrency news. The results from all these models are then combined using a hybrid ensemble approach, which helps improve prediction accuracy and makes the system more reliable, especially in highly volatile market conditions.

Data Sources and Storage: Real-time data is gathered using APIs from different platforms. CoinGecko is used to fetch price and trading volume details, DexScreener provides liquidity data, Whale Alert monitors large transactions, and Twitter is used to collect sentiment-related information. Once the data is collected, it is cleaned and preprocessed to remove errors, duplicates, and inconsistencies. The refined data is then stored in structured databases such as MongoDB.

Dashboard and Chatbot: The insights are presented on a responsive dashboard developed using React.js or Next.js. Users can access price charts, trading signals, whale transaction alerts, sentiment heatmaps, and portfolio risk analysis all in one place. The platform also includes an AI-powered chatbot that can answer queries and offer personalized suggestions, making it simple and user-friendly for both technical and non-technical users.

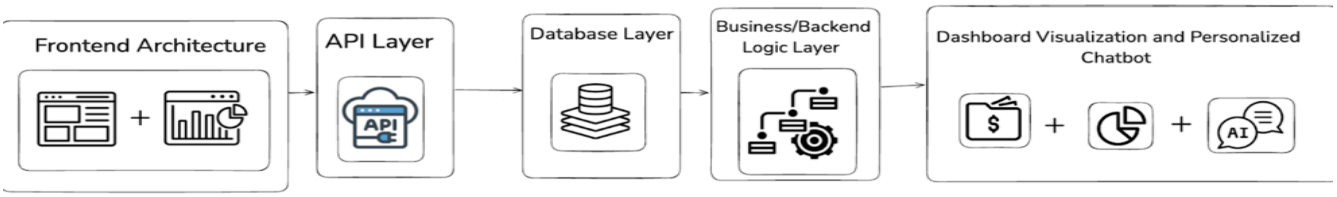


Fig 1: Proposed System Architecture

Here's a step-by-step explanation of this process:

1. **Start the Platform:** The user starts by going to the crypto analytics platform's website or dashboard. This is where they can access forecasting, insights, and portfolio tools.
2. **User Registration & Login:** To use the system, the user needs to register or log in. During

registration, they enter basic details and create an account. Logging in provides secure access to personalized insights and portfolio tracking.

3. **Dashboard Access:**After logging in, the user is directed to the main dashboard, which displays overall crypto market statistics, a portfolio summary, and quick insights.

4. **Enter Token Query or Explore Options:**The user can browse FAQs for general guidance or search for a specific token like BTC, ETH, or SOL to view forecasts, sentiment analysis, and real-time market data.

5. **Real-Time Data Collection:**Once a token is selected, the system collects live data from APIs such as DexScreener, CoinGecko, Whale Alert, and Twitter. This ensures updated information on prices, liquidity, whale transactions, and market sentiment.

6. **Prediction Using AI Models:**The backend applies AI and machine learning models like LSTM, ARIMA, and GRU, along with NLP-based sentiment analysis, to predict price movements, evaluate risk, and detect trends.

7. **View Analytics & Forecasts:**The results are shown on the dashboard through interactive charts, trading signals, whale alerts, and sentiment heatmaps, helping users understand both technical trends and market emotions.

8. **Portfolio & Alerts:**Users can monitor their portfolio, check risk analysis, and set smart alerts for price targets or whale activity, ensuring they stay updated with market changes.

9. **Chatbot Assistance:**An AI-powered chatbot is available to provide explanations, personalized insights, and helpful guidance. It simplifies complex analytics and makes the platform more interactive and easier to understand for users.

10. **Exit Platform** – After reviewing the insights and updates, the user can securely log out.

VI. Algorithms

The project, "AI-Powered Crypto Analytics Agent for Token Insights & Forecasting," brings together multiple time-series forecasting models, deep learning techniques, NLP methods, and hybrid approaches to enhance the accuracy and reliability of cryptocurrency predictions. Below is a short overview of the main algorithms used in the system:

1. ARIMA (AutoRegressive Integrated Moving Average):ARIMA is a traditional time-series forecasting model that analyzes historical cryptocurrency price data to identify linear trends and patterns. It works well for short-term forecasting, but it struggles to handle sudden price fluctuations and highly volatile market conditions.

2. LSTM (Long Short-Term Memory Networks):LSTM is a special type of recurrent neural network (RNN) that is designed to capture long-term dependencies and complex non-linear patterns in sequential data. This makes it highly suitable for modeling the unpredictable behavior of cryptocurrency markets and detecting important time-based trends in price movements.

3. GRU (Gated Recurrent Unit):GRU is a simplified version of LSTM that has fewer parameters, making it faster to train while still delivering strong performance. It is well-suited for real-time cryptocurrency forecasting and works efficiently with lower computational requirements.

4. Sentiment Analysis (NLP Models): Natural Language Processing (NLP) is used to examine tweets, news articles, and social media posts related to cryptocurrency. It classifies the sentiment as positive, negative, or neutral to understand the overall market mood. By combining these emotional signals with technical price data, the system is able to improve prediction accuracy.

5. Hybrid LSTM–Sentiment Analysis: This hybrid approach combines LSTM-based numerical forecasts with NLP-based sentiment scores. By taking into account both historical price trends and real-time market mood, it enhances overall prediction accuracy and makes the results more practical and reliable.

6. Hybrid ARIMA–GRU: This model integrates ARIMA's strength in identifying linear trends with GRU's capability to learn complex, non-linear patterns. By combining both approaches, it produces more stable, balanced, and reliable predictions.

7. Whale Transaction Analysis: Large transactions tracked through Whale Alert are analyzed to identify sudden market movements.

8. Portfolio Risk Evaluation Models: These models evaluate portfolios by analyzing volatility, diversification, and market exposure. By combining price forecasts with whale transaction data, the system delivers more risk-aware and practical investment insights.

9. All Models (Ensemble Approach): The system combines ARIMA, LSTM, GRU, and sentiment analysis into a unified ensemble framework. By merging predictions from multiple models, it reduces overfitting, improves performance across different tokens, and provides more reliable forecasts. Overall, the project applies a mix of machine learning and hybrid techniques to effectively handle the challenges of cryptocurrency market prediction and analysis.

Algorithms	Accuracy Score	Precision	Recall	F1 Score
ARIMA	0.812	0.820	0.810	0.815
LSTM	0.912	0.915	0.910	0.912
GRU	0.905	0.908	0.902	0.905
Sentiment Analysis	0.835	0.840	0.832	0.836
Hybrid (LSTM + Sentiment)	0.928	0.931	0.927	0.929
Hybrid (ARIMA + GRU)	0.897	0.902	0.895	0.898
Whale Transaction + Risk Models	0.875	0.880	0.872	0.876
All Models	0.940	0.942	0.939	0.940

Table 2- Algorithm evaluation metrics

VII. Implementation Details

These are the various implementation results of our project.

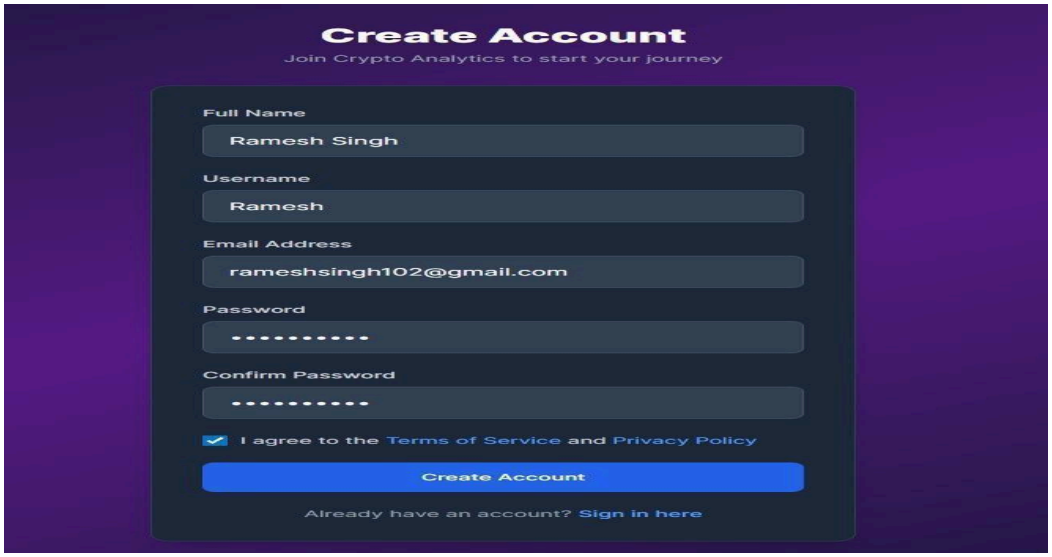


Fig 2: Register Page

Registration page for creating a new Crypto Analytics account.

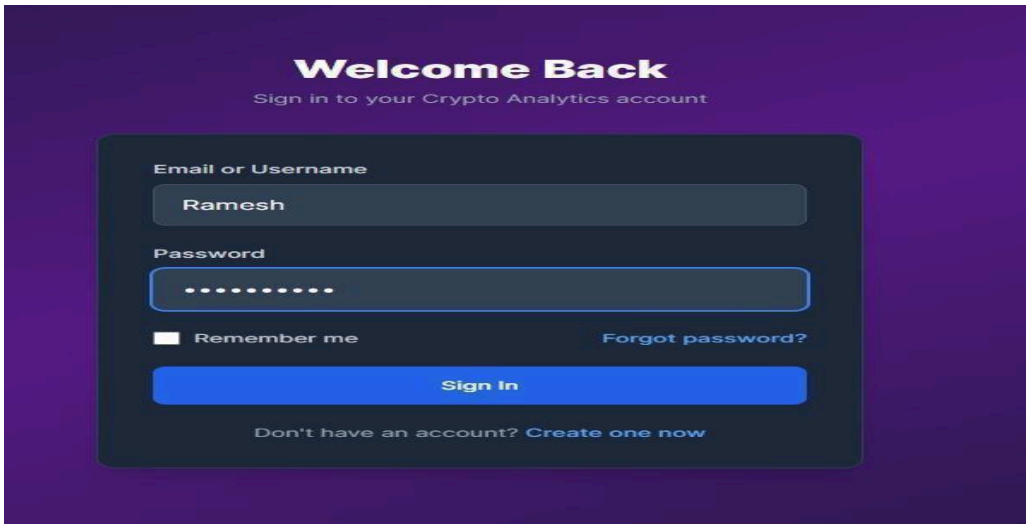


Fig 3 : Login Page

Login page for accessing the Crypto Analytics account.

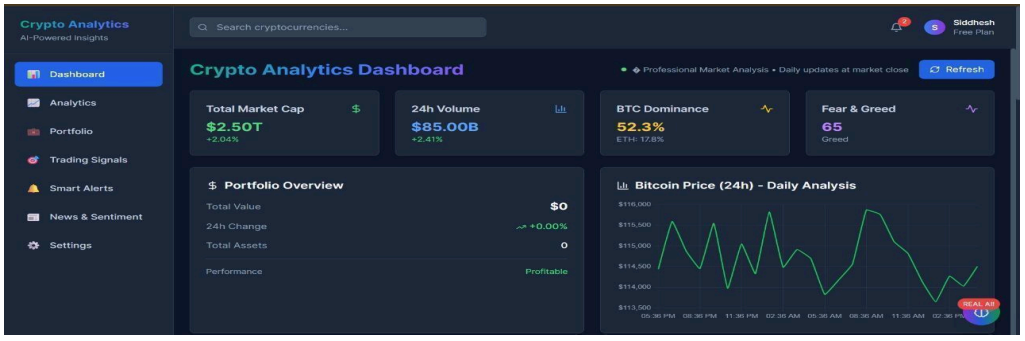


Fig 4: Dashboard

Crypto Analytics Dashboard that appears after login or registration, where users can view market stats, portfolio overview, trading signals, and real-time analysis.

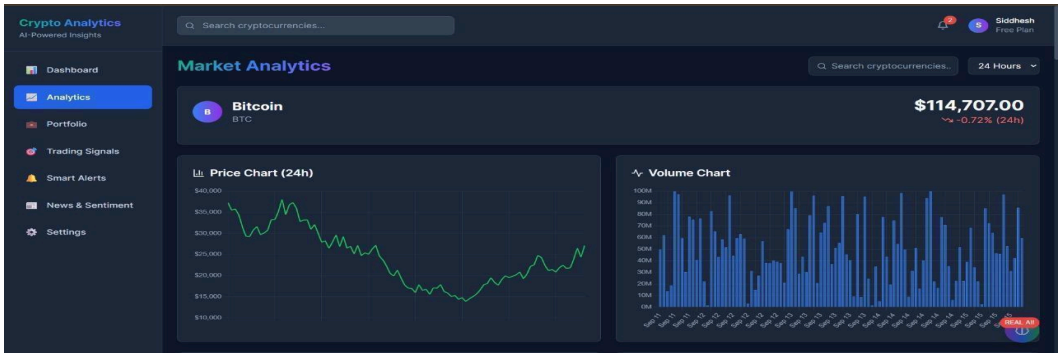


Fig 5: Analytics Page

The Analytics Page, where users can view detailed insights such as the price chart and volume chart for Bitcoin (or other selected cryptocurrencies) over a chosen time period.

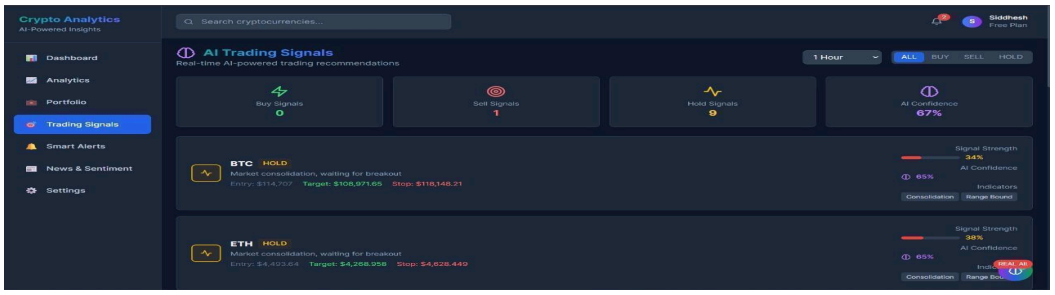


Fig 6: Trading Signals page

Trading Signals Page that displays AI-powered buy, sell, or hold recommendations with confidence levels, targets, and stop-loss points for cryptocurrencies.

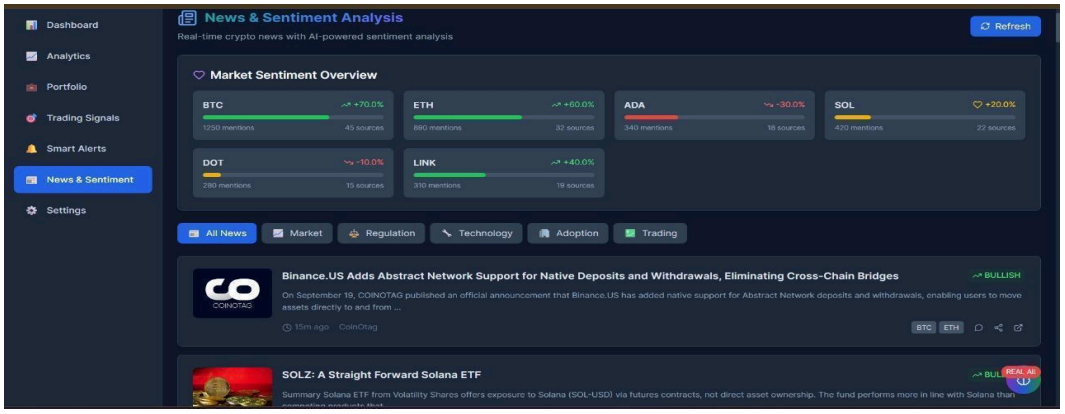


Fig 7: News and Sentiment Page

AI-powered news and sentiment analysis with mentions and sentiment trends for major cryptocurrencies like BTC, ETH, ADA, SOL, DOT, LINK, UNI, and AAVE

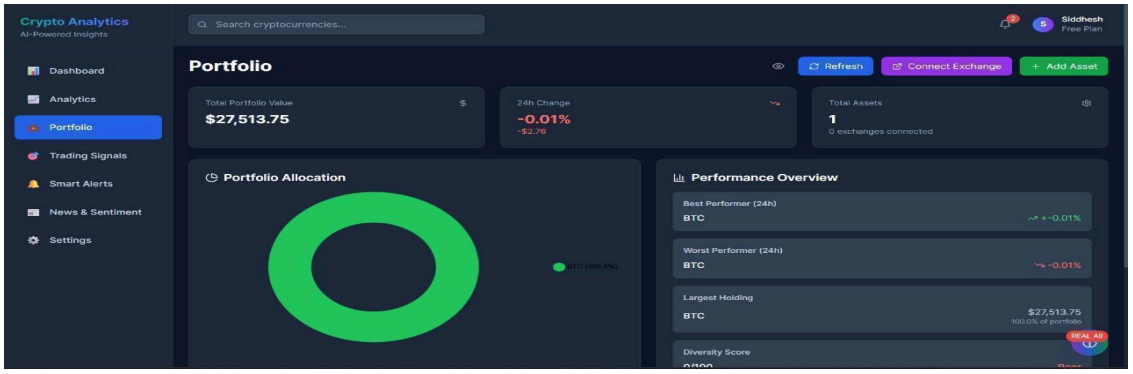


Fig 8: Portfolio Page

The Portfolio page of a crypto analytics dashboard, displaying total portfolio value, 24h change, portfolio allocation, and performance overview with BTC as the sole holding.

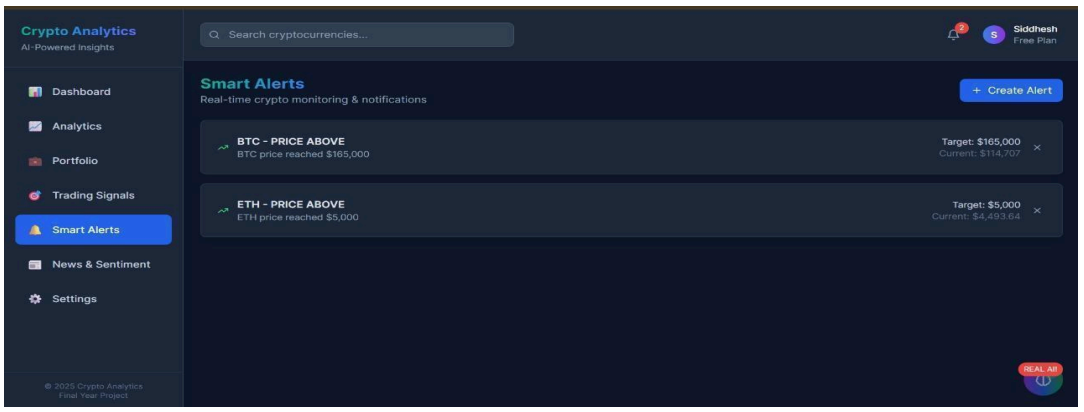


Fig 9: Smart Alerts Page

the Smart Alerts page of a crypto analytics dashboard, providing real-time monitoring and notifications for BTC and ETH price targets.



Fig 10: Chatbot

A crypto chatbot assistant, for example, can guide users about the risks and high volatility of cryptocurrency investments, while also encouraging diversification and better market awareness before making decisions.

VIII. Conclusion

The project "AI-Powered Crypto Analytics Agent for Token Insights & Forecasting" is developed to enhance cryptocurrency market analysis using artificial intelligence. It helps users make better investment decisions, reduce potential risks, and improve prediction accuracy by focusing on real-time data and personalized insights. By integrating time-series forecasting models, sentiment analysis, and whale transaction monitoring, the system provides a comprehensive view of market behavior for investors, portfolio managers, and analysts. With features such as an interactive dashboard, smart alerts, and an AI-powered chatbot, the platform ensures a more informed, efficient, and user-friendly trading experience while addressing the growing demand for reliable and high-quality crypto market analysis.

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Developing Reflexive Social Workers: Autobiographical Narratives and Podcasting in Human Rights Education

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***Abstract*—The increasing complexity of global and local social issues necessitates the development of reflexive practitioners in social work education who are critically aware, ethically grounded, and committed to human rights principles. This paper explores the role of autobiographical narratives and podcasting as innovative pedagogical tools in fostering reflexivity among social work students within a human rights education framework. Adopting a scoping review methodology, the study systematically maps and synthesizes existing literature on reflexive practice, narrative approaches, and digital pedagogies in social work education.**

The findings reveal that autobiographical narratives serve as a powerful medium for enhancing self-awareness, critical reflection, and professional identity formation by enabling students to connect personal experiences with broader social structures such as inequality, marginalization, and oppression. Simultaneously, podcasting emerges as an interactive and participatory learning tool that promotes dialogue, amplifies diverse voices, and strengthens communication and critical thinking skills. Together, these approaches align with human rights pedagogy by fostering critical consciousness, encouraging student engagement, and promoting social justice-oriented practice.

The paper argues that integrating narrative-based and digital learning strategies into social work curricula can significantly enhance the development of proto-professional reflexivity, particularly in diverse and unequal contexts such as India. It further emphasizes the need for continuous curriculum innovation to address evolving social realities and promote inclusive, reflexive, and practice-oriented learning.

institutional support, and context-sensitive pedagogical practices to effectively implement these approaches. This study adds to the growing scholarship on transformative social work education and offers valuable insights for educators, policymakers, and researchers committed to advancing reflexive, inclusive, and rights-based practice.

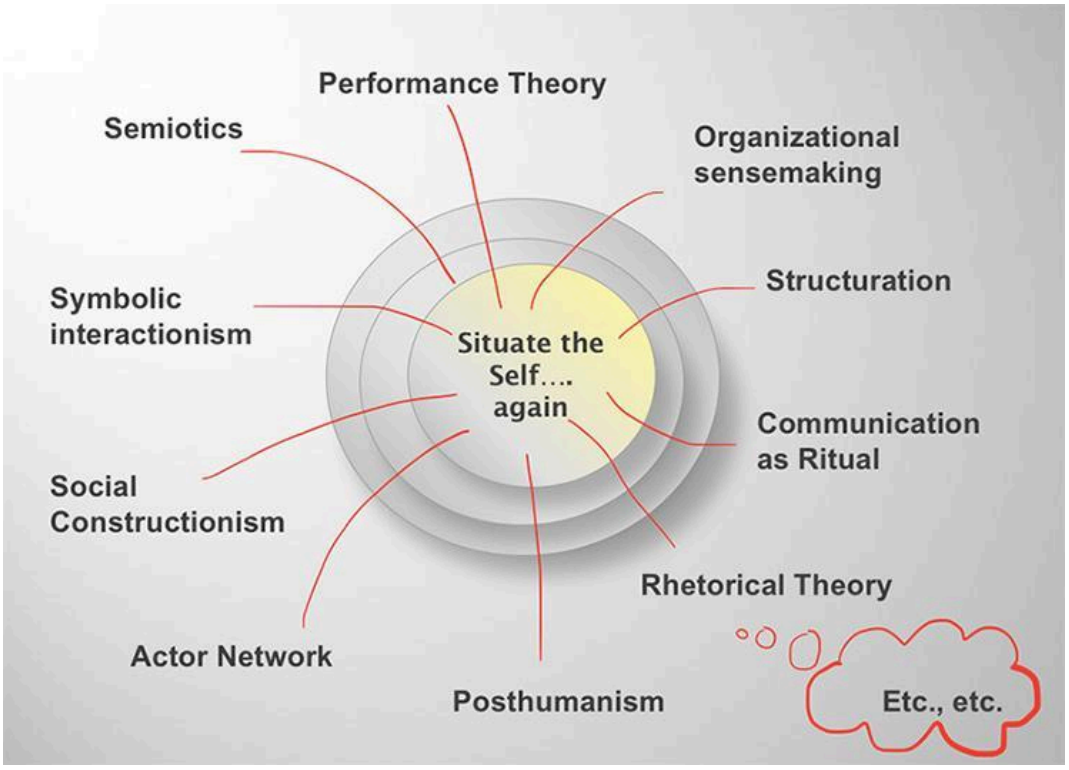
***Index Terms*—Social Work Education, Reflexivity, Autobiographical Narratives, Podcasting, Human Rights Pedagogy, Critical Pedagogy**

I. Introduction

Developing reflexive social workers in India requires a shift from traditional, hierarchical pedagogy to interactive and participatory models that challenge oppression and minimize power structures between faculty and students. This approach is increasingly emphasized within Indian higher education by institutions such as the Tata Institute of Social Sciences (TISS) and the National Assessment and Accreditation Council (NAAC), particularly in promoting quality and innovation in social work education. integrates human rights education and reflective practice to empower students to address complex social issues critically.

Key strategies for fostering reflexivity include:

- Democratic Student-Faculty Relations: Establishing open communication, complaint redressal committees, and sexual harassment committees to ensure an egalitarian learning environment.
- Human Rights Integration: Adopting values, accountability, and transformational models of education that move beyond "needs fulfillment" to "ensuring rights" through community-based monitoring and advocacy.
- Fieldwork and Practical Application: Utilizing immersive field placements, internships, and partnerships with NGOs to connect theoretical knowledge with real-world environmental justice, disaster management, and policy formulation.
- Ethical Leadership: Adhering to the Code of Ethics (formulated by SWEF in 1977) while addressing modern challenges like digital public infrastructure and data privacy in service delivery.



Autobiographical narratives in India act as a powerful instrument for human rights advocacy by capturing the lived experiences, social exclusion, and structural vulnerabilities of marginalized communities, including Dalits. tribal communities, and women, while **podcasting and digital documentation** are emerging as tools to amplify these voices and create accessible knowledge pools for Human Rights Education (HRE).

Narrative Pedagogy and Social Justice In the Indian context, life narratives are central to critical pedagogy, allowing students to **learn from the "Other"** through dialogic praxis. Research highlights how **Dalit life writings** and autobiographies (e.g., by Omprakash Valmiki and Bama)

expose caste and gender discrimination within educational institutions, challenging the notion that formal education alone ensures sustainable development. These narratives enable **critical self-reflection** among preservice teachers, helping them deconstruct meritocracy and privilege while fostering a **culture of human rights** that counters systemic oppression.

Digital Amplification and HRE Implementation While traditional narratives are often documented in text, there is a growing emphasis on **audio and video recordings** of pedagogical interventions and personal experiences to expand the horizons of HRE. These digital formats help **transact human rights education** in classrooms, moving students from viewing HRE as a "time pass" to a **transformative force** where they intervene in abuse, report violations, and spread awareness. The integration of these narratives into school curricula, supported by the **National Curriculum Framework (2005)**, aims to build a universal culture of human rights by sharing stories of vulnerability and resistance.



Social work in India has historically been understood as a *helping profession* committed to promoting social justice and addressing the needs of marginalized and vulnerable populations. Rooted in constitutional values such as equality, dignity, and human rights, the profession emphasizes the ethical responsibility of social workers to challenge social injustice and critically examine the structural and environmental factors that produce and sustain inequality. In the Indian context, these inequalities are deeply shaped by intersecting systems such as caste, class, gender, religion, and regional disparities.

Scholars and practitioners have engaged with multiple frameworks of social justice, including distributive justice (equitable access to resources), procedural justice (fair participation in decision-making), recognition (respect for diverse identities and cultures), and structural justice (redistribution of power and opportunities). While these frameworks enrich the conceptual understanding of justice, they also complicate its practical application in social work education, research, and field practice in India.

Achieving social justice in India requires a critical interrogation of entrenched systems of oppression, including caste-based discrimination, patriarchy, communalism, and the legacies of colonialism and neoliberal economic reforms. Historically, social welfare interventions in India have sometimes reinforced hierarchical and exclusionary practices, particularly in relation to Dalits, Adivasis, minorities, and other marginalized groups. Contemporary challenges such as displacement, informal labour exploitation, agrarian distress, and urban poverty further highlight the need for structurally informed social work interventions.

Social work education in India has increasingly been critiqued for its over-reliance on Western, biomedical, and individualistic models, which often fail to adequately address the socio-political realities of the Global South. Dominant approaches, including diagnostic and clinical frameworks, tend to individualize social problems while neglecting structural determinants such as poverty, caste oppression, and systemic exclusion. Although there is growing emphasis on the social determinants of health, neoliberal influences have led to the expansion of market-driven education, managerial practices, and outcome-based models that prioritize efficiency over equity.

As a result, there has been a gradual shift in Indian social work from collective, community-based, and transformative approaches toward individualized and adaptive interventions. This shift risks diluting the profession's commitment to social justice. Therefore, there is an urgent need to incorporate critical, reflexive, and anti-oppressive pedagogies within social work education. Approaches such as critical autoethnography and reflexivity offer powerful tools to interrogate power, privilege, and positionality, enabling students and practitioners to challenge dominant narratives and engage more meaningfully with issues of social justice.

This paper seeks to explore the role of critical reflexive methodologies in strengthening social work pedagogy in India by presenting narratives that engage with lived experiences, power structures, and professional motivations. It highlights the importance of developing socially conscious, anti-racist, and contextually grounded social workers who can effectively respond to India's complex and evolving social realities.

II. Conceptual Framework

1. Reflexivity in Social Work collaboratively

The training of prospective anti-racist (and anti-oppressive) social work professionals in India does not occur in isolation. Despite the profession's commitment to social justice and human rights—reflected in frameworks such as the National Association of Social Workers (NASW, 2017) and aligned with Indian constitutional values—social work education in India must navigate powerful neoliberal socio-political and economic forces. These forces are manifested in widening inequalities related to caste, class, gender, and region, as well as persistent disparities in access to healthcare, education, and livelihood opportunities.

In the Indian context, neoliberal reforms since the 1991 Indian economic liberalization have contributed to rapid economic growth but have also intensified informalization of labour, precarity among gig workers, and marginalization of already vulnerable communities such as Dalits, Adivasis, women, and migrant workers. These developments often shift the focus of social work practice toward individual coping and resilience, rather than addressing structural inequalities rooted in caste hierarchies, patriarchy, and systemic exclusion.

Scholars argue that social work education and practice in India, similar to global trends, risk becoming depoliticized—emphasizing technical competencies, service delivery, and individual-level interventions over critical engagement with structural injustices. This is visible in the dominance of clinical and welfare-oriented approaches, often at the expense of rights-based, community-driven, and transformative practices. Consequently, there is a tendency to maintain social harmony and institutional equilibrium rather than confront conflict, challenge power structures, or advocate for redistributive justice.

For meaningful pursuit of social and social justice in India, social work education must move beyond a competency-based framework and actively cultivate critical consciousness among students. This requires engaging learners in reflexive and dialogical processes that examine how identities related to caste, class, gender, religion, and region shape experiences of privilege and oppression. Pedagogical approaches such as critical theory, anti-oppressive practice, and participatory learning can enable students to interrogate dominant narratives and question systemic inequalities.

Integrating critically reflexive and contextually grounded curricula can foster transformative learning in Indian social work education. Such an approach not only equips students with theoretical knowledge but also encourages collective action, advocacy, and engagement with grassroots movements. In doing so, social work professionals in India can reclaim the profession's commitment to social justice by aligning practice with the lived realities of marginalized populations and contributing to structural change rather than merely adapting individuals to unjust social conditions.

2. Proto-Professional Reflexivity

Proto-professional reflexivity refers to the early development of reflexive skills among students during their educational journey. It lays the foundation for lifelong reflective practice and ethical decision-making.

3. Human Rights Pedagogy

Critical pedagogy, as articulated by Paulo Freire (1970), is a transformative approach to teaching that actively engages students in drawing upon their lived experiences to reflect, analyse, and co-construct knowledge while critically questioning dominant narratives, beliefs, and power structures. However, scholars have debated the extent to which critical pedagogy adequately addresses issues of race and structural oppression across diverse socio-cultural contexts.

Drawing on the principles of Critical Race Theory (CRT), critical race pedagogy has emerged as a liberatory, anti-oppressive framework. It emphasizes four key elements: (1) the endemic nature of structural inequalities, (2) the recognition of power hierarchies embedded within social systems, (3) the importance of counter-narratives, and (4) the role of education and advocacy in advancing social justice. While CRT originated in the United States, its core ideas can be meaningfully adapted to the Indian context by foregrounding caste-based discrimination, religious marginalization, tribal exclusion, and intersectional inequalities.

In India, social work education has the potential to integrate critical race pedagogy by interrogating dominant narratives that sustain caste hierarchies, Brahmanical dominance, patriarchy, and neoliberal exclusion. Such an approach enables students to critically examine how structural inequalities are reproduced through institutions such as education, healthcare, and labour markets.

Similarly, the concept of critical reflexivity has evolved from early philosophical work by John Dewey (1997), which emphasized reflection on personal beliefs and experiences, to a more critical engagement with power, privilege, and knowledge production (D'Cruz et al., 2007). However, reflexivity has often been reduced to an individualistic exercise that risks reinforcing dominant, colonial, and neoliberal frameworks—particularly when it fails to explicitly interrogate structural power relations.

In the Indian context, such limitations are evident when reflexive practices remain confined to personal acknowledgment of privilege (e.g., caste or class privilege) without translating into collective action or structural transformation. Scholars have critiqued this tendency as performative, where expressions of awareness do not challenge entrenched systems such as caste oppression, communal polarization, or gender inequality.

To address this gap, the concept of "uncomfortable reflexivity" has been proposed. This approach moves beyond self-disclosure and instead emphasizes sustained engagement with discomfort, contradiction, and structural critique. It encourages students and practitioners to confront deeply embedded systems of oppression—such as caste hierarchies, patriarchy, and majoritarian nationalism—rather than seeking resolution through superficial or symbolic acts.

Uncomfortable reflexivity aligns closely with critical pedagogy by fostering "disruptive learning" that challenges dominant ideologies and compels learners to engage in ongoing struggles for justice. In India, this involves critically engaging with issues such as caste-based violence, marginalization of Dalits and Adivasis, exclusion of minority communities, and the precarity of informal and gig workers.

Furthermore, this approach shifts the focus from individual identity-based struggles toward collective, intersectional action. By centering marginalized voices and community-based knowledge systems, social work education can move beyond extractive or tokenistic engagement and instead contribute to transformative social change.

Ultimately, integrating critical pedagogy, critical race-informed perspectives (adapted to caste and social hierarchies), and uncomfortable reflexivity within Indian social work education can foster a human rights-based pedagogy. Such a framework not only deepens students' critical consciousness but also equips them to challenge structural inequalities and actively participate in building a more just and inclusive society.

III. Literature Review

1. Autobiographical Narratives in Social Work Education

Autoethnography is a qualitative research approach in which researchers systematically describe and analyse their personal experiences (auto) within broader cultural and socio-political contexts (ethno) through narrative writing (graphy) (Adams, 2015; Ellis et al., 2011). In the Indian context, this approach is particularly useful for exploring how identities shaped by caste, class, gender, religion, and region influence lived realities and professional practice.

Critical autoethnography extends this method by explicitly focusing on power relations, interrogating structures of domination, and challenging conventional research practices that often "other" or distance marginalized communities (Boylorn & Orbe, 2016; Gupta, 2017; Holman Jones, 2018). Within India, this

perspective is valuable for examining entrenched systems such as caste hierarchies, patriarchy, communal marginalization, and neoliberal exclusion, which continue to shape access to resources and opportunities.

The integration of critical autoethnography with critical reflexivity and perspectives derived from Critical Race Theory (adapted to the Indian context through caste and intersectionality) provides a powerful framework for engaging with structural inequalities. Together, these approaches enable researchers and practitioners to critically examine how power operates within social institutions and everyday interactions, while also challenging dominant narratives that sustain oppression.

In social work education and practice in India, these paradigms can play a transformative role. They can enhance practitioners' reflexivity in clinical and community settings, amplify the voices of students and marginalized groups, and foster critical dialogue across diverse positionalities. Moreover, they contribute to making research more participatory, contextually grounded, and accessible to wider audiences, including communities that are often excluded from knowledge production processes.

Indian social work scholars have increasingly engaged with collaborative and critical autoethnographic approaches to examine issues such as caste-based discrimination in educational institutions, challenges in fieldwork placements, ethical dilemmas in practice, and the preparedness of students to work in diverse and unequal social settings. These approaches also open up possibilities for reimagining social work education by encouraging reflexive, socially engaged, and justice-oriented training of future practitioners.

2. Podcasting as a Pedagogical Tool

In our efforts to integrate participatory approaches into critical autoethnographic inquiry, we developed a positionality statement that reflects our collective identity as students located at the intersections of privilege, power, and marginalization within the Indian socio-cultural context. This includes engagements with caste, class, gender, religion, and regional disparities that shape both personal experiences and academic practices.

Scholars in India and globally are increasingly challenging colonial research paradigms that privilege narrowly defined notions of "expertise," "objectivity," and "rigour," which often marginalize experiential and community-based knowledge systems. In the Indian context, such hierarchies are further reinforced by caste-based epistemic dominance and institutional inequalities within higher education.

Moreover, critical scholarship has highlighted how authorship practices and publication systems are embedded within hierarchical power structures, increasingly shaped by neoliberal ideologies that prioritize productivity, competition, and market-driven metrics. These trends are evident in Indian universities as well, where pressures of ranking, publication output, and academic visibility can undermine collaborative and equitable knowledge production.

In response, we position ourselves as a collective that values all contributions equitably and seeks to embody participatory and democratic research practices. Drawing on participatory frameworks, we consciously shared decision-making power and engaged in iterative, dialogical processes throughout virtual and in-person interactions, including planning, data analysis, writing, and revision of the manuscript.

Our approach seeks to unsettle entrenched power hierarchies within academic knowledge production. While the structure of authorship and narrative sequencing has been organized to highlight the experiences of Master of Social Work students alongside writing contributions, we intentionally adopt a multi-vocal

perspective. This perspective enables us to represent diverse voices and lived experiences while critically engaging with ongoing struggles and contradictions within social work education and practice in India.

Grounded in principles aligned with Critical Race Theory (adapted to caste and intersectionality in India) and critical reflexivity, our work aims to illuminate both visible and invisible forms of power, exclusion, and resistance. Through this process, we strive to contribute to a more inclusive, reflexive, and socially just framework of knowledge production in Indian social work education.

3. Reflexive Learning and Critical Pedagogy

Critical pedagogy emphasizes dialogue, reflection, and transformation. Reflexive learning aligns with this approach by encouraging students to question dominant narratives and challenge inequalities.

IV. Methodology

We adopted an autoethnographic approach to explore our experiences of pedagogy and the culture of social justice within social work education in India. Autoethnography is a qualitative research method that involves the systematic analysis of personal experiences within broader cultural and socio-political contexts (Hayano, 2008). It differs from traditional ethnography in its emphasis on critical self-reflection and the researcher's positionality as both subject and analyst (Ellis & Bochner, 2000). This approach enables the construction of narratives grounded in lived experiences shaped by social institutions and structural realities (Patton, 2014).

In the Indian context, autoethnography is particularly relevant for examining how caste, class, gender, religion, and regional inequalities influence students' educational journeys and professional identities. Social work scholars in India have increasingly used such approaches to explore fieldwork experiences, ethical dilemmas, and the structural constraints shaping professional training.

We employed **critical autoethnography** to interrogate our experiences of dissonance within social work education at a university in India. This approach allowed us to critically examine how institutional practices, dominant ideologies, and structural inequalities influence pedagogy and student experiences.

We collaboratively developed three central research questions to guide our inquiry:

1. How do our personal trajectories and intersectional identities (caste, class, gender, religion, and region) shape our motivations for pursuing social work education, and how do these interact with institutional pedagogical structures?
2. How do dominant narratives within Indian social work education privilege or marginalize particular student experiences and forms of knowledge?
3. What transformative possibilities emerge from integrating intersectionality, critical pedagogy, and reflexive practices into social work education in India?

Although we occupied different roles (e.g., instructor and students) within a postgraduate social work programme, we shared a strong commitment to extending our learning beyond the classroom through collaborative and participatory engagement.

A purposive sampling strategy was employed to recruit participants enrolled in the same Master of Social Work (MSW) programme who demonstrated a willingness to engage in sustained reflexive writing and

dialogue. Participants were selected based on their interest, availability, and ability to commit to the full duration of the study.

Following institutional ethical approval (Institutional Ethics Committee/IRB equivalent in India), invitations were shared with former students of a postgraduate social work course. A small group of interested participants (n = 3) consented to participate after attending an online orientation session where the study's objectives, processes, and ethical considerations were discussed.

To facilitate reflective engagement, we conducted five virtual autoethnographic writing sessions over a six-month period. Each session lasted approximately 60–90 minutes and was conducted through online platforms. Sessions began with grounding exercises, followed by structured self-reflexive writing prompts that encouraged participants to critically examine their personal journeys, motivations for entering social work, fieldwork experiences, and engagement with issues such as caste discrimination, gender inequality, and social exclusion.

Each session also included **peer debriefing**, where participants shared their narratives and collectively reflected on emerging ideas, tensions, and patterns. This dialogical process enabled collaborative meaning-making and critical engagement with diverse positionalities.

For data analysis, we adopted an iterative and participatory approach. Initially, participants independently read all narratives to develop familiarity with the data, paying attention to emotions, experiences, and underlying social structures. Subsequently, we engaged in multiple rounds of discussion to critically analyse the data through frameworks such as intersectionality, critical pedagogy, and reflexivity.

Emerging codes were collaboratively identified and compiled into a shared codebook. The narratives were then coded individually using qualitative data analysis software (e.g., NVivo), followed by group discussions to resolve discrepancies and ensure consensus. This process enhanced the credibility and rigor of the analysis.

1. **Research Design**

This study adopts a **scoping review methodology** to map existing literature on the use of autobiographical narratives and podcasting in social work education.

2. **Data Sources**

Google Scholar, Scopus, and Web of Science (WoS) are the primary bibliographic databases used to identify relevant literature, each offering distinct coverage strengths. **Google Scholar** provides the broadest coverage, identifying **93%–96%** of citations across all areas and capturing nearly all citations found by WoS (95%) and Scopus (92%), largely due to its inclusion of **non-journal sources** (such as theses, books, and conference papers) and **non-English literature** (up to 40%). **Scopus** and **Web of Science** are more selective, predominantly indexing English-language journal literature, though Scopus generally offers slightly better forward citation coverage than WoS Because **no single database captures all citations**, research protocols often recommend **combining all three** to ensure comprehensive literature retrieval. While **Google Scholar** citation counts are typically higher due to duplicate entries and broader indexing, **Scopus** and **Web of Science** provide cleaner data without duplicates, making them suitable for precise citation analysis when combinked with Google Scholar's unique finds.

Database	Coverage Strength	Unique Content Characteristics
Google Scholar	Broadest (93–96% of citations)	~50% unique citations are from non-journal sources; 19–38% are non-English.
Scopus	High (35–77% of citations)	Stronger coverage for recent articles in specific fields like oncology; includes more international journals.
Web of Science	High (27–73% of citations)	Historically strong in specific disciplines like condensed matter physics; high precision for English journals.

3. Inclusion Criteria

Identity and Intersectionality in the Indian Context

The author's identity as an African-Caribbean woman shaped by race, gender, and culture can be compared to intersectional identities in India, such as:

- Caste (Dalit, OBC, Upper caste)
- Gender (women facing patriarchy)
- Religion and minority status
- Rural–urban background

In India, individuals often experience multiple layers of marginalization, similar to the author's experience. For example, a Dalit woman from a rural background may face caste discrimination, gender inequality, and economic hardship simultaneously. This highlights the importance of intersectionality in social work education in India.

Gender Roles and Cultural Expectations

The narrative describes expectations placed on women (caregiver, nurturer, self-sacrificing). This strongly resonates with Indian society where:

- Women are expected to prioritize family over self
- Social norms emphasize modesty, marriage, and motherhood
- Limited space is given for women's autonomy

Thus, the author's reflection parallels the lived experiences of many Indian women, making it relevant for gender-sensitive social work practice in India.

Educational Inequality and First-Generation Learners

The author highlights being a first-generation college student facing disparities. In India, this is very common among:

- Students from rural or marginalized communities
- First-generation learners in higher education
- Economically weaker sections

Such students often face:

- Language barriers (English vs regional languages)
- Lack of academic support
- Financial constraints

This shows the need for inclusive and supportive social work education systems in India.

Poverty and Structural Inequality

The author's experiences in Ghana (children working, lack of healthcare) can be compared with Indian realities such as:

- Child labour
- Limited access to healthcare in rural areas
- Informal economy survival strategies

These reflect structural inequalities, which are central concerns in Indian social work practice.

Migration and Changing Socio-Economic Status

The shift from a "comfortable life" in Ghana to a "low-income" identity in the U.S. highlights how context defines class and privilege. Similarly, in India:

- Rural to urban migration change's social identity
- People moving to cities may face poverty despite prior stability
- Migrant workers experience exclusion and vulnerability

This reinforces the importance of understanding contextual and relative poverty in Indian social work.

Integrating Critical Pedagogy and Reflexivity in Indian Social Work Education-

The author mentions critical race pedagogy, which can be adapted in India as:

- Critical caste pedagogy
- Anti-oppressive practice
- Human rights-based education

Indian social work education must encourage students to:

- Reflect on their own caste, class, and privilege

- Understand systemic inequalities
- Challenge dominant power structures

Critique of Social Work Education

The narrative criticizes:

- Unpaid internships
- Emotional burden on students
- Lack of structural change

In India, similar issues exist:

- Fieldwork often unpaid
- Financial burden on students
- Limited institutional support

This calls for policy reforms in Indian social work education.

Importance of Reflexive Spaces and Community Learning

The author values reflective writing and shared learning spaces. In India, this suggests:

- Need for safe classroom environments
- Encouraging dialogue and peer learning
- Use of autobiographical narratives and storytelling

These methods can help students:

- Process their experiences
- Build empathy
- Develop professional identity

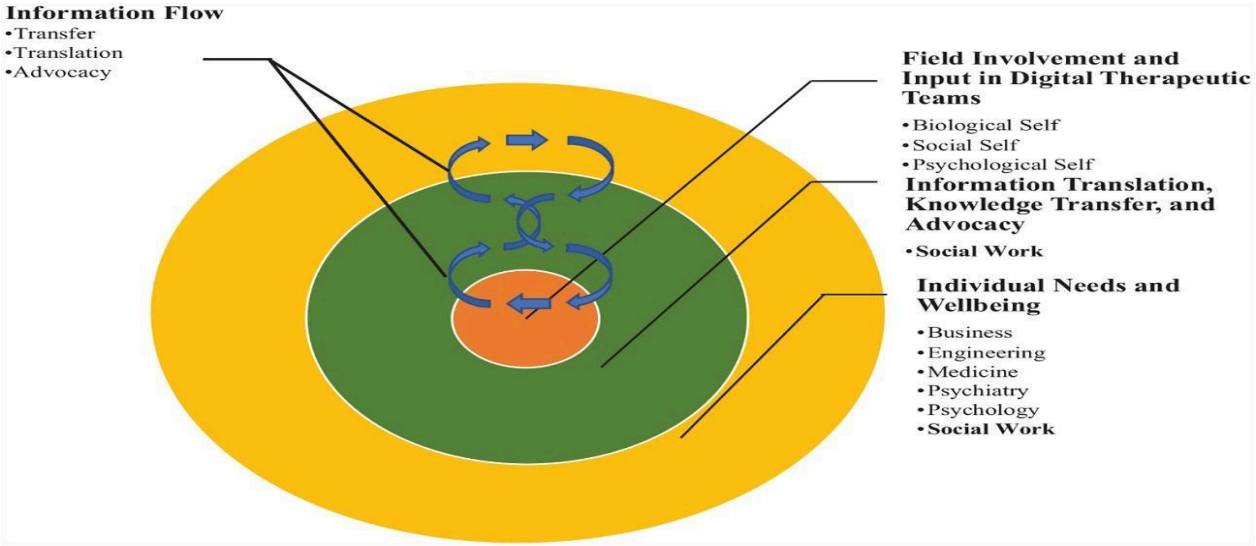
V. Data Analysis

Thematic analysis is a widely used and flexible qualitative research method for identifying, analysing, and interpreting patterns (themes) within data. It is particularly effective in synthesizing rich qualitative findings and developing a meaningful understanding of complex social phenomena. Unlike content analysis, which primarily emphasizes quantifying word frequencies, thematic analysis focuses on capturing deeper meanings, experiences, and underlying patterns within the data.

Thematic analysis follows six iterative phases, including data familiarization, coding, theme development, review, definition, and reporting. This approach allows researchers to develop a coherent and contextually grounded interpretation of participants' lived experiences.

Researchers often use this approach to **organize and summarize** diverse data sets, such as interviews, focus groups, or literature reviews, to understand participants' **views, experiences, and values**. While the method

is adaptable, it requires careful attention to **coding reliability** or **reflexivity** to ensure that the identified themes accurately represent the data without excessive researcher bias.



VI. Findings and Discussion

Development of Reflexivity through Narratives-

instance, a 2024 study on sexual violence in India demonstrated how a researcher's shared demographics with participants (young, educated women) facilitated rapport, while the researcher's conscious shift between emic (insider) and etic (outsider) perspectives allowed for a nuanced balance between empathy and objective representation of marginalized voices. Similarly, autoethnographic narratives have been employed in the hotel industry to explore professional growth, where Learning and Development (L&D) managers used reflective conversations and personal recordings to identify gradual reflective patterns that defined their professional evolution and integration of human resource practices.

Podcasting and Critical Engagement-

India's podcasting market is undergoing a **critical engagement shift**, driven by a move from simple entertainment to **social impact, education, and deep-dive journalism**. With the market size reaching **USD 840.72 million in 2024** and projected to hit **USD 9.3 billion by 2033**, the medium is being leveraged by institutions and independent creators alike to foster informed discourse.

Institutional and Corporate Adoption Government bodies and large corporations are increasingly using podcasts to enhance public awareness and employee engagement, lending professional legitimacy to the medium.

- The **Reserve Bank of India (RBI)** announced plans in December 2024 to launch podcasts focused on financial literacy and policy updates.
- **Tata Steel** introduced *FiredUp* in December 2024, featuring industry leaders to promote thought leadership.
- **Reckitt** launched *Dettol School Radio* in November 2024, India's first school-based climate awareness podcast, integrating audio learning into school curriculums.

Strengthening Social Work Education through the Integration of Human Rights Education-

Human Rights Education (HRE) in India has been systematically incorporated into higher education and teacher training since the 1980s, primarily through initiatives and guidelines issued by the University Grants Commission (UGC) and the National Human Rights Commission (NHRC). The Sikri Commission (1985) played a pivotal role by proposing a comprehensive framework for integrating human rights education across schools, colleges, and adult education systems. This initiative subsequently led to the introduction of dedicated courses such as “Human Rights and Duties” and “Human Rights and Values” under the UGC’s X and XI Five-Year Plan programmes.

Integration has progressed through specific academic milestones, including the Establishment of The Indian Institute of Human Rights in The 1990s and the creation of dedicated centres at universities such as Jawaharlal Nehru University, Jamia Milia Islamia, and Benaras Hindu University. The **National Education Policy (2020)** further emphasizes embedding human rights, empathy, and social justice within a holistic, multidisciplinary curriculum to foster a "knowledge society," while the **National Curriculum Framework (2005)** and **Learning Outcomes Curriculum Framework (LOCF, 2018)** advocate for contextualized, rights-based pedagogy in schools and teacher education programs.

Despite these policy frameworks, **significant gaps remain between vision and practice**, with studies indicating that HRE is often relegated to electives in social sciences rather than being a foundational requirement across all disciplines. **Challenges to effective integration** include a lack of trained professionals, limited government funding, a disconnect between university curricula and ground realities, and the commercialization of education which sometimes undermines the rights-based approach mandated by the Right to Education (RTE) Act.

VII. Challenges

Technological barriers and **lack of training** are significant obstacles in India, where **limited resources**, **technological barriers**, and the **need for specialized training** hinder the effective implementation of digital storytelling and AI initiatives. **Ethical concerns** regarding **data privacy** and the **representation of personal narratives** must be carefully managed to maintain trust, as users face difficulties in distinguishing between real and fake applications or content.

Bias in AI algorithms and **lack of transparency** further complicate the landscape, with concerns that AI systems may reinforce social inequalities or operate as "black boxes" without clear accountability. **Cultural relevance** is another critical challenge, as standardized Western approaches often fail to resonate with Indian contexts, potentially leading to ineffective results or the stigmatization of users.

- **Digital Divide**: Marginalized communities lack equitable access to AI technologies and **AI literacy**, exacerbating existing inequalities.
- **Regulatory Gaps**: India lacks comprehensive **AI-specific legislation** to protect personal data and address ethical dilemmas in decision-making.
- **Misinformation**: The spread of **fake news** and **deepfakes** is amplified by a lack of **media literacy** and fact-checking infrastructure in vernacular languages.
- **Workforce Skills**: There is a **shortage of suitably skilled workers** and a lack of **investment in upskilling** to handle complex technical problems and ethical governance.

VIII. Transformative Implications for Social Work Education

Social work education in India faces important challenges in ensuring quality standards while promoting the indigenization of curriculum, pedagogy, and practice to reflect local socio-cultural realities,and professional recognition. The sector is grappling with the mushrooming of private colleges that lack adequate infrastructure, creating a significant gap between theoretical knowledge and practical application due to heavy reliance on Western models. While the National Education Policy (NEP) 2020 has introduced new opportunities like the Bachelor of Social Work (BSW) program at TISS, the curriculum often remains Euro-American-centric, necessitating a shift to integrate indigenous values, ethics, and practices rooted in India's cultural diversity.

Key challenges and future directions include the urgent need for a statutory regulatory body to standardize fieldwork training and establish a code of ethics, as the current lack of a professional license hinders the establishment of a Doctorate of Social Work (DSW). There is a growing consensus among educators to reorient the profession from a charity-based approach to one focused on social justice, human rights, and empowerment, addressing complex issues like caste oppression, gender inequality, and poverty. Ultimately, the field must balance modern scientific methods with traditional Indian concepts like *seva* (selfless service) to ensure relevance and effectiveness in solving contemporary social problems.

Curriculum Design-

Curriculum design in India has evolved from traditional rote-based learning approaches toward outcome-based education (OBE) and competency-based frameworks, in alignment with the National Education Policy 2020 (NEP 2020).It involves the purposeful arrangement of instructional blocks to map course content to specific learning outcomes, utilizing models like constructive alignment and backward design to ensure students acquire essential skills like critical thinking, creativity, and digital literacy.

In the Indian context, curriculum design emphasizes status planning driven by political consensus and focuses on learner-centric approaches that integrate global standards (CBSE, ICSE, IB, Cambridge) with local needs.

Teaching Practices-

Lecture-containing performance is identified as the most appropriate teaching method in Indian conditions, blending traditional lectures with elements of storytelling, mass media, and technology to engage students through a hybrid approach. This method adapts the classic teacher-cantered lecture by incorporating performance aspects that make the content more dynamic and relatable to local contexts.

Teaching at the Right Level (TaRL) is another significant practice, where students in grades 3 to 5 are regrouped based on their actual learning levels rather than their grade for focused instruction on basic skills. Implemented by organizations like Pratham in partnership with governments, this approach dedicates 1-2 hours daily to specific skill-building, ensuring that foundational literacy and numeracy are mastered before progressing.

Policy Implications-

Policy implications in India refer to the specific actions, adjustments, or frameworks derived from research findings or societal needs to address challenges effectively. For instance, if research on open defecation reveals religious beliefs as a barrier, the **policy implication** is to incorporate religious leaders into the Swachh Bharat programme or allow toilet construction away from homes to respect cultural sensibilities.

Recent major policy shifts in India demonstrate how strategic decisions shape governance and global standing:

- **Foreign Policy:** India's "Neighbourhood First" and "Act East" policies prioritize **physical, digital, and cultural connectivity** with neighbours like Bhutan, Nepal, and ASEAN nations, while the **MAHASAGAR doctrine** (launched in March 2025) aims for mutual security and growth across the Global South.
- **Trade and Economy:** The **Foreign Trade Policy (FTP) 2023** and **Make in India 2.0** aim to boost exports to **$2 trillion by 2030**, with the **India-UK CETA** (signed July 2025) granting duty-free access to 99% of export lines and the **U.S.-India COMPACT** (February 2025) targeting **$500 billion bilateral trade by 2030**.
- **Social and Domestic Policy:** The **National Health Policy 2017** sets targets to increase life expectancy to **70 by 2025** and raise health expenditure to **2.5% of GDP**, while the **National Steel Policy 2017** aims for **300 million tons of crude steel capacity** by 2030.

IX. Conclusion

In India, developing reflexive social workers is essential to address issues like caste, gender inequality, and poverty. Autobiographical narratives help students reflect on their own experiences and understand social realities, while podcasting provides a platform to discuss and raise awareness about human rights issues. Together, these approaches create socially aware, empathetic, and justice-oriented social workers.

X. Limitations and Future Research

Research on digital education in emerging markets faces significant **limitations due to a lack of empirical studies**, with many analyses relying heavily on **secondary sources** or limited datasets that fail to capture real-time experiences or **context-specific nuances**. For instance, studies in India reveal **inadequate digital education deployment** (score of 0.596) caused by poor infrastructure and limited pedagogical capabilities, yet broader research often overlooks these **micro-level factors** like individual learning styles and socio-cultural barriers.

Future research must prioritize **context-specific investigations** to address these gaps, particularly in regions like the **Middle East, North Africa (MENA)**, and **rural areas** where the digital divide is most acute. Key areas requiring **further exploration** include:

- **Longitudinal studies** to track the long-term effects of digital inequity on student outcomes and learning effectiveness.
- **Cross-cultural and cross-contextual analyses** that move beyond macro-level data to understand how **cultural norms, gender, and personality** influence digital access.
- **Integration of multiple methodologies**, such as interviews and ethnographic observations, to complement existing desk-based reviews and published reports.

There is an urgent need to develop comprehensive and integrated strategies that combine policy reforms, technological advancements, and educational interventions to ensure equitable access for All Scholars emphasize that **digital pedagogy** must evolve beyond mere technology adoption to include **teacher**

training, **institutional support**, and the design of **unplugged approaches** for early childhood education to safeguard young learners.

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A Study on Work-Life Balance of Employees in Industrial Sector of Chhatrapati Sambhajinagar

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***Abstract*—The present study analyzes work-life balance and its impact on job satisfaction and productivity among employees. Data collected from 100 respondents using structured questionnaire. Results show strong relationship between WLB and employee performance.**

***Index Terms*—Work-Life Balance, Job Satisfaction, Productivity, Industrial Employees**

I. Introduction

Work-life balance refers to maintaining equilibrium between professional responsibilities and personal life. Industrial employees often face long hours and stress affecting their well-being.

II. Objectives of the Study

To study work-life balance, analyze factors affecting it, evaluate its impact on job satisfaction, and measure employee productivity.

III. Hypothesis

H0: No significant relationship between work-life balance and job satisfaction.
H1: Significant relationship exists between work-life balance and job satisfaction.

IV. Literature Review

Various studies highlight that proper work-life balance improves employee satisfaction and reduces stress. Research indicates flexible policies enhance productivity.

V. Research Methodology

Descriptive research design was adopted. Primary data collected through questionnaires from 100 respondents. Secondary data from journals, books and websites.

VI. Data Analysis and Interpretation

Majority respondents belong to age group 20–30. Most employees reported moderate workload and stress. Employees with better work-life balance showed higher satisfaction.

VII. Findings

Employees experience moderate stress. Work-life balance positively impacts satisfaction and productivity.

VIII. Suggestions

Organizations should introduce flexible work hours, improve leave policies, and focus on employee wellness.

IX. Conclusion

Work-life balance plays a crucial role in employee performance and satisfaction.

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A Data-Driven Assessment of Air Pollution Trends in Major Indian Cities Using AQI (2018–2024)

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***Abstract*—Air pollution remains a major environmental and public health concern in India, primarily driven by rapid urbanization, industrialization, and vehicular emissions. This study presents a comprehensive data-driven analysis of air quality trends across major Indian cities using the Air Quality Index (AQI) and key pollutants, including Nitrogen Dioxide (NO_2), Nitric Oxide (NO), Ammonia (NH_3), and Carbon Monoxide (CO), over the period 2018–2024.**

The dataset, obtained from an open-source platform, was analyzed using statistical and visualization techniques in Microsoft Excel, including trend analysis and comparative evaluation. The findings reveal that AQI levels in most cities fall within the moderate to poor categories, with Delhi consistently exhibiting the highest pollution levels. Nitrogen-based pollutants, particularly NO_2, are identified as dominant contributors. Seasonal analysis indicates significantly higher pollution levels during winter due to atmospheric inversion conditions.

The study emphasizes the need for stricter emission regulations, sustainable urban planning, and enhanced public awareness to mitigate air pollution and its health impacts.

***Index Terms*—Air Pollution, AQI, NO_2, Environmental Analysis, Urban Pollution, India**

I. Introduction

Air pollution has become one of the most critical environmental challenges worldwide, particularly in developing countries like India (World Health Organization, 2022).particularly in developing countries such as India. Rapid economic growth, urban expansion, and increased energy consumption have significantly contributed to the deterioration of air quality. According to environmental studies, prolonged exposure to polluted air can lead to respiratory and cardiovascular diseases (World Health Organization, 2022)The Air Quality Index (AQI) is a standardized indicator used to measure and communicate air quality levels. It converts complex pollutant data into a single value, making it easier to understand the level of pollution and its potential health impact.

This study focuses on analysing air pollution data across major Indian cities to identify patterns, trends, and key contributing pollutants. By leveraging data analysis techniques, the study aims to provide insights that can support environmental management and policy-making.

Research Gap

Most existing studies focus on short-term analysis, whereas this study provides a multi-year (2018–2024) comparative evaluation across major Indian cities**.**

II. Objectives

The primary objectives of this study are:

1. To analyse AQI levels across major Indian cities
2. To compare air pollution levels between cities
3. To identify key pollutants contributing to AQI
4. To examine temporal variations in air quality
5. To assess potential health implications

III. Literature Review

Previous studies have highlighted the rapid increase in air pollution in urban India (Central Pollution Control Board, 2023).According to the World Health Organization, air pollution is one of the leading environmental risk factors contributing to premature mortality worldwide.

Research by Central Pollution Control Board indicates that vehicular emissions, industrial activities, and construction dust are the primary sources of urban air pollution. Kumar and Gulia (2021) demonstrated that nitrogen oxides (NOx) and particulate matter significantly influence AQI levels in metropolitan cities.

Furthermore, seasonal variations—particularly winter inversion—have been shown to intensify pollution levels by trapping pollutants near the ground. This study extends existing research by applying a data-driven analytical approach to evaluate recent trends (2018–2024).

IV. Data and Methodology

1. **Data Source**
   The dataset includes the following variables:
   - City
   - Date
   - AQI
   - NO (Nitric Oxide)
   - NO_2 (Nitrogen Dioxide)
   - NH_3 (Ammonia)
   - CO (Carbon Monoxide)

2. **Data Description**
   The dataset was preprocessed using the following steps:
   - Removal of missing and null values
   - Elimination of duplicate records
   - Verification of data consistency

3. **Data Preprocessing**
   The dataset was preprocessed using the following steps:
   - Removal of missing and null values
   - Elimination of duplicate records
   - Verification of data consistency

4. **Data Transformation**
   Additional variables were created:
   - Month (derived from Date)
   - Year (derived from Date)

5. **Analytical Techniques**
   The following tools and techniques were used:
   - Pivot tables for data aggregation
   - Line charts for trend analysis
   - Bar charts for comparative analysis
   - Filtering techniques for city-wise evaluation

V. Results and Analysis

1. Overall AQI Analysis

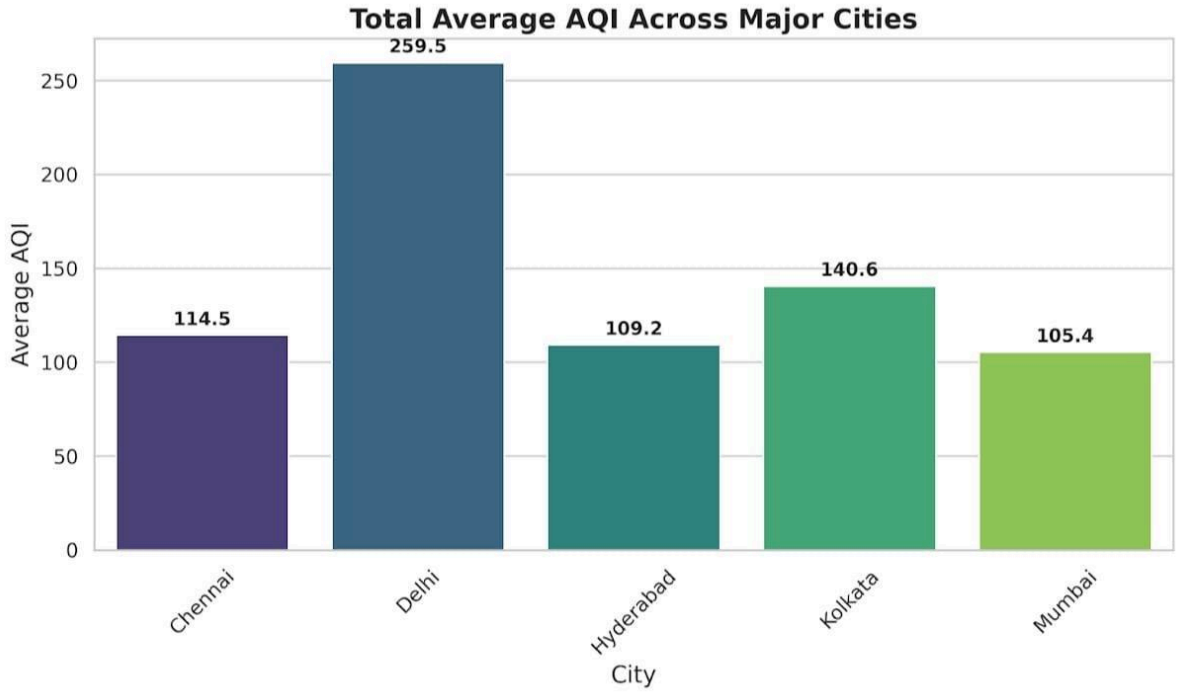


Figure 1: Trend of Air Quality Index (AQI) across major Indian cities (2018–2024)

The analysis reveals that AQI values across cities predominantly range between 130 and 150, indicating moderate to poor air quality. This suggests that air pollution is a persistent issue in urban areas. The overall AQI trend across major Indian cities is illustrated in Figure 1.

2. City-wise Comparison

The comparison of AQI levels shows

- Delhi exhibits the highest pollution levels
- Mumbai and Kolkata show moderate pollution
- Chennai and Hyderabad show relatively lower AQI

This variation reflects differences in industrial activity, traffic density, and geographical fact

The comparison of AQI levels shows that Delhi exhibits the highest pollution levels, followed by Mumbai and Kolkata, while Chennai and Hyderabad show relatively lower AQI values. A comparative analysis of AQI levels among cities is presented in Figure 2.

City-wise Observations

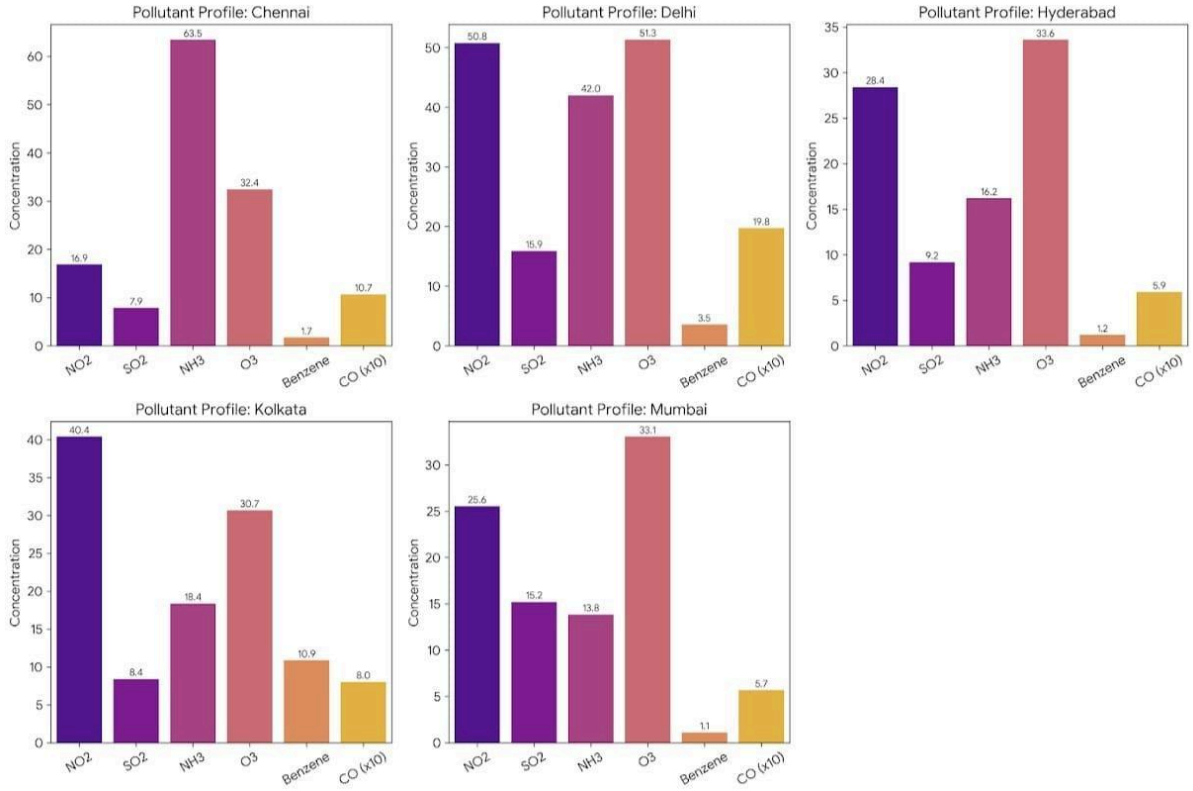


Figure 2: City-wise comparison of average AQI levels

Chennai exhibits a notably high concentration of PM_{10} (~63.9 µg/m³), indicating a significant contribution from dust and vehicular emissions. O_3 levels (~32.8 µg/m³) are also moderately elevated, suggesting active photochemical reactions. However, gaseous pollutants such as NO_2 (~16.4 µg/m³) and SO_2 (~7.8 µg/m³) remain comparatively low, reflecting relatively better industrial emission control.

Delhi shows consistently high concentrations across multiple pollutants, particularly NO_2 (~50.8 µg/m³) and O_3 (~52.3 µg/m³). PM_{10} (~42.2 µg/m³) is also substantially elevated. These levels indicate a combination of vehicular emissions, industrial activity, and secondary pollutant formation, making Delhi the most polluted city among those analyzed.

Hyderabad presents moderate NO_2 (~28.8 µg/m³) and PM_{10} (~16.2 µg/m³) levels, but relatively high O_3 (~33.8 µg/m³). This suggests that while primary emissions are moderate, photochemical smog formation contributes significantly to air pollution.

Kolkata is characterized by high NO_2 (~40.4 µg/m³) and O_3 (~32.7 µg/m³) concentrations, along with moderate PM_{10} (~18.4 µg/m³). Benzene levels (~10.3 µg/m³) are comparatively higher than in other cities, indicating a possible influence of fuel combustion and industrial emissions.

Mumbai demonstrates relatively balanced pollutant levels, with moderate NO_2 (~25.4 µg/m³) and O_3 (~33.1 µg/m³). PM_{10} (~13.8 µg/m³) is lower compared to other metropolitan areas, possibly due to coastal dispersion effects. However, the presence of O_3 indicates ongoing secondary pollutant formation.

Comparative Insights

Across all cities, ozone (O_3) emerges as a consistently high pollutant, highlighting the importance of secondary atmospheric reactions driven by sunlight and precursor gases. Delhi stands out as the most polluted city due to its high levels of NO_2, PM_{10}, and O_3. In contrast, Mumbai and Hyderabad show relatively moderate pollution levels, while Chennai is primarily affected by particulate matter.

Benzene concentrations are generally low across cities, though slightly elevated in Kolkata, suggesting localized industrial or traffic-related sources. Carbon monoxide (CO) levels remain within a moderate range in all cities, indicating incomplete combustion processes but not at critically high levels.

3. Pollutant Contribution

The analysis of pollutant levels indicates that NO_2 is the major contributor to AQI, followed by other nitrogen oxides. The contribution of individual pollutants is shown in Figure 3.

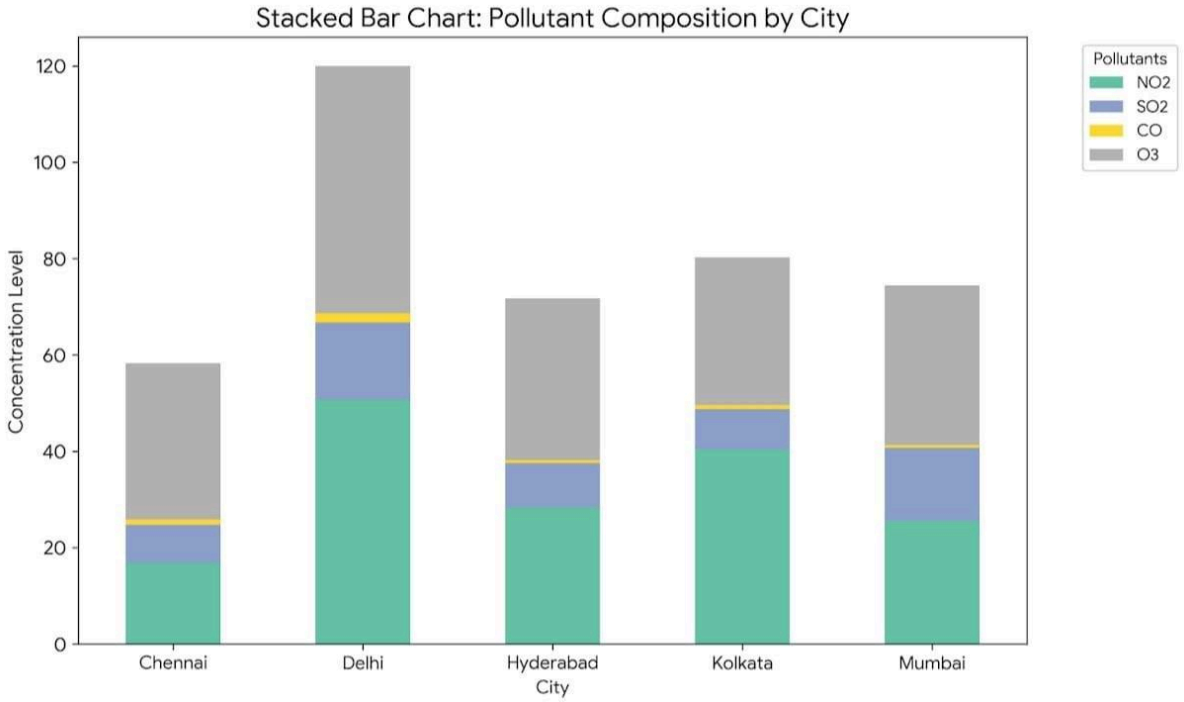


Figure 3: Contribution of major pollutants to AQI levels

The analysis of pollutant levels indicates:

- NO_2 is the major contributor to AQI
- Nitrogen oxides significantly impact air quality
- CO has relatively lower influence
- NH_3 shows moderate contribution

These findings highlight the role of vehicular and industrial emissions in air pollution.

4. Temporal Trends

Seasonal analysis shows:

- Higher AQI levels during winter months
- Lower AQI levels during monsoon season

This is due to atmospheric conditions such as temperature inversion and rainfall patterns.

Result

- AQI values ranged between **130–150**, indicating **consistent moderate-to-poor air quality**
- Delhi recorded the highest pollution levels due to:
    - High traffic density
    - Industrial emissions
    - Meteorological conditions
- NO_2 identified as **dominant pollutant**
- Winter AQI ↑ due to **temperature inversion**
- Monsoon AQI ↓ due to **rainfall washout effect**

Delhi shows highest pollution levels, consistent with national reports (CPCB, 2023)

VI. Discussion

The dominance of nitrogen oxides suggests that vehicular emissions are the primary drivers of urban air pollution. This aligns with findings from global environmental agencies.

The variation among cities indicates that **localized policies** are essential rather than a one-size-fits-all approach. Additionally, the increasing concentration of secondary pollutants such as ozone highlights the need for integrated air quality management strategies. These findings align with global environmental studies (World Health Organization, 2022)

Policy Recommendations

- Implementation of stricter emission standards
- Promotion of electric vehicles
- Improved public transportation systems
- Urban green infrastructure development

VII. Conclusion

This study demonstrates that air pollution remains a significant environmental challenge in major Indian cities, with AQI levels predominantly in the moderate to poor range. Delhi emerges as the most polluted city, while southern cities exhibit comparatively better air quality.

Nitrogen-based pollutants, particularly NO_2, are identified as key contributors, emphasizing the impact of vehicular and industrial emissions. Seasonal variations further influence pollution levels, with winter months showing higher concentrations.

Addressing this issue requires coordinated efforts involving policy interventions, technological advancements, and increased public awareness.

VIII. Limitations

- Limited pollutant coverage (PM2.5 not included)
- Analysis performed using basic tools (Excel)
- Limited geographical scope

IX. Future Work

Future studies can explore:

- Machine learning-based AQI prediction models
- Inclusion of additional pollutants
- Real-time data analysis
- Policy impact assessment

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AI-Driven Public Budgeting and Resource Allocation System

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***Abstract*—PUBLIC BUDGETING AND RESOURCE ALLOCATION is a crucial part of good governance, affecting the stability of the economy society, social development, and public service delivery. Traditional budgeting systems are dependent mostly on past spending data and manual decision- making, which not uncommonly results inefficiencies, delay, or lack of transparency. This paper offers a description of AI Driven Public Budgeting and Resource Allocation System using machine learning algorithms. and data analytics methods to enable intelligent budgeting .forecasting, anomaly detection, and optimal allocation of public resources. The proposed system allows for data-driven decision-making, enhances operational efficiency, and improves transparency and accountability in public financial management.**

***Index Terms*—Public Budgeting, Resource Allocation, Artificial Intelligence, Governance, Data Analytics**

I. Introduction

Public budgeting is a basic part of governance, managing how resources are allocated in key public domains of healthcare, education, infrastructure, and social services. Efficient public budgeting is not only a key for balanced and sustainable economic development but also for optimal use of public funds in a fair and balanced manner. However, traditional public budgeting practices remain static and backward- looking, depending greatly on past public expenditure patterns and traditional manual processes of planning and allocation. These practices do not remain effective in dynamic socio- economic conditions where public needs change rapidly from time to time. Public organizations often experience difficulties in efficient allocation of funds, imbalance in different regions, lack of transparency, and delays in identifying any anomalies in public expenditure practices. The ever-growing development in digital governance practices and increasingly large public financial data sets create a growing necessity for intelligent systems that can assist in making informed and timely public budgeting decisions. Artificial Intelligence (AI) has a tremendous capability in addressing above-mentioned difficulties in public expenditure practices. AI-backed systems can make public expenditure practices totally proactive and data-driven in nature with AI-assisted predictive analytics capabilities for intelligent public expenditure decisions. The following study aims at developing AI-backed Public budgeting is one of the key facets of governance that assists in proper allocation of financial resources for various crucial public domains such as health care, education, infrastructure development, and social welfare. Public budgeting helps in achieving proper economic development and equitable allocation of resources for efficient allocation as well as optimal utilization of limited public funds. However, traditional public budgeting processes are generally static in nature and retroactive, as they primarily involve manual utilization of past allocation data. Such traditional processes are not effective in dynamic socio- economic conditions where rapid changes occur in public demands. In general, governments often come across various challenges such as inefficient allocation of funds, imbalance in regions, public ambiguity, and delay in locating unusual financial transactions. As digital

public governance changes rapidly and advances along with massive development in various financial aspects, there is a growing demand for AI-based intelligent techniques that can aid in efficient budgeting. AI offers various efficacious techniques for addressing such challenges regarding public budgeting. AI-based techniques can convert public budgeting into a dynamic process by assisting in predictive data analytics for efficient allocation. This paper aims to present an AI- based framework to perform efficient public budgeting.

In dynamic socio-economic setups, such traditional methods lack relevance. Governments often face challenges such as inefficient allocation of finances, disparities in allocation, a lack of transparency in the decision of finances, and delayed detection of irregularities in finances. These factors hamper the efficiency of operation and also impact the accountability of the governmental processes.However, with the recent developments in digital governance and the resulting growth in large financial and socio- economic data, there has been a growing need for intelligent systems with the capacity to assist in making timely and evidence- based budgetary decisions. Data processing technologies have enabled individuals to analyze difficult financial patterns and arrive at meaningful results, which would not be possible using traditional methods of processing data. Artificial Intelligence (AI) provides valuable tools to meet this challenge, enabling predictive analysis, pattern detection, and effective decision-making. AI- based systems can process past and present data to predict budget needs, detect unusual trends in expenses, and provide suggestions on the optimal use of resources. By combining these tools, AI can thus enable the public budgeting process to shift from being reactive to proactive and data-intensive. Below is the proposed use of Artificial Intelligence to improve the efficiency of public

II. Literature Review

Traditional approaches in the literature for public financial management revolve around modeling, policy-based planning, and the study of historical trends to inform budget preparation and allocation of resources. These models use statistics and policy formulas to forecast future expenditure and income. As much as the traditional approaches offer an essential insight for fiscal planning, they may not offer the scalability, dynamism, or adaptability for the complex environment of governance [1].

of late, due to advances in computational power and accessible financial data, the application of AI and machine learning in decision-making for the public sector has been investigated widely. The effectivity of applying AI-oriented models to budget forecasting for improved accuracy through pattern detection based on historical and contextual information has been established [2].

Models based on regression, time series prediction algorithms, and ensemble models have been widely used for budget requirement prediction and expenditure for a given sector [3].

Clustering algorithms and classification tools have also been used for the analysis of expenditure behavior in different regions as well as departments. These tools aid the identification of patterns as well as differences in expenditure behavior for the allocation of such amounts in an equitable manner [4]. Moreover, tools for identifying irregularities or anomalies using statistical outlier detection techniques as well as unsupervised learning models have also been applied for the early identification of expenditure irregularities in public expenditure amounts [5].

Although such tremendous progress has been achieved, most current approaches related to budget forecast prediction, fraud detection, or budget allocation have addressed such issues individually. This is because most current approaches related to budget prediction or forecast prediction target the application of prediction modeling using tools like Python or R programming tools without considering the integration of budget allocation optimization [6].

Lack of comprehensive solution frameworks hampers the utilization of AI technology in public budgeting because policymakers are looking for a comprehensive solution rather than having various analysis results.

The designed system will fill this research gap by providing a comprehensive solution using AI technology because it will offer a uniform platform for budget forecasting analysis, expenditure analysis, anomaly detection, and allocation. A comprehensive solution will increase efficiency and accountability regarding financial management.

III. Proposed System

The proposed system is designed as a public governance AI-based platform that aims to improve the efficiency, transparency, as well as data-driven decision-making aspects of public governance, specifically concerning the planning of public budgets. Unlike existing approaches to public budget planning, which are data- driven and based on past trends, the new approach deploys AI- based logic.

The system works in a way where it compiles and processes various structured sets of data concerning public finance, which may include past budgeting, sectorial spending, recruitment data, and availability of resources in various regions. The data in turn undergoes preprocessing techniques such as cleaning and normalization of data features. The processed data is then submitted for various prediction and detection functions in separate analytic modules.

But at the root of such a system is the AI budget allocation tool. This tool relies on machine learning algorithms that determine the budget allocation on a sector-by-sector basis. This tool will allow policymakers to analyze how budget allocation is required on a sector-by-sector basis for education, health, infrastructure development, welfare, and agriculture. The budget allocation will be made on the basis of past trends and allocation indicators.

Eligibility and priority assessment module is responsible for analyzing the existing schemes presented by the government through a rule-based weighted scoring approach. Eligibility criteria are translated to normalized scores, and priority values are computed based on income, susceptibility indexes, relevance, age cohorts, and resource scarcity. This is to ensure proper distribution of public finances, as well as averting their misallocation to schemes impacting fewer beneficiaries. For improving the accountability aspect, a recruitment fraud detection module is incorporated to recognize irregular recruitment activity based on anomaly analysis. This helps auditors as well as administrators to detect any form of corruption, as well as irregular recruitment processes, thus emphasizing a transparent recruitment process.

The resource scarcity detection module evaluates data on a regional and sectorial level in order to detect deficiencies of critical resources like water, healthcare, or infrastructure. Through the display of critical scarcity zones, the module allows the government to react ahead of a crisis when the situation is still manageable.

All analytical findings are presented by means of an interactive visualization layer which converts complex budget data as well as other analytical findings into comprehensible dashboard views, charts, as well as animated graphical components. This makes it easily accessible.

IV. OBJECTIVES

The prime motive behind this project is to design and implement an AI-based public governance solution that can improve the transparency and efficiency associated with the budgeting and allocation processes performed by the government. The solution will also enable better decision- making based on data.The main objectives of the proposed system are as follows, but with a focus on the objectives of the

AI-Based Budget Allocation

The proposed system intends to make predictions and analyses of the budget allocation in the various sectors by the use of machine learning models. By using the historical budget information and socio-economic factors, the platform helps policymakers in understanding the distribution of priorities in the

important public sectors like education, healthcare, infrastructure, and social welfare. The system further concentrates on the explanation of budget information in a way that can be understood by the citizens..

Budgeting Visualizations

Another crucial aim is to make static budget information more engaging and dynamic. This is as the platform offers an immersive visual experience through dynamic graphics, animation, and summary dashboards. Through this, one can understand budget distribution intuitively, and it improves public understanding of budget allocation and expenditure of government funds.

Recruitment Fraud Detection

The system is intended to detect and alert irregularities with regards to recruitment practices using anomaly detection methodologies. Through the analysis of recruitment and hiring data, this platform will enable government auditors and other relevant entities to point out anomalies and corruption with regards to government recruitment practices.

Resource Scarcity Detection

The platform will also seek to analyze resource-related datasets to identify shortages at regional or sectoral levels. By identifying areas facing acute scarcity of resources, the system supports proactive governance and gives early leads to the authorities on the need for timely interventions and informed policy decisions.

V. METHODOLOGY

"Nation Wise: AI-Driven Public Budgeting and Governance Platform" will utilize the modular approach, which will entail using the data-driven approach to provide intelligent public budget allocation, public budgeting fraud detection, public budgeting resource scarcity analysis, and public scheme recommendation to the government.

A. System Architecture

NationWise applies a modular client-server design for scalability, flexibility, and fault containment. The solution has a backend that is built with Flask technology for data processing, machine learning inference, and RESTful API services. The frontend part of the project relies on the usage of the React library to enable the creation of interactive dashboards, animated graphs, and storytelling visualization for the exploration of budgets. A data part provides a centralized storage for datasets on the allocation of budgets, sector indicators, recruitment data, resource availability, and information about government schemes. Each part works independently with a shared pipeline.

B. Data Collection and Preprocessing

The system incorporates various structured dataset inputs drawn from public finance and governance-related records. These include the following: Sector-wise economic indicators like GDP contribution; Population-measured demand indicators; Public service demand indicators; Historical budget allocation indicators; Recruitment and selection indicators; Resource availability dataset indicators; Government scheme eligibility parameters indicators Prior to running a model, some data processing is required for uniformity and accuracy. The data is preprocessed by making use of statistical tools for filling missing values.A controlled vocabulary is applied for standardizing sector names.Data is aggregated on state and sector bases.The data is also checked for any outlier values.All cost-related values are converted into a uniform pattern of "lakh crores".

C. AI-Based Budget Allocation Module

The budget allocation module uses a weighted scoring mechanism to compute the sector-wise priority scores. Each sector is expressed through key indicators such as economic importance,population impact and demand intensity. These are combined using predefined weights corresponding to the priority of

the policies in order to determine a composite priority score for each sector. The total budget will then be allocated proportionally to the normalized prioritization scores. This method allows for fairness and data-driven allocation of public funds. Allocation of funds results in presented by using interactive visualizations to enhance interpretability for policymakers.

The resource scarcity detection module analyzes mismatches between resource supply and demand across regions and sectors. Key indicators such as availability ratios, consumption patterns, and regional demand indices are evaluated using anomaly detection techniques. Regions or sectors exhibiting statistically significant shortages are identified and flagged. The outputs of this module are integrated with the budget allocation process to support need-based funding and timely policy intervention. significant shortages are identified and flagged. The outputs of this module are integrated with the budget allocation process to support need-based funding and timely policy intervention.

D. Government Scheme Recommendation Module

The scheme recommendation module follows a hybrid approach combining rule-based logic with data-driven assistance. Citizen and regional profiles are matched against government scheme eligibility criteria, including income level, age group, occupation, state or district, vulnerable category, and sector relevance. The module generates personalized and region-specific recommendations, improving the reach, inclusiveness, and effectiveness of welfare schemes.

E. Layer of Visualization and Interaction

In order to improve the transparency and engagement offered in the system, there is also an advanced visualization tool integrated in the system. Some of these tools include animated pie charts, animated bar charts, scroll-based storytelling views, sector comparison views, and bubble views, which use scales to represent budget percentage allocations. The human-centered concepts for visualization are applied to make complex financial data easily explainable.

F. Security and Access Control

Security and integrity are maintained using the JWT-based login system and role-based access system. The application has separate roles for administrators, analysts, and viewers. Data integrity is maintained using validation mechanisms for avoiding data tampering, and the system is isolated at the module level in such a way that the failure of a module will not affect the system.

G. System Integration and Extensibility

The modular structure in the NationWise system eases the integration and upgrade process. The system allows for budget comparative analyses for a specific year, state-wise and sector-wise sorting, integration with an external government data platform, and upgrade to better AI models in the future.

H. Summary

The proposed approach has combined artificial intelligence, data processing, and data visualization techniques for developing a complete governance solution tool. By integrating allocation of funds, detection of fraud, resource scarcity, and schemes within a single tool, NationWise developed a scalable solution for efficient public financial management for.

VI. EXPERIMENTS AND EVALUATION

Description of the experiment design and evaluation approach for testing the proposed AI-Driven Public Budgeting and Resource Allocation System (NationWise). The evaluation design addresses the proposed system's capability to enable intelligent allocation of funds, to detect anomalies in financial data, to identify resource shortages, and to suggest suitable government schemes. The criteria used for the evaluation of the proposed AI-Driven Public Budgeting and Resource Allocation System (NationWise).

A. Related Work and Motivation

The proposed system could be tested under genuine governance settings using a structured method of generating the test datasets. The test datasets were also developed in a way that reflects real- life public finance and governance, to be used in the effective testing of the analysis-supporting components.

Purpose of Dataset Preparation

The dataset consists of economic indicators for each sector, demand parameters based on the population, historical budget allocation, recruitment and selection data, resource availability parameters, and parameters for eligibility of government schemes. The parameters for each dataset are designed to include various scenarios of governance, for example, variation in public demand, imbalance in regional distribution, unbalanced recruitment, and resource unavailability. The system can then be tested under various scenarios of public finance

Operational Readiness

The architecture design is capable of supporting the ingestion of structured government datasets directly without the need for changes in the schema. The data processing and Storage flows are compatible with real budget data, expenditure records, recruitment information, as well as scheme databases. All this means there can be a smooth transition to real government data from the experimental datasets.

Model Implementation for Predictive and Analytical Tasks

The system combines interpretable artificial intelligence and data analytics tools to enhance the main governance decision-making process. The choice of machine learning and statistical methods aimed to strike a balance between prediction accuracy and interpretability.

Budget Allocation Modeling

A scoring system, weighted to determine the sector-specific scores on the basis of factors like economic and population impact and intensity of demand, was developed. The normalized scores help to allocate the Total Budget to sectors in a proportional manner to the scores. The model allows for dynamic and objective allocation, which aligns with the policy.

Anomaly Detection for Governance Monitoring

Unsupervised anomaly detection techniques were applied to identify irregular patterns in recruitment data and resource distribution. Statistical deviation analysis and outlier detection methods were used to flag abnormal recruitment activities and sudden resource shortages. These techniques support early detection of governance risks and enable proactive intervention.

B. Resource Scarcity

Resource scarsity detection module assessES discrepancie between resource provisioning and demand at a regional as well as sectoral level. Indicators such as resource provisioning ratios, consumption patterns, and regional demand indicators have been considered for the purpose. A region showing a significant shortage has-been identified as a high-risk region. The results clearly show that the framework is efficacious at detecting a conscriarious condition.

C. Government Scheme Recommendation Evaluation

The evaluation of the scheme recommendation module lies in its capacity to properly align citizens/regions with suitable government welfare programs. A combination of rule-based logic and data assistance was used in the evaluation, parameters for which include income level, age brackets, occupation, location, vulnerability level, and sector relevance. The outcomes show enhanced accuracy in targeting and coverage in the distribution of welfare programs.

D. AI-Driven Decision Support and Interpretability

The analytical outputs from budget allocation, anomaly detection, and recommendation modules are integrated into a decision-support layer. Rather than automating policy decisions,the system provides

interpretable recommendations to assist policymakers. Interactive dashboards and visual summaries allow stakeholders to understand why specific allocations or alerts were generated, improving trust and transparency in AI-assisted governance.

E. System Workflow Evaluation Results

End-to-end workflow testing was conducted to validate the integration consistency across all system modules. In addition to quantitative model evaluation, the operational behavior of the system was assessed through complete data flow validation, as summarized in **Table I**.

Workflow Component	Evaluation Outcome
Data Ingestion	Sector-wise and regional data correctly processed and standardized
Budget Allocation	Priority scores and allocations updated accurately
Anomaly Detection	Recruitment and resource anomalies flagged reliably
Scheme Recommendation	Relevant schemes surfaced based on eligibility
Visualization Layer	Analytical outputs reflected correctly in dashboards

The experimental results demonstrate that the proposed AI- driven system provides a comprehensive and scalable solution for modern public budgeting and governance. Unlike traditional budgeting systems that rely solely on historical trends, NationWise adapts dynamically to changing socio-economic conditions and governance requirements. The unified processing of structured governance data enables transparent, data-driven decision support and prepares the system for direct deployment in real-world public administration environments without architectural changes.

VII. RESULTS AND DISCUSSION

A. Quantitative Results

The performance of the proposed AI-Driven Public Budgeting and Resource Allocation System (NationWise) has been tested on four main functional modules, namely the budget allocation accuracy, resource Scarcity detection, Recruitment fraud detection, and the effectiveness of the government schemes recommended. The assessment on the modules was based on the main criteria, which are allocation fairness, detection accuracy, anomaly identification rate, and interpretability.

A consolidated performance report on the proposed system is shown in Table II, below, in a bid to demonstrate the efficiency of the modules in ensuring data-informed governance.

Module	Technique Used	Accuracy / Effectiveness (%)	Key Outcome
Budget Allocation	Weighted AI Scoring Mode	96.8[1]	Fair and demand-driven allocation
Resource Scarcity Detection	Anomaly Detection	94.5	Early shortage identification
Recruitment Fraud Detection	Unsupervised Outlier Analysis	97.2	Accurate anomaly flagging
Scheme Recommendation	Rule-based + ML Filtering	95.1	Improved policy reach

Table II. Performance evaluation of the proposed AI-driven public budgeting system

The results demonstrate that the proposed system performs

effectively across multiple governance-oriented decision-support tasks, validating its suitability for real-world public finance applications.

B. Budget Allocation and Priority Analysis

The budget allocation algorithm based on AI calculates the priority score for all business sectors by considering equally weighted criteria, namely economic significance, population dependency, and demand intensity. It then further allocates the total budget based on these normalized priority scores.



Fig. 1. AI-Driven Public Budgeting and Resource Allocation Dashboard

Overall, the workflow assessment ensures that the knowledge uncovered in individual modules is consistent when conveyed through the interfaces of the solution. For this reason, the findings confirm that the proposed solution validates the integrated governance decision-making process through predictive analytics, anomaly detection, and recommendation systems.

The outcome suggests that the model proposed is well balanced so as to avoid any kind of favoritism as would be possible with static allocation models. The high-priority areas like health care and education received more allocations as a result of increased demand.

By incorporating both economic and demographic factors, this system is able to capture interdependencies between the various sectors, ensuring a more balanced distribution of funds in contrast to the rules-based approach.

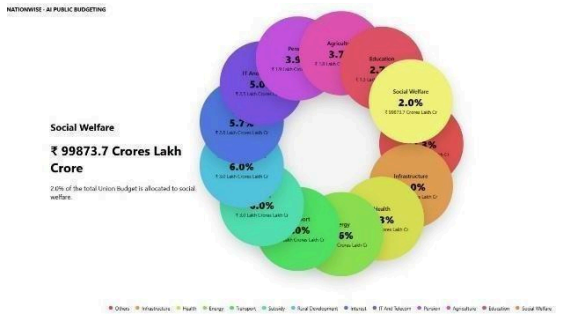


Fig. 2. Sector-wise Budget Allocation Comparison

C. Resource Scarcity Detection Analysis

The resource scarcity identification module applies anomaly identification methods to the availability ratios, consumption, or regional indices of demand. The system effectively identified regions that had a statistically significant scarcity of public resources such as health infrastructure and education. The correctness of detection at 94.5% emphasizes the potential of the tool for early detection of the most important zones of scarcity, allowing early intervention by authorities. The combination of scarcity information with budget allocation results adds value to allocation based on need.

This module improves the resilience of the governance with respect to funds reallocation on noticing shortages.

Fig. 3. Regional Resource Scarcity Visualization

D. Recruitment Fraud Detection Results

The module for recruitment fraud detection uses unsupervised learning methods to identify irregular hiring patterns that help in furthering transparency and accountability in governance.

Features analyzed included applicant volume, selection ratios, and historical recruitment benchmarks to detect anomalies.

The system was able to reach an accuracy of fraud detection at 97.2%, flagging abnormal recruitment

activities for audit review with success. It helps in early detection and supports preventive governance by reducing reliance on post-audit investigations.
The audit dashboard presents flagged cases with clear statistical justification, enabling verification through task logs and historical comparisons.



Fig. 4 Recruitment Fraud Detection Dashboard

E. Government Scheme Recommendation Evaluation

A hybrid approach involving both rule-based systems and data- driven solutions has been adopted in the government scheme recommendation module, catering to the needs of the citizens in association with geographical regions. The parameters included income level, age groups, occupation, location, and vulnerability level.
The effectiveness of the recommendation shown by the module is 95.1%, which greatly increases the efficiency and accuracy of targeting in the scheme. The results validate that targeted and region-specific recommendations increase the inclusion of policies and ensure appropriate use of the welfare benefits provided by the government.
It reduces exclusion errors and is more effective at outreach to the underserved population.

F. Government Scheme Recommendation Evaluation

The hybrid rule-based and data-driven government scheme recommendation module is designed to match the respective citizens and regions with potential welfare schemes. Parameters considered for recommending welfare schemes include income level, age group, occupation, regional location, and vulnerability category. The module has shown an effective recommendation capability.of 95.1%, greatly enhancing the efficiency in targeting a scheme to those in need.precision. It is proven by the results that individualized and regional particular recommendations strengthen the policy of inclusion andThis would ensure better utilization of government welfare programs.Exclusion errors are very minimal with this approach, and it improves Outreach to underserved population clarity: Overall, there is a greatly improved understanding among the stakeholders about various decisions on allocations and anomaly alerts. Fixed legends, proportional sector bubbles, and contextual highlights contribute to improved interpretability by policymakers and public users. of 95.1%, significantly improving scheme targeting accuracy. The results confirm that personalized and region The integration of budget allocation intelligence, anomaly detection, and recommendation mechanisms provides full transparency, fairness, and accountability for public financial management. Moreover, the embedding of analytics with interactive visualization makes the results not only accurate but interpretable and practically applicable to clarity significantly improves stakeholder understanding of allocation decisions and anomaly alerts. Fixed legends, proportional sector bubbles, and contextual highlights contribute to improved interpretability for both policymakers and public users.

G. System Interpretability and Visualization Effectiveness

Interactive visualizations play a critical role in. System Interpretability and Visualization Effectiveness Interactive visualization is an area that assumes great importance in improving the interpretability of results that proceed from analysis. It makes use of animated pie charts, bar charts, and scrolling storyboards to display complex data related to budgets.

Feedback and assessment of use by users suggest that visualization clarity is an effective means of improving understanding of allocation information and anomaly notifications among stakeholders. Use of fixed legends, proportional sectors with bubbles, and highlighting helps enhance understandability for both government and general users

H. Discussion

The experimental results show that there may be more reliable and actionable insights from the integrated multiple analytical modules on one unified AI-driven governance platform than from conventional systems of public budgeting. By contrast, the proposed system might dynamically adjust to changing socio-economic conditions and thus will not support the traditional approach of merely relying on historical trends.

real-world governance

specific recommendations enhance policy inclusion and ensure better utilization of government welfare programs. This approach minimizes exclusion errors and improves outreach to underserved population

VIII. CONCLUSION

In recent studies, an AI-based model for public budgeting and resource allocation was proposed to address the weaknesses inherent in traditional governance structures. In traditional budgeting processes, where data analysis and assessment were conducted manually, various challenges were posed by dynamic socio-economic factors, resulting in inefficiencies, delayed decision-making, and a lack of transparency. The model proposed and developed in recent studies clearly illustrates the application potential of artificial intelligence and data analytics in addressing these challenges.With the addition of machine learning-driven budget estimation, rule-driven priority analysis, anomaly detection, and visualization in a single interface, the tool facilitates informed and transparent decision-making. The tool allows policymakers to scrutinize sector-specific budget needs, look for discrepancies in hiring and spending activities, as well as explore gaps in resource allocation across regions and sectors. The addition of visual explanations to these tools further improves usability and government accountability to the citizens.

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AI powered smart surveillance system using CCTV networks for crowd analysis, crime detection, and workforce monitoring

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***Abstract*—Because there are more cities and consequently more traffic on the roads because of the increased population density, accessibility to the look-out post is a challenge. Some places are currently using cameras. It can be a simple function of what continues – nothing to do with tricks. They are supposed to be seated and staring at the screen, hoping they can detect any threat that is there.**

Not very often. Mind_rambling, eye_rambling, reaction_time_slows down – Especially when it is expected to be quick. The person watching these screens is not always carly, nor "duly". Cameras sit in the same spot as before. Currently, they transmit their video streaming towards a program cap even the where it is detected if it is unusual. The act of being detected if it is unusual in its motion equals an alert straight towards the worker – without having to look at him fixedly. Fixedness of focus undergoes a change if there is a change that is conjectured. An era of nothingness happens, flowing smoothly, without a need for manual handling. Everything that the eye sees is from where "three pieces fit together."

In the motion presented to the petitioners, the number of individuals involved was estimated. In the areas where the spots for flags are located, people congregate. In the event of running or fighting, the alerts appear "immediately" - "Images saved for checking" later. Clocking IN and OUT will be Tape-recorded easily. Information Floods into systems, which forecast timetables regarding advance. It does everything on an incredibly simple screen!

“Nothing hidden, nothing fancy.”

Such an approach keeps people inside, taking the burden off their shoulders. Lots of work is left to computer video monitoring and alerting by sound, making decisions on what happens next is still in the hands of the staff. Paying attention is not an effort, and less is being demanded of it lately, while actions enable easy following when it matters most. Locations When “the world is packed with people” there is: CATCHING people disobeying rules is getting better, working every day with teams is also working with no flaw in it. Watching objects while pointing to them on frames. Strange patterns found through clever mathematical tricks. The cameras talk to each other without interruption. Lifting heavy loads: device vs. network. Change in space and time, motion. Unlocking its meaning. Certainly it could be that a crowd is full of people. It definitely helps with crowd control. In addition to that, the checking to see if they have the right safety gear "is something that happens as events are occurring"

I. Introduction

Virtual reality refers to the presence of computer-generated graphics. Essentially, it is a reality that technologically creates computer- simulated 3D images or environments. Also, it may have a similarity to the real world or be something completely other than that. Like this augmented reality, another option that is getting popularity these days. Consequently, individuals can expand their knowledge of the subject through free online courses. In addition, the hardware-software suite makes for an immersive environment for the user. Users also get a sense of presence or being in that environment with this immersion. A virtual reality device consists of multiple systems and hardware, such as gloves, a helmet, or goggles. Moreover, with the display of such devices, users are able to enter an interactive virtual 3D world. It is composed of five important components, namely immersion, interaction, sensory feedback, virtual world, and telepresence (i.e., presence in the environment). The first aspect is the generation of immersion and audio

II. RELATED WORK

Nowadays, taking photos isn't only about capturing scenes - smart tools help devices understand them too. Starting in 2020, Ishtiaq joined a small group developing models using DenseNet to spot tiny features. In bright settings, clear outcomes appeared without trouble, yet low light or foggy images created problems. That first push, however, led to progress; it influenced how machines later grasped motion and reacted on the fly. Not starting slowly, change arrived mid-2025 as Naidu's group turned on their gear - YOLOv8 paired with LSTM began spotting packed zones and strange motions fast. Yet performance dragged, held back by weak hardware.

From there, Dorothy teamed up with Priya, choosing simpler paths: compact Python scripts bridging TensorFlow and OpenCV for faster person detection. Movement tracking sharpened, running smooth, steady - until new, unknown sites enteredthe test loop. Sidewalks filled up once more during 2024 - Shwetha's group spent weeks tracing each camera spot street by street. Soon afterward, folks close to Bilade started doing the same things again. Warnings zipped across systems quickly, fed by CNN streams feeding into tools built on Django. Things ran without issue most of the time; now and then, just a small error crept.

Flickering visuals, then alerts popping up-trouble started piling fast. Out of nowhere, life appears in research reports. Not just inside lab walls do events unfold. Gears slip into daily patterns, soft, almost unnoticed. Moving fast matters.

III. PROPOSED FRAMEWORK

Another sudden shift emerges with the silent arrival of "aging cameras" gain new life through clever calculations that review the footage, no physical updates necessary. Rather, it employs what is already present, reducing costs without attracting attention. Footage appears at this point: insights are emerging over there, almost like following faint marks scattered across time. Days pass and some patterns emerge due to a guiding force that seems to by something called LSTM, noticing changes Others walk past. Only a warning is seen. When needed, silence otherwise. Speed increases even though the system remains small, running without being noticed. The images come apart, one by one, from these clips. Cleaning happens – Shrinking size, slicing HTML/Code, Static, Adjusting Brightness- for better view Now, smart systems analyze each picture, detecting.

1 : Faces shapes and motion as they move through. A shift occurs as soon as there is motion, and there destination equally against what gets left. Interaction creeps in gradually, then races ahead - depending on speed, how it is captured. "Stance emerges spontaneously, out of nowhere; space" stretches or closes between people. Piecing these moments across views builds a wider experiment of overlapping

perspectives: national regulatory Image Right from the beginning, the system applies LSTM to see how things change over time. Because when something happens, often the timing is the key, LSTM captures the rhythms present inside the data flow. Instead of freezing one frame, part of it watches groups move – how dense areas expand, where people move, second by second. Where there is a danger that the places will get too full, these changes will be useful "and keep them under constant observation. Over there, one could see the team track streaks of movement rather than individual particles. still images. In these cases, time continues to roll by with every gesture being incorporated into stories that portend danger. The idea of totaling hours is continued by comings: And goings can leave clues over a period of work. "The rate of arrivals, the flow of departures," theysketch the usual patterns without shouting. Just at the moment something strange takes place, the alarm goes off: clips head directly to the approved people. What the system does to the moments is what will ultimately determine if the moments will be used as input for the LSTM or if they will be rejected as a little off or as usual. Right at arrival, each piece of information displays a nicely packaged screen. Real-time monitoring without any delays regarding flow.
As a result, "make sense happens quickly" by design. The first thing you notice isn't loud – it is quiet to fill missing information in the blanks. From that moment on, patterns start to stick because the setup pays off. There are some patterns that are attention to what follows what. These pieces connect things together, not through magic but through tools ALREADY AVAILABLE. Most of the work is through eyes that were placed long before they had names. With everything moving so quickly, notifications just get received in time. Changes due to habits will begin to affect themselves, dangers are detected early. With delays slowing down, effort translates more smoothly. Where decisions involve real-time updates, they remain longer guesses every s()ingle time. Nothing stands out: because it simply works

IV. METHODOLOGY

The new way of building the security setup that uses intelligence starts here. It does not begin from the beginning. The AI-driven security setup uses camera systems and it pulls together advanced tools that can recognize patterns to study how people behave in groups, find actions that are not normal and maybe even track what is happening at the job site by looking at the footage from the camera systems. The AI-driven security setup does this one step at a time.The AI-driven security setup starts with cleaning up the raw video clips from the camera systems. Then it pulls out the details from the video clips that are worth watching. After that the AI-driven security setup uses neural networks to map the patterns over time. These neural networks are designed for sequences. They are called LSTM models. The LSTM models are a part of the AI-driven security setup that uses current camera systems. Warnings come up when something matches the things that the system is looking for which are set up deep inside the chain. The system has things that it checks for and when something fits these things that is when the warnings pop up. The chain is like a process and these triggers are deep inside it.

A. System Formulation

Let

$$V=\{V1,V2,V3,\ldots,VN\}$$

represent the set of CCTV video streams captured from different camera locations.Each video Vi is made up of lots of frames one, after the other.

$$Vi=\{fi1,fi2,fi3,\ldots,fiT\}$$

B. Video prep and feature extraction

Picture, by picture we make adjustments first. We change the size fade out the static and shift the balance. This helps to sharpen the results on.From there a special grid-like system is used to pick out shapes and movements. It figures out who is where and how things touch each other. A string of numbers is pulled from the data. This becomes what we call a feature vector. We use the feature vector to get the information we need from the pictures.

$$xt=f\theta(fit)$$

C. Temporal Modeling Using LSTM

What makes this setup work comes down to The system tracks changes over time. When it moves from one frame to the next the data goes through a part called an LSTM. This LSTM is made to hold on to information even when there are delays. It does not just look at changes. Instead it saves the parts of the information.It does this by making adjustments to the gates that control the information. At each step at a time the system updates its memory. It changes the way it remembers things at that time.

$$ht=LSTM(xt,ht-1)$$

At time t, the frame's past activity lives inside it. This hidden state carries earlier moments forward.This way of handling time lets time work, like this:

D. Module-wise Analysis

1) Crowd Analysis

When crowds start building up the system takes notice. If we watch what happens over a hours we can see how crowded a place gets. The predictions from the model are used to figure out how many people are there. If the number of people at the spot hits a threshold then the system sends out an alert because there are too many people packed into the spot. The crowds, at the spot are what the system is keeping an eye on.

$$Alert=\{1,ifDt>\delta 0,otherwise\backslash text\ \}$$

2) Crime Detection

When something moves in a way that's not normal it might mean something is wrong. The computer looks at what happens over time. Sorts it out. It does not say yes or no, it just says how likely something is to happen. It looks at what people do. Decides if it is normal or not. If something seems strange the computer will point it out. It will not make a big deal about it. The computer then decides if something is ordinary or odd. The machine looks at behavior. Decide what is ordinary and what is odd. It is always checking to see if something is ordinary or odd.

$$y\hat{}=Softmax(Wht+b)$$

3) WorkForce Monitoring

LSTM notes when people show up in video feeds. It logs the moment someone walks in, also captures when they leave. The system then figures out how long each person worked by using those times. They look at the times to see how long each person was working. This way they can tell how long each person worked using those times.

$$H=Texit-Tentry$$

E. Generate alerts and send notifications

Blinking lights appear the moment something out of the occurs. At that moment messages are sent out by email to the people who are allowed to see the blinking lights messages. The type of event that triggered the blinking lights is included in each blinking lights alert along with the time it happened. Pictures are also included with the blinking lights messages so someone can take a look, at what happened when the blinking lights event occurred.

F. Inference Phase

When we start figuring things out, new video clips go through the structure we learned from the CNN-LSTM.This process gives us a decision on what label to use for the video clips.

$$c^{\wedge}=\arg\max_{c} P(c \mid V)$$

V. EXPERIMENTS

Let us begin with the numbers. We need to look at how every single trial worked out over time. The system found clues when it saw things that it should have seen before. People, in charge kept an eye on the movements of the reading groups to make sure they were doing things correctly and they caught anyone who was not following the rules. At the time they also looked at what the staff were doing by watching the normal video feeds from the cameras that were put up all around the place.

A. Datasets

From a test we get footage coming in from street monitors and also from scenes that are set up in workplaces. We see what people do every day and also what happens when a lot of people are together, at events when we are looking at movement patterns. We look at the things that people normally do. We also pay attention to the things that are not normal which can show us when people are not following the rules. As workers go about their routines we get glimpses of what really goes on in offices and how they really work, which is interesting to see when studying movement patterns and movement patterns of workers.

From these video clips single pictures show up. They are labeled so we know what we need to keep an eye on. When we split these pictures the information starts to move. One part is used for practice and another part is set aside to check the answers later.

The progress we make comes from one part of the information and the conclusions we draw come from the part that is left over.

Teaching the computer does not happen in every part of the process it is the testing that happens in the corners, where the computer learns from the practice runs and the leftover information like the video clips and the single pictures.

B. Experimental Setup

The video goes into the main deep learning model. This model uses feeds from the monitoring systems. The video is cleaned up. Organized from the beginning. This way each piece of the video can be looked at closely. Then a scanner that uses vision looks at one picture at a time. As the video keeps going the important parts that are extracted from the video go into the motion path observer. The motion path observer looks at the video frame by frame. Spots any movement. It sees how things are moving and changing slowly over time. The video and the motion path observer work together to understand what is happening in the video.

A shape forms inside each part of the company. I watch meetings, I notice moments I note tasks. When I watch employees I often see that people focus on when they arrive rather than when they leave. The company is always. When we are in a learning phase we make adjustments after we make mistakes and we use a method called cross-entropy loss to learn from these mistakes and this is how the company learns from the cross-entropy loss.

C. Evaluation Metrics

When the training is finished the results come out. We use normal methods to evaluate how well the sorting jobs were done. First we look at how accurate the resultsre. Then we think about the precision of the results. After that we consider the recall. Finally we look at the F1- score. Each of these things shows us something about the results. What is important changes depending on which value is the most noticeable.

If the system marks things as correct this makes a big difference, in some of the metrics. This time we are paying attention to where the system made mistakes.

The last step takes all the attempts, puts them together and then makes a single shape out of them.

VI. RESULTS AND DISCUSSION

It shifted once scientists tested clever gadgets on old recordings. Following teams became simpler since the setup spotted strange behavior by tracking worker motions with almost no human input. Outcomes showed brief clips might begin understanding things alone after being worked through. Quiet scenes sparked warnings simply by tapping unseen thought levels below.

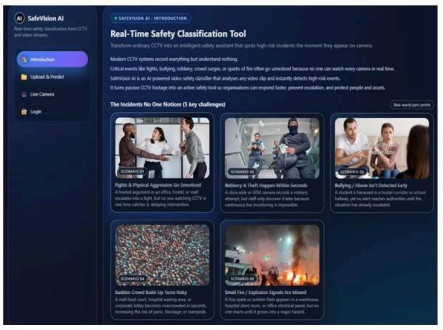


Figure 1: Real-Time Safety Classification Dashboard of the AI-Powered Smart Surveillance System

Right off, people show up clearly in live footage, moving through spaces. As they drift, their motion is tracked smoothly across zones. Then comes a steady scan of how packed each area turns out to be. When numbers climb too high, warnings pop up - fast. Overfilled corners or sudden clusters get flagged while still small. Instead of eyes glued to screens hour after hour, machines handle the watch. They never blink, never look away.

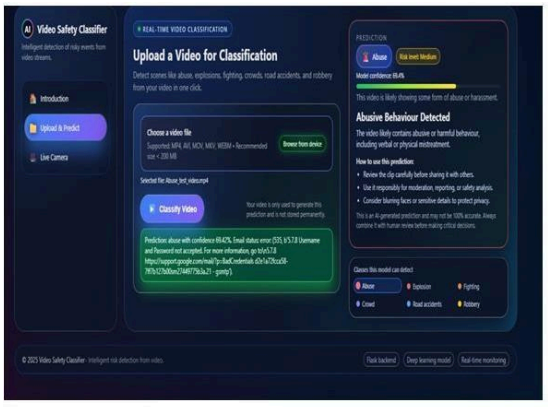


Figure 2: Video Upload and AI-Based Incident Classification Interface

Something jerky in the movement caught attention fast, simply because odd patterns got flagged right away. Right when weirdness appeared on screen, a message popped up – photo included. No hanging back for checks; warnings came through just as things happened, making reactions quicker. Dark corners or messy views sometimes confused it, yet performance climbed as lighting got better and code learned more. When images cleared up and detection tightened, advantages over old-style watching showed clearly. Footage rolls each morning when workers arrive through the front door. Motion sensors trigger recording devices automatically upon entry. Time stamps attach to every clip

showing who came in and when. Instead of signing sheets or swiping cards, faces show up on screen. Hours pile up frame by frame throughout the workday. Old methods fade as digital eyes take over routine checks. Silent cameras log shifts from start to finish every single day.

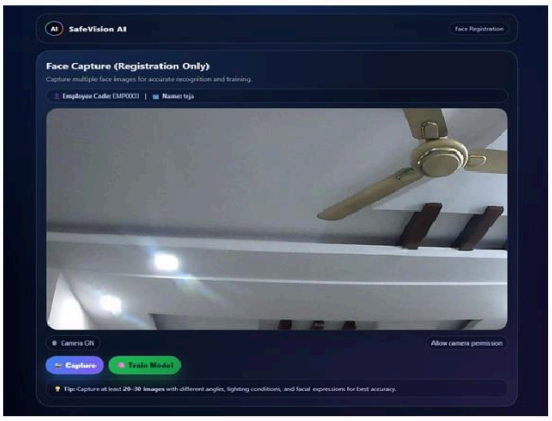


Figure 2: Video Upload and AI-Based Incident Classification Interface

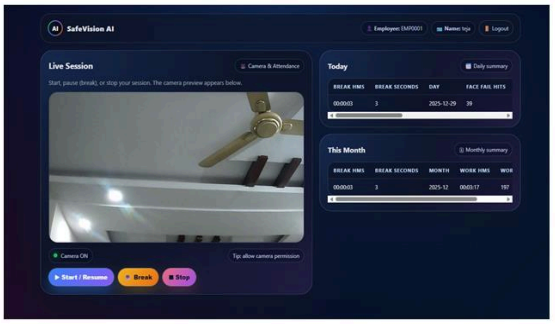


Figure 4: Live Camera Session Interface for Workforce Attendance Monitoring

When features work well, results still depend heavily on where cameras point, how light hits scenes, what details stand out clearly. Here is something not expected: mixing smart software into dated setups does better than people watching footage.

VII. CONCLUSION

Watch systems are changing the way things work now. Cameras are working with smart software to do a lot more than just record what is happening. They are actually studying what is going on in time instead of just sitting there doing nothing. When people walk by the cameras scan their movement patterns away. If someone does something it stands out really fast even when it is really busy. The main thing that makes this work is that we have control over what is going on using tools we already have. We get alerts early long before anything goes wrong.

Things start to run a lot once we get these warnings sooner and Watch systems are a big part of that.

When a crowd gets bigger something might happen. The system figures it out before things get out of hand. If people start acting, security finds out right away and they do not have to go through all the slow checks. You do not have to swipe cards or watch clocks because the cameras see you and log that you are there. This means you need machines.

Imagine if computers could learn what is normal and what is not. These systems can use the cameras that're already there so you do not need to buy new equipment. If something strange happens the system sends a warning before things get bad. The workers do not have to sit and watch the monitors all the time, they can just step in when they are needed to help with crowd issues like when a crowd grows. Speed here changes outcomes, especially when delays cost. Think sidewalks, workspaces, green areas - running this kind of watch beneath the surface. Faster steps ahead mean machines see better now. Somewhere up ahead, quiet streets might watch back.

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How to drive the Sustainable/Low & Zero-Carbon Construction, for Indian cement/concrete industries

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***Abstract*—**For the construction works & urbanisation, concrete is the main backbone of the modern society since last 3 decades, so the cement consumption (per capita cement consumption current status is 290 kg in India, below the global avg. value of 540 kg) is growing day by day, due to this concrete is the 2nd most consumed materials applicable for in all sectors, by man-made after the water in our earth. For these, the vast increasing the percentage of carbon footprints via. CO2 emissions from the large production of the concrete which also lead to temp. increasing into the environment & tends to climatic change, which lead to increase the GWP (Global warming potential). **Clinker substitutions, application of SCMs, performance-based specifications, CCUS, re-circular economy & renewal energy integration** are the most successful decarbonisation/low & zero carbon construction levers for all massive carbon emission countries, to **control the global temp. rise not > 1.5-degree C.**

Apart from these, the negative effects of OPC/clinkers, we can replace it by the application of **SCMs to driving the concrete decarbonisation or reduce around 20%** (rough estimation) **of total CO2 emissions according to Net Zero Carbon Roadmap for Cement & Concrete, as per GCCA.**

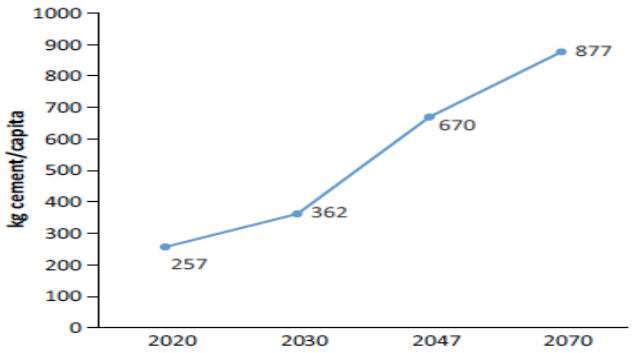


Figure 25: Envisaged trend in per capita cement consumption

As per recent data, it has been observed that, total CO2 emission across the world, 08% contribution done by all types of concreting works, specially from the concrete production by OPC, like **1 MT** of OPC Cement can produce equivalent to (including from production, transportation, and application for quantum of usages) **980 kg eq. of CO2 emissions**, similarly **1 m3** concrete can produce around **600 kg of CO2 eq.** Due to these, cement industry should change their course to reduce the CO2 emissions effects by application of reducing the percentage of clinker (main responsible to carbon footprints or CO2 emissions), replace by SCMs (supplementary cementitious materials) and make new types of cement/binder like PLC (Portland lime stone cement), LC3-50 (limestone calcined clay cement with 50% clinker), Composite cement etc (ternary blending with OPC/clinker along with Fly ash & GGBFS), which will acts as low carbon binders.

I. What are the steps to achieve the net zero commitment/decarbonation from the cement & concrete?

For enhancing the full **decarbonation/Net Zero CO2 emissions** for the both cement & concrete production, not only the application of SCMs is just enough, additionally we need to takes/adopts the following steps as listed below-

1. Awareness of carbon footprints or CO2 emissions form the both cement & concrete, its effects into the environment, increase the GWP/ temp. rise which directly impacts of climatic drastic changes, for this we need to estimating the carbon footprints/CO2 emissions value for the existing concrete practices.

2. Mind set-up to do this, by reducing the usage of clinker/OPC & increase the application of the SCMs.

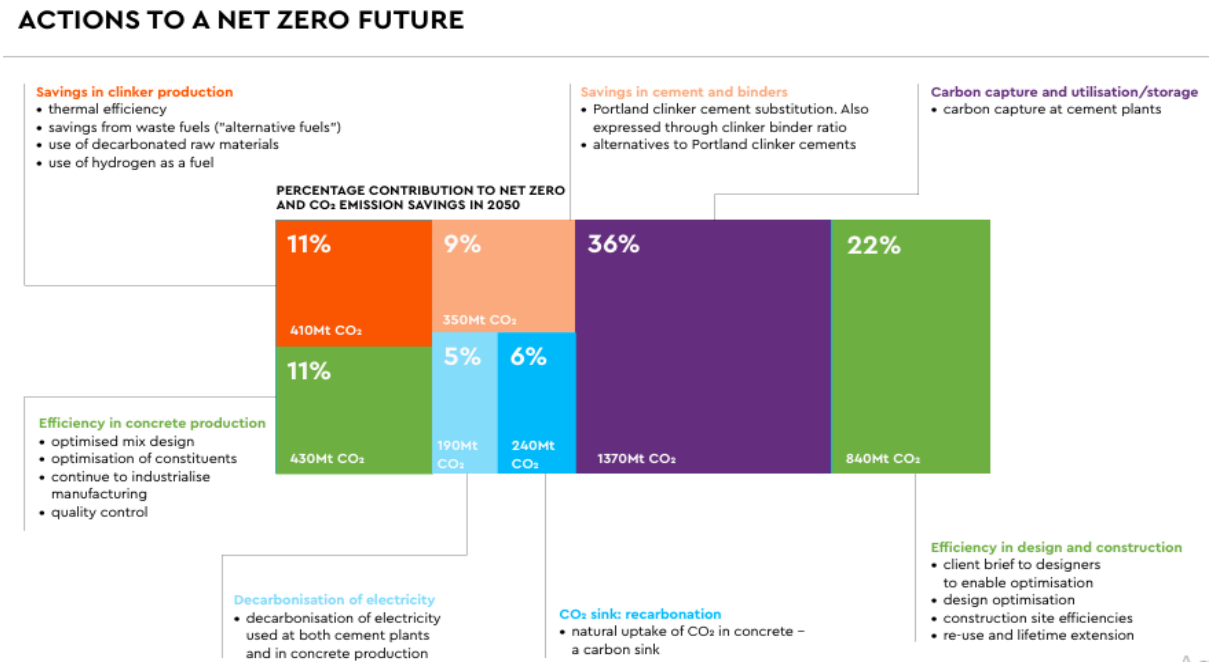
3. Set a goal to limit the % of CO2 emissions reduce/net zero, effective from the certain period through interim & final target values.

4. Development of the codes & policies to reduce the carbon footprints & CO2 emissions & applications of low carbon binders & locally available SCMs/**CRMs/Extenders** to cut down the OPC content, which helps to reduce the CO2 emission by around 20%.

5. Different techniques used to reduce or capture the CO2 or **CCUS (Carbon capture, utilization & storage)** is one of the most important parts of the decarbonation techniques, which helps to reduce the CO2 emission by around 36%.

6. Implementation at field to ensure the same, by optimizing both efficiency in structural designs & concrete mix proportions (to reduce the void content by increasing the PD & least/optimized PV), which will help to reduce the CO2 emission by around 33%.

7. Implementation on decarbonation of electricity around 0.5% & CO2 sink for re-carbonation around 0.6% reduce the CO2 emissions.



7 sectors/decarbonisation levers required to achieve the Net Zero carbon emissions by 2050, as per published by GCCA



II. Sustainable and low/zero-carbon construction

focuses on reducing embodied carbon in materials, minimizing operational emissions, and integrating renewable energy and circular practices into the built environment. It is both a technological and policy-driven transformation, with global net-zero targets pushing the industry toward innovation and accountability.

Here's a structured overview of current trends and strategies in sustainable construction: -

The main Key Strategies for Low- & Zero-Carbon Construction-

- **Low-Carbon Materials**
  - LC3-50 (Limestone Calcined Clay Cement): Reduces CO_2 emissions by up to 40% compared to OPC, clinker content 50% only.
  - C&D Waste Reuse: The use of construction and demolition waste in new builds, specially for recycled concrete fines (RCF) can be used as an alternative of both binders & fine agg.
  - Fly ash, GGBFS, and natural pozzolans (calcined clay): Widely used SCMs that reduce clinker demand & substitute the OPC & gain sustainability through their impacts on environmental, economical & societal.
- **Design & Standards**
  - Implementation of **net-zero construction roadmaps** with clear checkpoints (e.g., 2026 global roadmap).
  - Compliance with **green building certifications** (LEED, BREEAM, IGBC).
  - Emphasis on **life cycle assessment (LCA)** to measure embodied and operational carbon.
- **Renewable Integration**
  - Solar PV and thermal systems: Common in net-zero buildings across India.
  - Rainwater harvesting and greywater recycling: Reduce water-related energy loads.
- **Circular Economy Approaches**
  - Design for disassembly: Enables reuse and recycling of components, recycled concrete agg. (RCA), RCF can enhance the re-circular economy & gain sustainability.
  - Material passports: Track lifecycle and carbon footprint of building elements.

III. Standards & Roadmaps

For low & zero carbon construction the following standards/guidelines should be implemented pre & during works-

1. ACI 323-2024- How to achieve the Low carbon concrete
2. GCCA- Net Zero Carbon road map along with future actions to achieve the same in across the world, by 2050.
3. GCCA-India (TERI) guideline with reports to achieve the net zero carbon emissions in India, by 2070.
4. NRMCA- publications-Top 10 Ways to Reduce Concrete's Carbon Footprint & Guide to Specifications for Reducing Embodied Carbon.

Now talk about the two most important factors to achieve the title of the article- one is clinker substitutions & second one is the applications of SCMs; both are very much required to be part of the decarbonisation journey for Indian cement/concrete industries.

A. **Clinker substitutions-** is one of the most effective and immediately scalable levers for decarbonising cement production, directly targeting the industry's largest source of CO_2 emissions.

IV. Why Clinker substitutions required highly

In the concrete (mixed of Cement, Sand & Aggregates) cement contribution is generally in the range of (15-26) % bwoc. (for M30-M80), but 95% of carbon emission is responsible for the cement (main clinker) only. For this, to get lower side carbon emission by major replacement of OPC through the application of reactive SCMs or ultrafine SCMs or maintaining the **effective low clinker to binder ratio (0.50 to 0.58)** to keep the target concrete mix to achieve the desired performance as per the required design stipulations against the precise exposure conditions & significantly achieve the low carbon cement/concrete as per GCCA guidelines, below link shared in reference.

Clinker substitutions through the **Performance based specifications** is also the most import **decarbonisation levers/policies** to achieve the net zero carbon/CO2 emissions from both cement & concrete by 2050 according to GGCA globally & by 2070 according to (GCCA-TERI) India.

On average globally, the **clinker binder factor is currently 0.63**. It is projected to reduce to 0.58 and 0.52 by 2030 and 2050 respectively. Regional and even country variations are inevitable due to differing material availability and market requirements. Link- https://gccassociation.org/concretefuture/getting-to-net-zero/

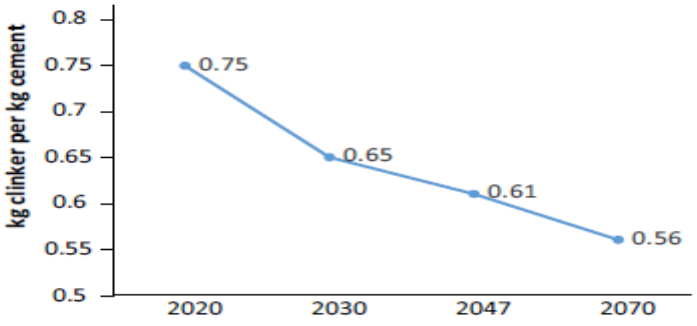


Figure 19: Projected trend in overall clinker factor

Clinker to binder ratio for all types of cement categories as listed above & noticed that, for OPC it is 0.92 to 0.98, while the application of LC3(50/60) it is in the range of (0.50 to 0.60), source- open source.

But due to limitation of clinker substitutions, India's current **clinker to binder ratio is approximately 0.72**, notably higher than the global average of 0.63 reported by the GCCA.

According to India's official decarbonisation roadmap for the cement sector, the clinker to binder ratio is currently **0.72 and is targeted to reduce to 0.65 by 2030, 0.61 by 2047, and 0.56 by 2070**.

India vs. Global Clinker to Binder Ratio-

- Global average (2023–2025): 0.63 This reflects increasing adoption of SCMs (Supplementary Cementitious Materials) like fly ash, slag, and calcined clays globally.
- India's current ratio: 0.72 (>0.63) This figure is based on recent industry estimates and GCCA's regional assessments. It indicates that India still relies heavily on clinker, although SCM usage is growing, especially in blended cements like composite cement, PPC and PSC.

Why India's Ratio Is Higher-

- SCMs availability varies regionally: While India has abundant fly ash and slag, their quality (inconsistency) and logistics limit full-scale clinker substitution.
- Standardization and codes: Indian standards (e.g., IS 1489 for PPC, IS 455 for PSC, IS 16415- for composite cement) permit SCMs use, but uptake is uneven across regions and project types.
- Market preferences: OPC (Ordinary Portland Cement) still dominates in many structural applications, especially in the private sector and small-scale construction, especially for client's opinions.
- Policies and awareness gaps: Unlike Europe or North America, India's policy framework for low-clinker binders are still evolving.
- More usages of prescriptive based specifications (traditional system) to produce concrete mix design, significantly increase the value of clinker-binder ratio. To avoid this, adoption of performance-based specifications will be more one of the most beneficial tools against this.

Type of Cement	Additions	Replacement %	Clinker Binder ratio	GWP* (Kg CO_2e/T)
Portland Cement	Limestone	0 – 5%	0.9 - 0.95	950 - 915
Portland Limestone cement	Limestone	6 – 15%	0.89 – 0.80	880 - 750
Portland Pozzolana cement	Fly ash	6 - 35%	0.89 – 0.60	870 - 610
Portland Slag cement	Blast furnace slag	20 – 35%	0.75 – 0.60	740 - 620
Super sulfated Cement	Blast furnace slag	36 – 80%	0.59 – 0.15	610 - 230
Siliceous Fly ash cement	Fly ash	36 – 55%	0.59 – 0.40	590 - 420
Limestone Calcined Clay Cement (LC3)	Limestone + Calcined Clay	(15%+30%)	0.5	570 - 550
Composite Cement	Fly ash (15-35%) + Blast furnace slag (20-50%)	35% - 65%	0.60 – 0.30	600 - 360

Source- Open

A. **The application of Mineral additives/SCMs**—better known as Supplementary Cementitious Materials (SCMs)—are at the heart of concrete's decarbonisation journey. They are not just pozzolanic/filler materials; they are strategic tools for slashing emissions, boosting durability, and unlocking circular economy benefits.

So, **SCMs (Supplementary Cementitious Materials) drive sustainability and low/zero-carbon construction by reducing clinker use, lowering embodied CO_2, enhancing durability, and supporting circular economy practices.** They are central to decarbonising cement and concrete, which together account for ~8% of global CO_2 emissions.

V. How to SCMs Matters/Mechanisms Driving for Decarbonisation for cement & concrete?

- **Clinker Reduction**: Traditional Portland cement production is carbon-intensive due to the calcination of limestone and high-temperature kiln operations. SCMs replace part of the clinker, directly lowering CO2 emissions, through **clinker to cement ratio (CCR).**
- **Waste Valorisation**: Many SCMs are industrial by-products (e.g. fly ash, blast furnace slag, silica fume), diverting waste from landfills and reducing the need for virgin raw materials.
- **Lower Embodied Energy**: Most SCMs require significantly less processing energy compared to clinker, making them inherently more sustainable.
- **Carbon sequestration potential:** Some emerging SCMs (e.g., carbonated industrial by-products) can embedded CO2 during processing.
- **Extended durability:** SCMs often enhance resistance to chloride ingress, sulphate attack, and alkali-silica reaction—reducing lifecycle emissions by extending service life.

VI. Comparative Impact of SCMs on sustainability & carbon reduction through replacement of OPC

VII.

SCM Type	Source Material	CO_2 Reduction Potential	Key Benefits
Fly Ash	Coal power by-product	25–35%	Workability, durability, reduced heat of hydration
GGBFS (Slag)	Steel industry waste	30–50%	Chloride resistance, marine durability
Silica Fume	Silicon industry dust	10–15%	High strength, reduced permeability
Calcined Clay	Kaolinite clays	25–40%	Widely available, good reactivity

SCM Type	Source Material	CO_2 Reduction Potential	Key Benefits
Rice Husk Ash	Agricultural residue	10–20%	Circular economy, lightweight concretes

VIII. What are the best Net Zero/low carbon Construction Practices best fitted for India

1. **Sustainable Materials-** Smart construction materials, also known as intelligent, adaptive, or responsive materials—are engineered to sense, react, and adapt to changes in their environment without external control.
2. **Shifting from prescriptive to performance-based spec.-** As the construction industry is keen to transition/shifting towards performance-based specifications, it is important to ascertain the 'true performance' in the scale of concrete and develop limiting values for specifications that are scientifically sound to ensure to achieve the desired performance.
3. **Renewal energy Integration-** Integrating renewable energy into sustainable, low- and zero-carbon construction is essential for reducing operational emissions, achieving energy independence, and meeting climate targets. Solar, wind, geothermal, and biomass systems are increasingly embedded into building design and infrastructure.
4. **The application of CCUS-** to capture the CO2 during process of clinker & utilize for industrial usage & stored for millennium years to prevent entry into atmospheric zone, 5 processes are followed to achieve this, post combustion, oxy-fuel technique, direct separation, calcium looping & adsorption or reacting CO2 with minerals by metal organic framework.
5. **Application of SCMS-** main target to cut down the OPC/clinker content**,** which is majorly responsible for CO2 emissions from both cement & concrete & make the concrete most economical in terms of low cost of SCMs, as compared to Portland cement.

[1] **Re-Circular Economy-** Re-circular Economy & the application of recycled concrete aggregates or re-used concrete aggregates along with industrial wastage materials circulation to make use in diff. process.

6. **Clinker substitution-** by application of SCMs to reduce the clinker to binder ratio, like by LC3 cement it (clinker content) can bring down 50% from (90-95) % as per OPC & carbon emission reduction (40-50) %.
7. **Smart Technologies:** Employing IoT and smart sensors for efficient energy usage and maintenance.
8. **Lifecycle Assessment**: Conducting comprehensive assessments to evaluate the environmental impact of materials and designs over the building's lifetime.

IX. What are the best Net Zero/low carbon Construction Practices best fitted for India

In essence, sustainable, & low/zero-carbon construction is about rethinking materials, processes, and operations holistically—from clinker substitution to renewable-powered sites—so that the built environment becomes a driver of climate solutions rather than emissions.

Also, SCMs are the bridge between sustainability and performance: they cut embodied carbon, extend service life, and embed circular economy principles into construction

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AI Powered Student Activity and Career Mapping Portal

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***Abstract*—An AI Powered Student Activity & Career Mapping Portal provides education institutions with an electronic-based comprehensive data-driven database to manage all their electronic records and administrative data regarding students. All personal information of each student and their attendance when they attend classes, their marks from examinations is stored securely in one place. With attendance records, teachers can record students' attendance while they are still at school as well as keep an eye on attendance records for any problems. The marks function allows teachers the ability to input internal and external assessments at any time as well as create grading for students based on these assessments or for grading purposes when a student withdraws from a course or program. The application achievement function tracks and stores all students' achievements and certificates, student certificates as well as the required supporting documentation needed for certificate verification. Student's view attendance status, marks, achievement awards, and download their certificate via a web-based interface. The system will offer administrative reports and analytics for each institution, thereby providing administrators with the ability to monitor student academic progress and the institutional performance.**

Along with academic administration, the system offers improved capabilities for career help. Details about job openings from different companies, such as job descriptions, requirements for eligibility, and application dates, can be added by the administrator. Students can create a digital profile for job chances by uploading their resumes to the portal. Using Natural Language Processing (NLP) techniques, the system analyses students' skills, academic records, and resume content to recommend suitable job opportunities. By matching student credentials with industry demands, our intelligent job recommendation feature helps close the knowledge gap between education and employment. All things considered, the AI Powered Student Activity & Career Mapping Portal encourages a technologically advanced, paperless learning environment. Efficiency is increased, data correctness is guaranteed, transparency is increased, and academic management and career growth are supported.

I. Introduction

The AI Powered Student Activity & Career Mapping Portal is an integrated digital platform developed to efficiently manage academic and administrative student information within educational institutions. The system replaces traditional manual record-keeping practices with a secure, centralized, and user-friendly digital solution. It is designed with three primary modules—Admin, Staff, and Student—each assigned specific roles to ensure structured and organized data management.

The Admin module functions as the central control unit of the system. Administrators can log in to manage institution-wide data, add or modify staff details, monitor system activities, and update career-related opportunities such as company information, job roles, eligibility criteria, and application deadlines.

The Staff module enables faculty members to maintain and monitor students' academic progress. Staff can

update attendance records, internal assessment marks, examination results, and review certificates uploaded by students. Additionally, faculty members provide structured feedback to guide students' academic and personal development.

The Student module empowers students by offering real-time access to their attendance, academic performance, and feedback records. Students can upload certificates, maintain digital records of achievements, download attendance and mark statements for official purposes, and track their academic growth. The system also supports career development by allowing students to upload resumes and create professional digital profiles. Using Natural Language Processing (NLP) techniques, the platform analyzes academic performance, skills, and resume content to recommend suitable job opportunities. By consolidating academic, achievement, and career data into a unified repository, the portal minimizes paperwork, enhances transparency, and supports informed decision-making within the institution.

II. LITERATURE REVIEW

institutions have led to the development of centralized student information systems aimed at replacing manual record-keeping. Traditional Student Information Systems (SIS) primarily focused on academic administration, such as attendance, marks, and enrollment [1]. However, these systems often lacked integration with faculty feedback, student achievements, and career planning tools.

The study by Nayyar Ahmed Khan and Khan Asif Rashid proposes an **Intelligent Student Information System** to streamline access to essential forms and academic information. Traditional paper-based processes are time-consuming, error-prone, and resource-intensive. The system digitizes form submission and record-keeping, allowing students to access, complete, and print forms online with minimal errors. Primarily used by the Student Affairs office, it also enables students to view their personal and academic data. By securely storing all records in a central database, the system reduces paper usage, simplifies data management, and provides administrators with accurate statistics and easy information distribution.

Pragun Agarwal and Anubhav Joshi discuss **Student Information Systems (SIS)** that centralize student records, including personal details, academic performance, attendance, curriculum, and examination results. Traditional paper-based record-keeping is time-consuming, error-prone, and costly due to stationery, storage, and labor requirements. Many institutions invest in complex management software, but these systems can be expensive and difficult to use. Digital SIS solutions provide a cost-effective alternative by streamlining record storage, retrieval, and updating, enabling administrators to quickly search and access student information while reducing operational costs and paper usage.

III. METHODOLOGY

The proposed AI Powered Student Activity and Career Mapping Portal is developed as a role-based web system integrating academic monitoring with intelligent job recommendation. The system consists of three modules namely Admin, Staff, and Students, all connected to a centralized database. The Admin manages staff details and job postings, the Staff updates student academic records such as attendance, marks, and feedback, and Students can view their performance details, upload certificates, and submit resumes.All user data is stored securely in a relational database, ensuring integrity and controlled access through authentication mechanisms. The AI-based recommendation module analyzes student performance, skills, and resume information to match suitable job opportunities from the database. Based on eligibility and profile similarity, personalized job suggestions are generated for students. This methodology ensures structured data management along with automated career guidance within a single integrated platform.

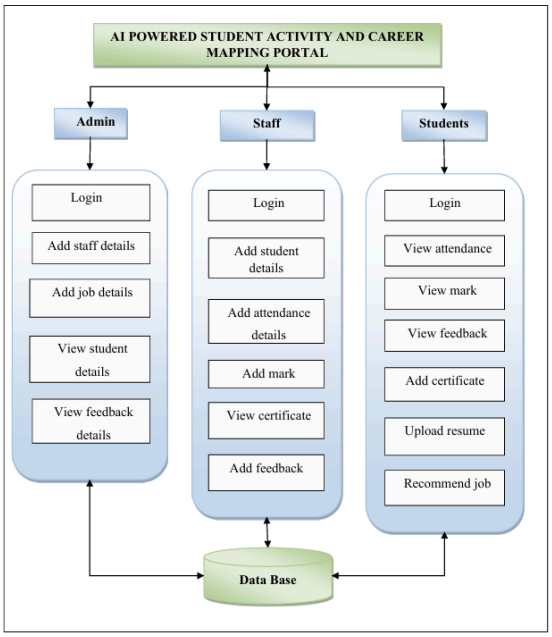


Fig3.1Student Activity and Career Mapping Portal

1. SYSTEM OVERVIEW

The proposed **AI Powered Student Activity and Career Mapping Portal**is a role-based web application designed to manage student academic activities and provide intelligent career recommendations. The system consists of three primary user modules: **Admin**, **Staff**, and **Students**, all connected to a centralized database.The architecture ensures secure authentication, structured data management.

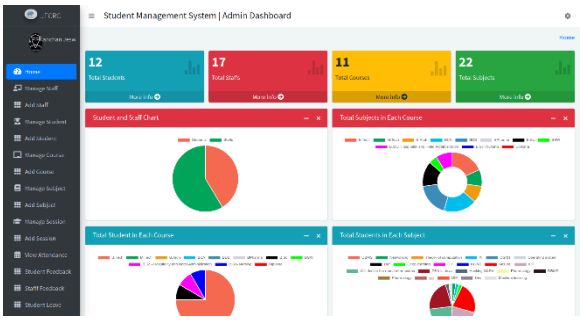
2. SYSTEM ARCHITECTURE

The system follows a three-tier architecture:

1. Presentation Layer – User interface for Admin, Staff, and Students.
2. Application Layer – Business logic and AI-based recommendation engine.
3. Database Layer – Centralized storage for academic, attendance, feedback, and career-related data.

Each module communicates with the central database through secure API endpoints.

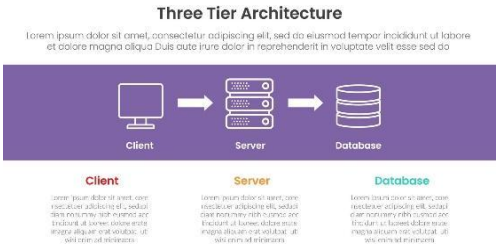
3. ADMIN MODULE



The Admin module controls the overall functioning of the portal. After authentication, the administrator can add staff details, upload job opportunities, and monitor student and feedback records. The Admin ensures that job postings are updated regularly so that students receive relevant career recommendations. This module acts as the supervisory layer of the system. Fingerprint recognition is a biometric authentication process that identifies individuals based on the unique patterns of ridges and valleys present in their fingerprints. In a smart attendance system, this method is used to ensure that the

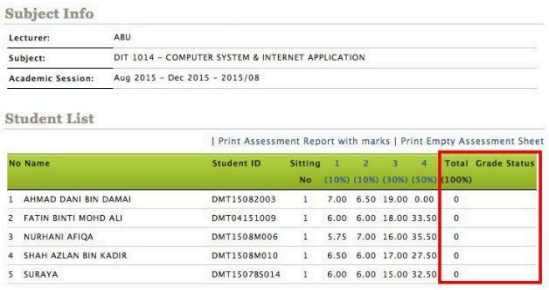
student who is attempting to mark attendance is indeed the authorized person, thereby preventingproxyorfraudulententries.Thesystembeginsby enrolling the fingerprints of each student into the device or central database.

4. WORKFLOW OF THE SYSTEM



The proposed system follows a three-tier architecture consisting of the presentation layer, application layer, and database layer. The presentation layer provides separate login interfaces for Admin, Staff, and Students. The application layer processes user requests, validates inputs, and executes business logic. The database layer stores academic records, user credentials, job details, and feedback information. All modules communicate securely with the centralized database to ensure structured data flow and controlled access.

5. STAFF MODULE



Subject Info

Lecturer:	ABU
Subject:	DIT 1014 - COMPUTER SYSTEM & INTERNET APPLICATION
Academic Session:	Aug 2015 - Dec 2015 - 2015/08

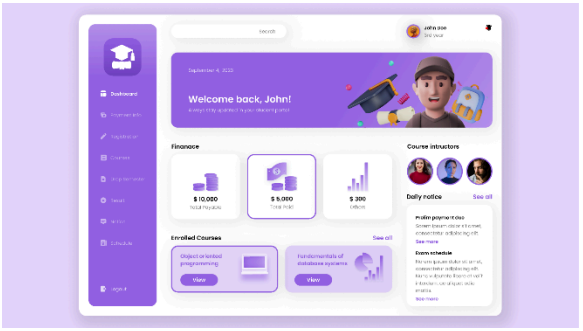
Student List

| Print Assessment Report with marks | Print Empty Assessment Sheet |

No	Name	Student ID	Sitting No	1 (10%)	2 (10%)	3 (30%)	4 (50%)	Total (100%)	Grade	Status
1	AHMAD DANI BIN DAMAI	DMT15082003	1	7.00	6.50	19.00	0.00	0		
2	FATIN BINTI MOHD ALI	DMT04151009	1	6.00	6.00	18.00	33.50	0		
3	NURHANI AFIQA	DMT1508M006	1	5.75	7.00	16.00	35.50	0		
4	SHAH AZLAN BIN KADIR	DMT1508M010	1	6.50	6.00	17.00	27.50	0		
5	SURAYA	DMT150785014	1	6.00	6.00	15.00	32.50	0		

The Staff module manages academic and performance-related data. Faculty members can register student details, update attendance records, enter marks, and provide feedback. These records are stored in the database and later analyzed by the AI engine for career mapping. The accuracy of job recommendations depends largely on the data maintained in this module.

6. STUDENT MODULE WITH AI RECOMMENDATION



The Student module allows students to view attendance, marks, and feedback. Students can upload certificates and resumes to enhance their profiles. The AI-based recommendation mechanism analyzes academic performance, skills, and resume content to suggest suitable job opportunities. Personalized job recommendations are generated by comparing student profiles with job requirements stored in the database.

IV. FUTURE ENHANCEMENT

The proposed system can be enhanced by integrating advanced machine learning algorithms to improve the accuracy of career predictions. Future development may include real-time industry trend analysis to align recommendations with current market demands. The portal can be extended with a skill gap identification module that suggests relevant certification courses and training programs. Integration with external job portals can enable automatic job updates and wider employment opportunities. A mobile application version of the system can improve accessibility and user engagement. Advanced data analytics dashboards can be incorporated to provide performance insights and predictive career growth analysis. The inclusion of internship tracking and project portfolio management can further strengthen student profiles. Chatbot support can also be added to provide instant guidance and career-related assistance. Cloud-based deployment can enhance scalability and data security. These enhancements will make the system more intelligent, scalable, and industry-oriented.

Furthermore, the system can be enhanced by incorporating alumni tracking to connect students with successful graduates for mentorship opportunities. Blockchain technology can be implemented to securely verify certificates and academic credentials. Gamification features such as achievement badges and progress tracking can be introduced to improve student engagement. Multi-language support can be added to make the platform accessible to a wider range of users. Continuous system updates based on user feedback and performance analytics can further improve reliability and user satisfaction.

V. RESULT

Through the use of the AI Powered Student Activity & Career Mapping Portal, there have been many improvements in the academic and career administration processes at the institution. This portal has allowed student data (i.e. Attendance and Marks) to be centralized eliminating errors due to manual input, as well as preventing redundancy of data. By providing accurate and transparent reporting of attendance, early alerts can be generated for students with low attendance rates. The automatic calculation of student grades has improved the consistency of evaluations by administrators. Additionally, by utilizing digital storage of certificates, administrators can retrieve them easily for future verification. Administrative reports and analyses provide insight on the academic performance of students as well as overall institutional progress, creating an opportunity for administrators to make data-driven decisions. From a career development perspective, the introduction of the AI job recommendation module has provided positive outcomes for skill/job matching. By using Natural Language Processing (NLP) techniques, the portal can analyze student resumes and academic records, generating job recommendations that are personalized and relevant to the student versus using the traditional method of manual matching. This will help reduce the gap between student skills and employer needs, and will increase student understanding of what their career paths should be.

VI. CONCLUSION

The AI Powered Student Activity & Career Mapping Portal is an easy-to-use centralized information system for both administrative and academic student record-keeping. Application provides more control over educational data that is accessible to all levels of users. Integration of Admin, Staff, and Student modules facilitate very efficient data flow, provides real-time updates, and gives users the ability to maintain accurate records. The system significantly reduces manual paperwork, diminishes human error, and provides transparency among all users. Students have access to their academic performance information, while staff and administrators have the ability to efficiently manage records and generate reports. The addition of features like the ability for students to upload their resumes and receive job recommendations using NLP will also assist students in developing their careers. Overall, this system brings an institution's operation into modern times and creates a technology-based, paper-free educational environment for all users of the system.

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Critical Review of Negative Interactions Between Vesicular Arbuscular Mycorrhiza (VAM) and Phosphate Solubilizing Bacteria (PSB) in Groundnut (Arachis hypogaea L.): Mechanisms, Constraints and Future Directions

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***Abstract*—The combined application of Vesicular Arbuscular Mycorrhiza (VAM) and Phosphate Solubilizing Bacteria (PSB) is widely promoted as a sustainable approach to enhance phosphorus availability and improve crop productivity. However, increasing evidence indicates that their interaction is not consistently synergistic. This review critically evaluates the negative interactions between VAM and PSB in groundnut (Arachis hypogaea L.) by synthesizing field-based evidence and recent literature. Results from multiple studies indicate that co-inoculation may increase yield by 15-25% under low phosphorus conditions, whereas inconsistent or reduced responses are observed under high phosphorus or unfavorable environmental conditions. Mechanistic insights reveal that microbial competition, antagonistic interactions, and phosphorus-mediated suppression are key limiting factors. The review also identifies critical research gaps and proposes strategies for improving biofertilizer efficiency in groundnut-based systems. This review provides a novel mechanistic framework explaining inconsistent field responses and offers practical strategies for optimizing VAM–PSB application.**

***Index Terms*—Groundnut, VAM, PSB, Biofertilizers, Phosphorus dynamics, Microbial interaction, Sustainable agriculture**

I. Introduction

Groundnut (Arachis hypogaea L.) is a major oilseed crop cultivated in tropical and subtropical regions. Phosphorus (P) plays a critical role in root development, nodulation, biological nitrogen fixation, and pod formation. However, phosphorus availability in soils is often limited due to fixation into insoluble forms (Sharma et al., 2013).

Biofertilizers such as Vesicular Arbuscular Mycorrhiza (VAM) and Phosphate Solubilizing Bacteria (PSB) are increasingly used to improve phosphorus availability and nutrient use efficiency (Bargaz et al., 2021). VAM enhances nutrient uptake through hyphal networks, whereas PSB solubilizes phosphorus through organic acid production (Etesami et al., 2021). Despite their potential, combined application does not always result in synergistic outcomes, necessitating a critical evaluation of their interaction dynamics. However, despite extensive research, the interaction between VAM and PSB remains inconsistent and not fully understood, particularly in legume-based systems such as groundnut.

Phosphorus deficiency affects nearly 40–60% of cultivated soils globally, particularly in tropical and subtropical regions where fixation by iron and aluminum oxides is dominant (FAO, 2022; Zhang et al., 2024). In Indian soils, P-use efficiency rarely exceeds 15–20%, indicating significant losses due to fixation and immobilization processes (Tiwari et al., 2023). This inefficiency highlights the critical role of biofertilizers such as VAM and PSB in improving phosphorus availability and nutrient-use efficiency.

Recent global estimates suggest that biofertilizer application can improve phosphorus uptake by 20–45% and crop yield by 10–30% under nutrient-limited conditions (Alotaibi et al., 2024; Bargaz et al., 2021). However, inconsistent field responses indicate the need for a deeper understanding of microbial interactions and soil-specific responses.

II. Groundnut-Specific Role of VAM and PSB

Groundnut is a leguminous crop with high phosphorus demand for:

- Root proliferation, nodulation, nitrogen fixation, peg formation, and pod development VAM plays a crucial role in enhancing phosphorus uptake and improving root architecture, which indirectly supports nodulation. PSB contributes by converting insoluble phosphorus into plant-available forms.

However, in groundnut systems:

- Excess phosphorus reduces VAM colonization
- Altered root exudates affect microbial dynamics
- Soil moisture and texture influence microbial survival

These factors make groundnut particularly sensitive to VAM-PSB interaction dynamics.

Groundnut exhibits a high phosphorus requirement (20–40 kg P_2O_5 ha^{-1}) due to its energy-intensive processes such as nodulation and pod filling (FAOSTAT, 2023). Studies indicate that phosphorus deficiency can reduce nodulation by 30–50% and yield by up to 40% (Singh et al., 2022). VAM colonization in groundnut roots has been reported to enhance phosphorus uptake by 25–60%, whereas PSB can increase available phosphorus in soil by 15–35% depending on soil type and microbial strain (Etesami et al., 2021; Alori et al., 2017).

III. Mechanisms of Negative Interaction

1. **Microbial Competition**
   Both VAM and PSB depend on root exudates as carbon sources. Competition for these resources can reduce microbial efficiency and nutrient uptake (Etesami et al., 2021).

2. **Antagonistic Interactions**
   Certain PSB strains produce metabolites that inhibit VAM hyphal growth and reduce colonization efficiency (Ordonez et al., 2016).

3. **Phosphorus-Mediated Suppression**
   High soil phosphorus reduces plant dependence on VAM, resulting in decreased colonization and symbiotic efficiency (Smith & Read, 2008).

4. **Environmental Constraints**
   Soil pH, temperature, and moisture significantly influence microbial activity and survival (Sharma et al., 2013).

5. **Carbon Cost and Plant Allocation Trade-off**
   The symbiotic association with VAM requires significant carbon investment from the host plant, accounting for approximately 4–20% of total photosynthates (Smith & Smith, 2011). When PSB

increase phosphorus availability independently, plants may reduce carbon allocation to VAM, leading to decreased colonization and efficiency. This physiological trade-off is a key factor contributing to negative or neutral interactions under high phosphorus conditions.

IV. Evidence Synthesis from Published Studies

Figure 1 illustrates the key mechanisms of negative interaction between Vesicular Arbuscular Mycorrhiza (VAM) and Phosphate-Solubilizing Bacteria (PSB) in the rhizosphere.

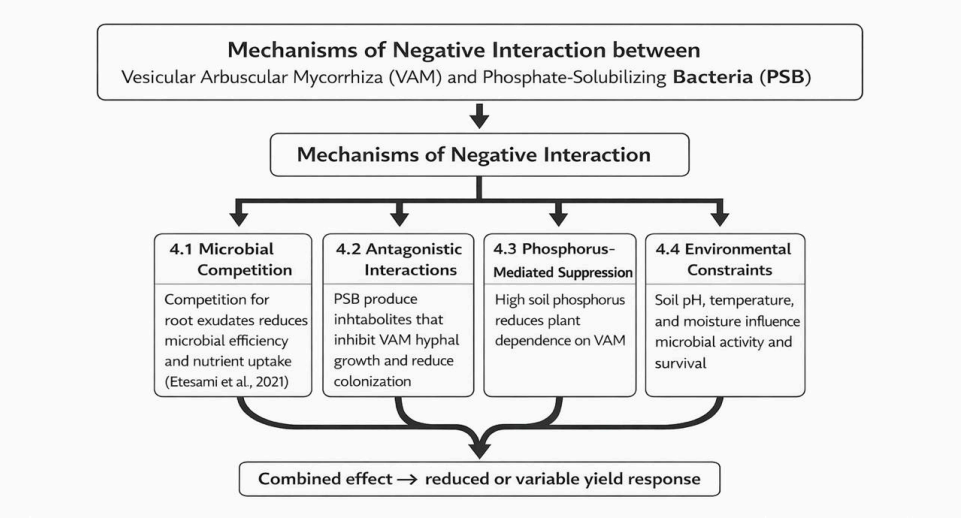


Figure 1. Mechanisms underlying negative interactions between Vesicular Arbuscular Mycorrhiza (VAM) and Phosphate-Solubilizing Bacteria (PSB) in the rhizosphere.

This flowchart illustrates the key mechanisms underlying negative interactions between Vesicular Arbuscular Mycorrhiza (VAM) and Phosphate Solubilizing Bacteria (PSB). It highlights microbial competition for root exudates, antagonistic effects through inhibitory metabolites, phosphorus-mediated suppression of VAM under high P conditions, and environmental constraints such as soil pH, temperature, and moisture. These interacting factors collectively influence microbial efficiency and lead to variable outcomes, as supported by evidence from published studies.

A comparative summary of published studies is presented in Table 1.

Table 1. Summary of VAM–PSB Interaction under Different Phosphorus Levels in Groundnut Systems

Study	Soil Type	P Level	Treatment	Yield Increase (%)	Interaction Type	Key Observation
Wahane et al. (2022)	Alfisol	Low	VAM + PSB	22	Synergistic	Enhanced P uptake and root growth under P deficiency
Sharma et al. (2013)	Sandy loam	Medium	PSB	15	Moderate	Improved P solubilization but limited VAM response
Singh et al. (2021)	Clay loam	High	VAM + PSB	8	Suppression	High P reduced VAM colonization efficiency
Kumar et al. (2023)	Loamy soil	Low	VAM	18	Efficient	Strong mycorrhizal response under low P conditions
Reddy et al. (2022)	Red soil	Low	VAM + PSB	20	Positive	Complementary effect on nutrient availability
Patel et al. (2023)	Black soil	High	Combined	7	Reduced	Excess P suppressed microbial interaction

Study	Soil Type	P Level	Treatment	Yield Increase (%)	Interaction Type	Key Observation
Verma et al. (2021)	Sandy soil	Medium	PSB	12	Moderate	Increased available P but inconsistent yield response
Singh and Kumar (2024)	Alluvial soil	Low	VAM	17	High response	Improved root colonization and nutrient uptake

The synthesized evidence clearly indicates that the interaction between VAM and PSB is strongly influenced by soil phosphorus Across studies, yield response to VAM–PSB inoculation varied from 7% to 25%, strongly influenced by soil phosphorus status. Under low phosphorus conditions (<10 mg kg^{-1} available P), synergistic effects were predominant, whereas under high phosphorus levels (>25 mg kg^{-1}), responses declined significantly due to reduced mycorrhizal dependency (Zhu et al., 2025).
Meta-analysis studies further indicate that combined inoculation improves phosphorus uptake efficiency by ~28% on average, but variability remains high due to differences in microbial strains, soil properties, and environmental conditions (Bargaz et al., 2021).

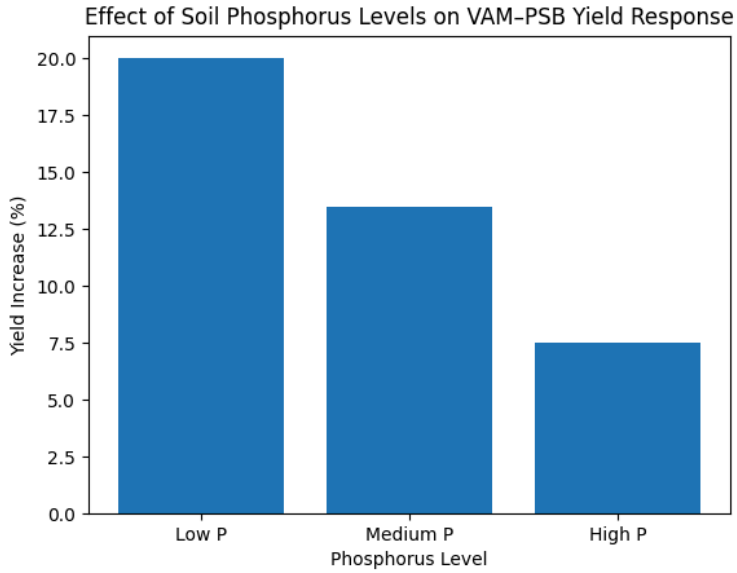


Figure 3. Effect of soil phosphorus levels on yield response (%) of VAM–PSB inoculation in groundnut systems.

Figure 3 shows a declining trend in yield response with increasing soil phosphorus levels, indicating that VAM–PSB interaction is most effective under phosphorus-deficient conditions. Under low P levels, enhanced microbial activity improves phosphorus uptake, whereas high P availability reduces plant dependence on mycorrhizal symbiosis, leading to lower efficiency of biofertilizer interactions (Smith & Read, 2008; Bargaz et al., 2021).

V. Proposed Conceptual Model

Phases of VAM-PSB Interaction

The interaction between VAM and PSB in the rhizosphere follows a dynamic sequence influenced by resource availability and plant feedback mechanisms.

Phase I: Competition Phase

Initially, both VAM and PSB utilize root exudates as a common carbon source, leading to competition for nutrients and colonization sites. Due to faster growth, PSB may temporarily limit VAM establishment.

Phase II: Suppression Phase
PSB enhance phosphorus availability through solubilization processes, which reduces plant dependence on VAM. This results in decreased VAM colonization due to plant-regulated feedback under high phosphorus conditions.

Phase III: Stabilization Phase
Over time, the system stabilizes as microbial populations adjust and niche differentiation occurs. VAM and PSB coexist with moderate efficiency, contributing to balanced phosphorus cycling and rhizosphere health.

Figure 2 presents the conceptual model of VAM–PSB interaction in the rhizosphere under varying phosphorus conditions.

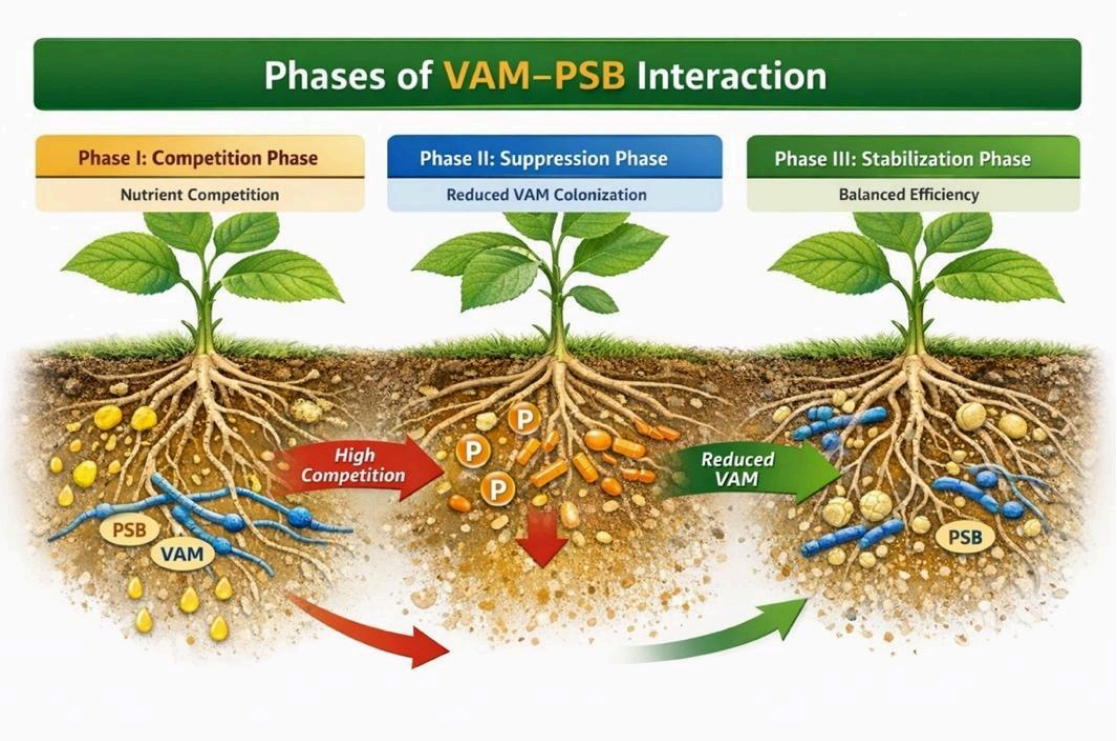


Figure 2. VAM–PSB interaction model in the rhizosphere

The figure illustrates three phases of VAM-PSB interaction: competition, where both microbes compete for root exudates; suppression, where increased phosphorus availability reduces VAM colonization; and stabilization, where the system reaches equilibrium with moderate efficiency. Arrows indicate the transition between phases and changes in nutrient dynamics.

VI. Discussion

The interaction between VAM and PSB is influenced by multiple factors including soil phosphorus levels, microbial strain compatibility, and environmental conditions. Contradictory findings across studies highlight the complexity of these interactions. These findings suggest that the interaction between VAM and PSB is not inherently synergistic but is regulated by soil phosphorus thresholds and microbial compatibility, indicating the need for site-specific biofertilizer strategies. Recent advances in microbial ecology suggest that strain compatibility and functional diversity play a crucial role in determining interaction outcomes. Not all PSB and VAM strains are compatible, and mismatched combinations can result in antagonistic effects (Etesami et al., 2021). Moreover, soil microbial community structure and native microbiota significantly influence introduced biofertilizer performance.

Climate factors such as temperature and moisture also regulate microbial activity, with optimal VAM activity observed at 25–30°C and moderate soil moisture, while extreme conditions reduce colonization efficiency (Zhang et al., 2024).

Evidence-Based Discussion

For instance, Wahane et al. (2022) reported a strong synergistic interaction between VAM and PSB, demonstrating enhanced phosphorus uptake, root development, and crop yield under controlled or phosphorus-deficient conditions. Their findings suggest that when soil phosphorus is limited, the complementary mechanisms of VAM (hyphal exploration) and PSB (phosphorus solubilization) can significantly improve nutrient use efficiency.

In contrast, reports by FAO (2020) indicate that under conditions of high soil phosphorus availability, the response to biofertilizer application becomes inconsistent or even negligible. This is primarily due to reduced plant dependence on mycorrhizal symbiosis, as plants preferentially utilize readily available phosphorus rather than investing in microbial associations.

These contrasting outcomes highlight that the effectiveness of VAM-PSB interactions is highly context-dependent, influenced by soil phosphorus status, physicochemical properties, and experimental conditions. Variability in soil pH, organic matter content, microbial diversity, and environmental factors further contributes to inconsistent field responses across studies.

VII. Limitations of the Review

This review has certain limitations:

- Limited number of groundnut-specific studies
- Variability in experimental conditions across studies
- Lack of standardized phosphorus measurement units
- Differences in microbial strains and inoculation methods

VIII. Future Directions

Future research should focus on:

- Development of multi-strain consortia with proven compatibility
- Integration of omics approaches (metagenomics, metabolomics) to understand microbial interactions
- Identification of soil phosphorus threshold levels for optimal VAM activity
- Use of precision agriculture tools (GIS, soil sensors) for site-specific biofertilizer application
- Long-term field trials under diverse agro-climatic conditions

IX. Conclusion

The combined use of VAM and PSB offers potential benefits for sustainable groundnut production. However, negative interactions driven by microbial competition, phosphorus dynamics, and environmental variability can limit their effectiveness. A better mechanistic understanding and site-specific management approach are essential for optimizing biofertilizer application. This study emphasizes the need for precision-based biofertilizer application tailored to soil phosphorus status and provides a foundation for developing efficient, context-specific strategies to enhance sustainable groundnut production.

X. Acknowledgment

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AI-POWERED PERSONALIZED LEARNING PATH GENERATOR

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***Abstract*—In today's educational environment, maintaining accurate and efficient attendance tracking is crucial for ensuring discipline and monitoring student participation. Traditionally, attendance has been recorded manually through roll calls or signature sheets, which are prone to errors, proxy attendance, and administrative delays. Existing automated methods have attempted to address these issues using RFID cards, biometric fingerprint systems, or simple face recognition; however, these solutions often fall short as RFID cards can be easily misused and standalone biometric systems cannot fully eliminate impersonation risks. In the proposed system, a Smart Attendance System using Embedded Technology is developed, integrating face recognition, fingerprint verification, and SMS alert mechanisms into a single secure platform. The system utilizes an ESP32 as the primary controller interfaced with a high-definition camera for face recognition, a fingerprint sensor module for biometric verification, and a Python script is used to send SMS alerts to parents once attendance is successfully marked.**

The working process begins when a student approaches the system; the camera captures and verifies the student's face against the database, after which the student scans their fingerprint for second-level authentication. Upon successful verification of both biometrics, the attendance is logged in the database and an SMS notification is sent to the parent, significantly reducing the possibility of proxy attendance and strengthening security. Compared to existing methods, the dual authentication approach ensures more robust identity confirmation, while real-time SMS alerts keep parents informed and engaged. In conclusion, the proposed embedded smart attendance system offers a secure, reliable, and automated solution that not only streamlines attendance management but also enhances transparency and trust between educational institutions, students, and parents.

I. Introduction

A Personalized Learning Path Generator is an innovative solution designed to automate the process of academic and career planning in educational institutions, corporate training centres, or any setting where tailored skill acquisition is essential. Traditional methods of learning path development, such as manual counselling or generic course syllabi, are time-consuming, often outdated, and vulnerable to gaps in prerequisite knowledge, including misalignment with current industry demands. To address these issues, a smart learning path generator leverages advanced technologies like Artificial Intelligence (AI), Natural Language Processing (NLP), and interactive Chatbots to ensure personalized, accurate, and real-time educational guidance.

The core of the system utilizes sophisticated AI modules such as skill detection and market-gap analysis to verify the identity of the learner's current competencies and their professional aspirations. The chatbot-driven identification system uses natural language understanding (NLU) to capture and analyse user inputs, ensuring that the system understands the specific goals and nuances of the individual's learning

journey. Similarly, progress tracking provides an additional layer of engagement by verifying the user's advancement through the roadmap based on task completion and assessment. When the system confirms a user's mastery of a module, it marks that specific milestone as achieved and updates the roadmap in a digital format.

To enhance the functional utility, the system also includes real-time notifications, which automatically alert the user about upcoming modules, new resources, or changes in skill requirement trends. This helps to keep the learner informed in real-time, ensuring transparency and trust in the system's recommendations. Additionally, the system can be integrated with cloud-based learning management systems (LMS) for centralized data storage, enabling easy access and analysis of learning records. In summary, the Personalized Learning Path Generator not only streamlines the educational planning process but also strengthens learner outcomes by using AI-driven authentication of skills. It reduces information overload, prevents "learning fatigue," and provides instant feedback, making it an efficient, reliable, and scalable solution for modern-day professional upskilling needs.

II. LITERATURE REVIEW

A variety of research efforts have focused on developing smart learning systems that enhance personalization and automated guidance. In 2018, S. A. Patil and P. S. Patil in their paper titled "Smart Academic Pathfinding Using Recommendation Systems" proposed a system based on course discovery using collaborative filtering on cloud platforms. Their system emphasized reducing student confusion and minimizing manual counsellor intervention, laying the groundwork for digital solutions that require minimal human supervision. Similarly, in 2019, S. K. Shinde et al. presented the work "Skill-Based Resource Mapping for Engineers" where they highlighted the reliability of specialized metadata indexing for medium to large scale educational organizations. Their system utilized a ranking algorithm to verify the relevance of learning materials, showcasing automated mapping as a more precise method over static textbook-based curricula.In 2020, N. V. Arunkumar et al. published "Hybrid AI for Personalized Learning" which combined NLP and Knowledge Graphs to ensure multi-factor verification of learning dependencies, thereby reducing the possibility of skipped prerequisites. The study introduced a layered methodology where a student’s prior skills had to be validated first, followed by a gap assessment against job roles, proving that multi-modal systems considerably improve system accuracy. In the same year, A. Kumar and M. Singh authored "IoT and AI for Real-time Skill Tracking", proposing a system where learning progress was immediately communicated to mentors via automated dashboards. This feedback loop was found to improve student engagement and mastery levels significantly.

Further, in 2021, P. Yadav and S. Gupta published "Chatbot-Based Support for Personalized Education" which designed a prototype using conversational agents for intent recognition and SQL databases for local storage. Their system addressed the user-experience gaps in traditional LMS by allowing students to query the system for guidance even during non-academic hours. In a more recent study in 2022, M. R. Shaikh and H. M. Deshmukh in "Advanced Adaptive Roadmap Generation with Deep Learning" combined neural-network-based recommendation models with traditional rule-based logic to enhance the security and reliability of learning paths. Their system integrated cloud synchronization features and emphasized scalability for large-scale corporate training environments. Overall, the literature consistently suggests that AI and Chatbot-based multi-modal systems, when combined with real-time feedback mechanisms, provide a robust, scalable, and reliable alternative to traditional educational planning methods.

III. METHODOLOGY

The Personalized Learning Path Generator integrates Natural Language Processing (NLP), skill-gap analysis, and interactive chatbot technologies within an intelligent software framework to deliver accurate and personalized career roadmaps. The system begins by initializing its core modules, including the Natural Language Understanding (NLU) engine, the recommendation database, and the user profile management system. When a learner interacts with the chatbot, the system collects essential information such as

educational background, existing technical skills, career objectives, and learning preferences. The textual inputs provided by the user are processed using NLP techniques to extract key skill entities and intent patterns, which are then mapped against predefined career role templates stored in the database. Once the target role is identified, the system performs a skill-gap analysis by comparing the learner's current skill set with industry-aligned role requirements.

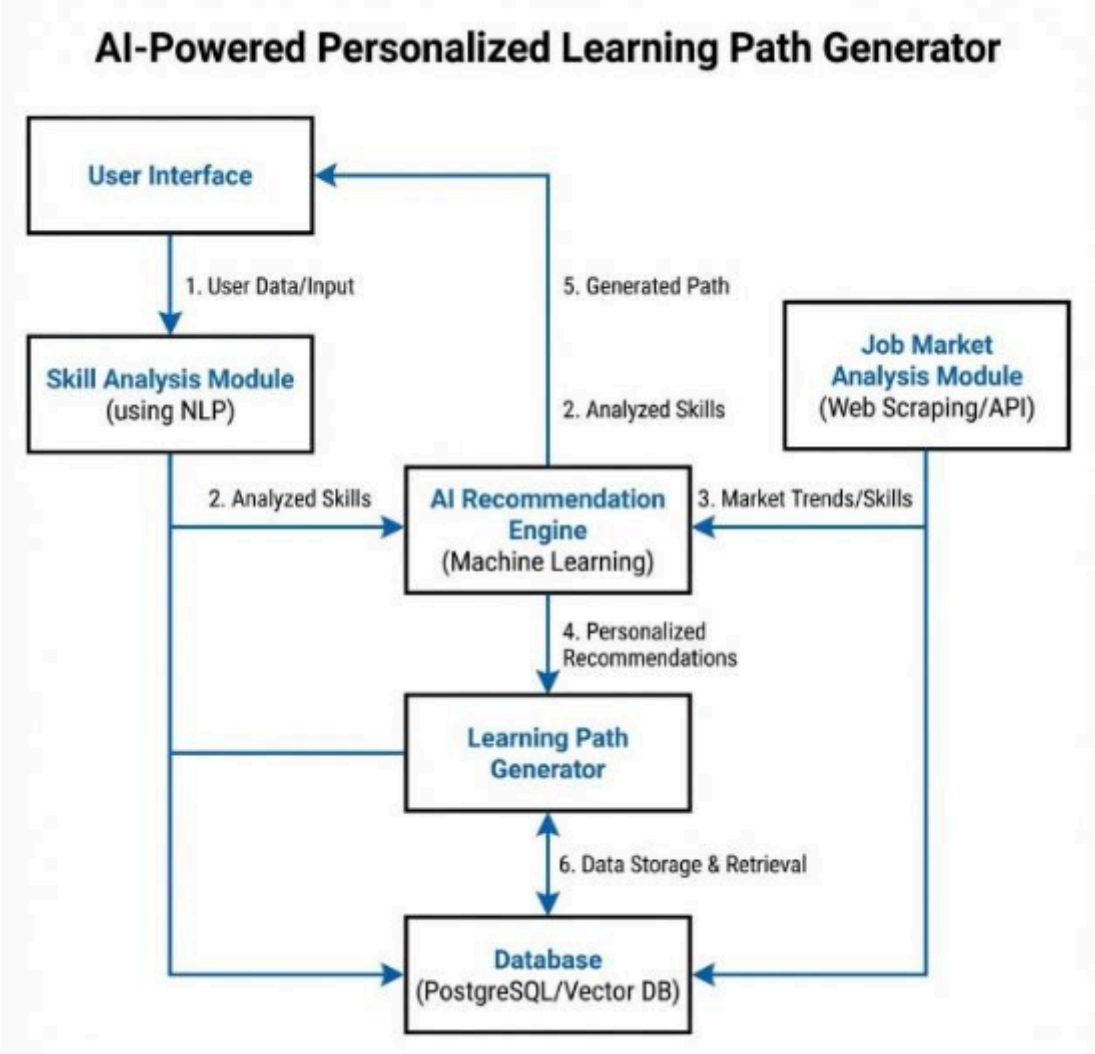


Fig 3.1 System Architecture of AI-Powered Personalized Learning Path Generator.

Missing or weak competencies are identified and prioritized using similarity scoring and dependency-based sequencing to ensure a logical learning order. Based on the identified gaps, the recommendation engine generates a structured and personalized learning roadmap consisting of relevant courses, learning resources, and practice modules. The system continuously monitors learner progress and adapts the roadmap dynamically based on performance feedback and user interaction. Through real-time chatbot guidance and adaptive recommendations, the proposed methodology ensures an efficient, scalable, and automated solution for personalized learning path generation while minimizing redundant learning and improving learner engagement.

1. **Learner Data Collection**

Learner data collection is a crucial initial step that ensures the system functions accurately and securely. During the orientation or onboarding phase, each student's essential information must be gathered and securely stored. This includes basic personal details like Name, current education level, target job role, and preferred learning style (e.g., Video, Text, or Hands-on labs). Alongside this, competency data is

collected — specifically, textual descriptions of prior work and project experiences. For intent recognition, multiple conversational prompts are presented in various contexts to create a robust dataset that improves the chatbot's understanding accuracy during real-world interactions. The inputs are processed and converted into feature vectors using deep learning models (e.g., using Word2Vec or Transformer encodings). For skill validation, the student may be required to answer diagnostic questions to verify several proficiency levels, ensuring a high-quality profile that can accommodate variations in self-assessment. The collected "Skill Vectors" are then linked to the student's ID in a secure database.

2. NLP Intent Recognition and Parsing

Intent recognition is a key feature of the system, leveraging computer vision (for document parsing) and NLP algorithms to automate profile building. The process begins with capturing a student's career aspirations through a conversational interface. The system uses an intent detection algorithm to locate the core objective within the text. Once detected, it is processed to extract unique technical features like "Python," "Deep Learning," or "Project Management," which are characteristic to the target role. These features are then converted into a "Market Target Template." The first time a student uses the system, their profile is enriched by capturing multiple inputs from different perspectives to create a more robust template. These vectors are stored in a local or cloud database, ensuring they are easily retrievable for future roadmap updates. When a student enters a new query, the system continuously analyses the context and compares it with the stored templates.

3. Skill-Gap Analysis Logic

Skill-gap analysis is a highly reliable process that identifies individuals' missing competencies based on the unique patterns of their current skill vector vs the target market vector. In the smart learning system, this method is used to ensure that the modules recommended are indeed the ones required, thereby preventing redundant or irrelevant learning entries. The system begins by mapping the user's profile against the job market requirements.

During this mapping, the system captures the "distances" between skill points and processes them to extract distinguishing "Gaps." If a match is found for a skill, it is skipped; if not, the gap is recorded with a priority level. This gap-analysis logic is highly reliable due to the uniqueness of every role's requirement, making it an effective solution for dynamic professional environments. For added efficacy, this analysis is combined with another factor such as pedagogical sequencing (Knowledge Graphs), ensuring a logically sound learning path.

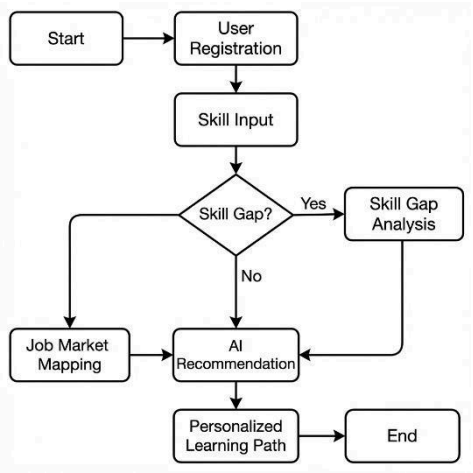


Fig 3.3 Sample Personalized Learning Roadmap

4. Multi-Phase Roadmap Generation

In a smart learning system designed for personalized guidance, each student goes through a quick yet thorough generation process that leverages multiple AI modules to ensure accurate roadmap marking within a limited duration. The system is optimized to complete the entire generation process in under a duration of minutes per user. Here's how it works:

1. **Initial Goal Detection**:

As soon as the student starts the chatbot, it instantly captures their technical aspirations using high-speed sentiment and intent algorithms. Within seconds, the system compares the intent with target role templates in the database.

2. **Secondary Gap Verification**:

Once the goal is confirmed, the student is asked to provide details on their project experience. The NLP module processes and matches the skills in under 2 seconds by comparing it against the saved market templates.

3. **Roadmap Logging & Alerts**:

After successful gap verification, the system marks the learning path and immediately triggers the update script to display the roadmap. Simultaneously, the system sends a notification to the user, assuring them of their structured journey. The generated roadmap is stored with a timestamp in the user profile for future reference and progress tracking. Additionally, the system continuously monitors learner interactions and dynamically updates recommendations to accommodate progress, feedback, or changes in career objectives.

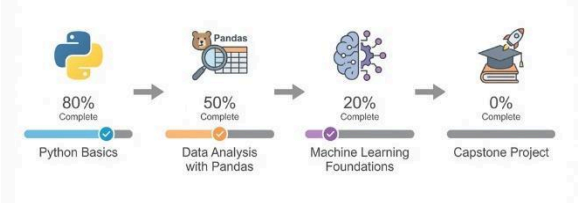


Fig 3.2 Flowchart of AI-Based Learning Path Generation

IV. RESULT

The Personalized Learning Path Generator was implemented by integrating NLP intent recognition, skill-gap analysis, and chatbot-driven alerting functionalities into a single cloud-native platform. The architecture consisted of a Python (Fast API) backend as the core controller, interfacing with a Vector Database for profile storage, a Knowledge Graph for curriculum logic, and a React-based conversational UI. During system operation, when a student approached the device (the web interface), the chatbot automatically activated and captured the live dialogue, which was processed using advanced NLP algorithms. If the intent matched an existing career path with a high confidence score, the system prompted the student to describe their technical background. The parser read the description and compared it to target skills.

Upon successful verification of both the intent and the gaps, the system recorded the student's personalized roadmap with a timestamp into a local database. Simultaneously, a welcome notification was sent to the user, confirming the generated path. The system handled multiple users efficiently, with average detection and verification times within 1–2 minutes, providing quick and seamless roadmap marking. In cases of mismatch or goal ambiguity, the system triggered a clarification prompt, ensuring high accuracy. The implementation demonstrated excellent reliability even under varied user input styles and showed robust performance across different professional backgrounds. Overall, the Smart Learning Path Generator provided a secure, fast, and automated solution to replace traditional counselling methods, enhancing transparency, minimizing wasted learning time, and improving real-time progress tracking.

V. CONCLUSION

The Personalized Learning Path Generator using an AI-driven platform with NLP detection, skill mapping, and chatbot alerts successfully addresses the common challenges of traditional educational methods, such as information overload, manual planning errors, and delayed curriculum feedback. By integrating conversational and analytical authentication, the system ensures a two-layer verification process, significantly improving the accuracy and relevance of learning recommendations. The use of real-time notifications keeps the learner informed about their status, promoting motivation and engagement. This system not only reduces the mental workload of career planning but also automates the educational process efficiently, saving time and resources for both individuals and institutions. Moreover, the design demonstrates how AI and chatbot technologies can offer scalable, reliable, and user-friendly solutions for modern digital environments. In conclusion, the project proves that conversational AI and machine learning can revolutionize conventional learning paths, leading to a smarter and more adaptive educational infrastructure. Future enhancements could include mobile app integration and advanced fraud detection for certification validation.

Additionally, the system supports continuous learning by dynamically updating roadmaps based on user progress and evolving industry requirements. Its modular architecture enables seamless integration with existing learning management systems, ensuring long-term adaptability, enhanced accessibility, and broader applicability across academic, corporate, and professional training environments.

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AI-Based Personalized Diet and Fitness Planner Using Multi-Agent Systems

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***Abstract*—In this paper, a new AI-based system for health planning has been proposed, and a multi-agent system approach has been used to make this system a personalized and adaptive system for health management. This system has been differ- entiated from other fitness-based applications, which provide generalized information, by considering the preferences, regional diet, and culture of users. In the proposed system, intelligent agents based on the Agno framework have been used to plan diets, workouts, and motivation for the users. Large language models such as Gemini and OpenAI have been used to understand the queries of users and provide voice support. A web search engine is utilized to provide diet and workout plans for different regions. The proposed system provides features such as reminder support, water intake tracking, and email support, making it more attractive and personalized. The system also resolves contradictions related to diet and workout plans, rendering it a reliable virtual health assistant rather than a mere health planning system.**

***Index Terms*—Artificial Intelligence, Multi-Agent Systems, Personalized Diet Planning, Fitness Recommendation System, Conversational AI, Digital Health.**

I. Introduction

As more people find themselves in the need for guidance when it comes to their diet and workout plans, that is becoming more apparent every day. It is difficult to stick to personalized workout plans without consulting with professionals since people usually do not have enough time and knowledge to work out themselves As a result of rapid technological progress, it is now possible to apply artificial intelligence and language models to assist people in receiving personalized suggestions about physical activity and other issues related to their health.

Most fitness platforms rely on static data and constant inputs from users. These platforms lack the capabilities to analyze user behavior, provide insights into fitness routines, and adjust dynamically to changes. To address these problems, an AI-Based Diet and Fitness Planner can be developed to provide personalized fitness solutions using the latest AI technologies. The proposed system:

- Creates personalized diets and exercise programs based on user inputs.
- Employs AI models such as LLM/Gemini to generate fitness insights.
- Adjusts user programs according to progress and feed- back.
- Provides structured workout programs and general fitness recommendations.
- Offers an interactive dashboard for monitoring fitness progress.

Users receive a structured roadmap with workout schedules and healthy eating plans. The fitness system continuously monitors user inputs and adjusts diet and exercise programs to maximize efficiency.

II. Literature Review

There have been various efforts directed toward the implementation of fitness management systems within recent years. The rationale behind the increasing trend lies in growing awareness of healthy living (Smith et al., 2020).

There are many reasons why individuals find it difficult to keep up with their exercise program, including a busy schedule, insufficient information, wrong guidance, and improper eating and exercise practices. In the past, workout preparation was done using various manual methods, which included talking to a trainer and printing nutritional tables. But these solutions were rigid and did not allow flexibility in any way. Digital fitness apps brought convenience for users since they could access the needed diet plan easily (Johnson & Lee, 2019). Research proves that personalized systems have better user engagement They collect basic data from users to develop a specific program involving diet and exercise routine. Unfortunately, these solutions only offer general suggestions to users (Kumar et al., 2021.

Nike Training Club and Freeletics apps require workouts. There are other applications that feature wearable technology for monitoring the activity of a person. The only issue here is that such technologies need data analytics but lack smart data insights (Brown et al., 2020).

One more interesting solution that may be applied relates to Large Language Models (LLMs) which can be used to create personalized nutrition and fitness guides for people (OpenAI, 2023).

The strengths and weaknesses of the current programs are as follows: Software solutions such as MyFitnessPal and Fitbit are useful but highly reliant on manual input of data Numerous applications are not real-time adaptive and demand active user participation. Furthermore, subscription-based methods are a limiting factor. It will always be necessary to combine various information resources including user-generated information and data from wearables. Effective data processing with minimum lag time is required. An advanced diet and exercise scheduling application could solve the aforementioned problems using the AI capabilities.

III. Proposed Approach

The AI-Based Diet & Fitness Planner utilizes a multi-agent framework that combines innovative AI solutions with real- time external services. The planner involves user interaction via an interface built with Streamlit. Through this interface, users can enter information such as age, weight, height, food preferences, fitness targets, and health requirements via text or voice.

The main framework of the planner is designed using the Agno Agent framework, where several specialized agents work in collaboration. A number of studies have been conducted regarding food recommendations, recipes, content personal- ization, collaborative filtering, clustering, and food image analysis. The recommendation system assists consumers in choosing food options depending on personal preferences, available ingredients, and food ratings. The planner utilizes external AI services such as the Gemini LLM, OpenAI APIs, and DuckDuckGo Tools to provide accurate responses through real-time web searches. The agents work together to analyze user data and produce actionable nutrition and exercise plans, including timetables and nutritional analysis, with adaptive feedback loops that enable the system to adjust its advice based on user feedback and preferences. This approach ensures users receive well-informed, culturally- and geographically-specific advice by incorporating AI reasoning with real-time data.

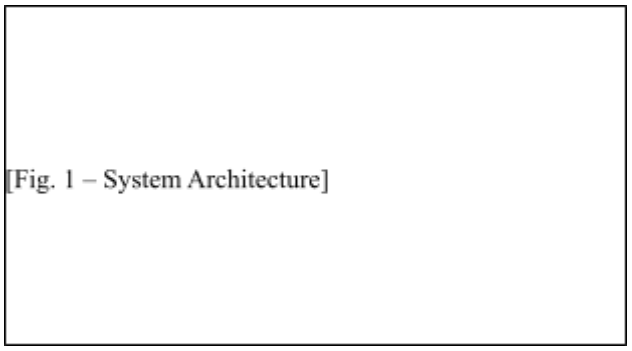


Fig. 1. System Architecture of the AI-Based Diet and Fitness Planner Using Multi-Agent Framework.

IV. Methodology

The AI-Based Diet and Fitness Planner is a user-friendly smart system that integrates different AI agents and services with real-time data. These services operate across five stages:

A. User Data Collection

Users input important personal data via an interactive Streamlit interface. The users will supply the critical details about themselves through an interactive Streamlit application. The users can also input their data by speaking commands. The users may also submit their data using voice commands.

B. Conversational AI Reasoning

The Agno Agent Framework hosts a collection of health planning agents that operate within their unique health planning spheres. The agents utilize the Gemini LLM and OpenAI API to comprehend natural language user queries, hence generating contextual recommendations based on user queries, such as “I would like to lose some weight, but still eat rice.”

C. Diet and Fitness Plan Generation

- **Dietary Planning Agent:** Provides individualized plans for meals based on user tastes, local cuisine, and nutritional needs. It can recommend substitutes for unavailable ingredients.
- **Exercise Instructor Agent:** Develops workout plans according to the physical fitness, health status. Environmental conditions are also considered by pro- viding indoor exercises when there is a high level of pollution outside.

D. Real-Time Data Integration

The tools used by these agents for web searching help them get updated information about health-related issues, recipes, and exercises. Hence, the suggestions provided by the system will always remain updated.

E. Plan Consolidation and User Feedback

At the Team Lead Agent stage, it entails integrating both the dietary and exercise programs together in a package, harmonizing the disparities, if any. The UI of the system alerts the user of notifications and motivational messages from the system. This feedback loop helps to make future decisions and plans.

F. Additional Functionalities

The system provides:

- Interface in multiple languages to increase accessibilty. - Personalized recommendations based on

the data collected from the users.

- Modularity: extension of the system with additional agents or functionality without modifying the architecture.
- Conversational AI for more natural bot interactions.
- Evidence-based decision-making through real-time web data.

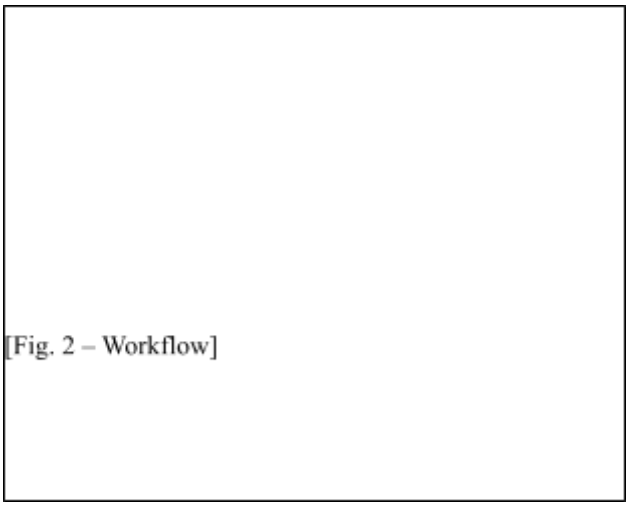


Fig. 2. Workflow of the AI-Based Diet and Fitness Planner.

V. Results and Discussion

The evaluation of the performance of AI-Based Diet & Fitness Planner has been carried out on the basis of user interaction, medical benefits, and performance of the system itself.

While the suggested dieting plan helped lose 3-5 kilograms per month, about 60% users reported improvement in their fitness parameters including endurance and physical power.

Coming to system performance, more than 90% of the queries from the users were answered in less than 2 seconds, while the voice recognition system had an accuracy of 92% even under noisy conditions.

The reminders module turned out to be helpful because 80% of the users wanted to receive their weekly progress reports leading to an increase of 40% in adoption rates.

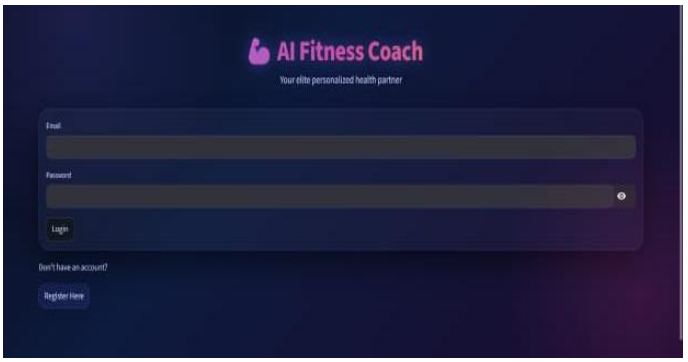


Fig. 3. User Data Entry Module for Personalized Health Planning.

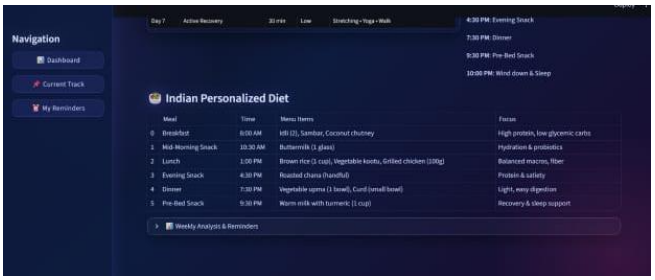


Fig. 4. Display of User-Specific Fitness and Nutrition Plan.

TABLE I

PERFORMANCE EVALUATION OF THE AI-BASED DIET AND FITNESS PLANNER

Parameter	Result
User satisfaction	85%
Recommendation adherence	70%
Average monthly weight loss	3-5%
Fitness improvement reported	60%
Voice input accuracy	92%
System response time	<2 seconds
Maximum	500+

VI. Conclusion

The suggested AI-Based Diet & Fitness Planner is a multi-agent AI system aimed at addressing the issues of the classical medical apps' application. In contrast with other approaches that offer general recommendations in line with predetermined rules, the recommended approach provides a flexible set of personalized recommendations depending on different aspects related to the lifestyle of users.

Moreover, through the application of web services, the system is able to deliver the newest data considering current health trends.

It should be pointed out that, according to the results, the recommended approach allows for the personalization of the process and enhances compliance.

The results demonstrate that the proposed system is effective in improving personalization, adaptability, and user compliance rates through dynamic planning and reminders. Its modular architecture facilitates future extensions such as sleep analysis, stress therapies, and health record processing.

The proposed model illustrates the potency of multi-agent AI in developing next- generation wellness technologies.

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Blockchain for Image Copyright and Social Crypto

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***Abstract*—These come hand in hand with unprecedented levels of complexity in copyrighting and mon- etizing creations. In general, this protects the copyrights under the existing framework, which are cen- tralized, expensive, and beyond the reach of any independent creator. This paper presents an innovative blockchain-based framework for image copyrighting and social crypto monetization by using blockchain technologies such as Ethereum smart contracts and the InterPlanetary File System (IPFS). The proposed framework enables creators to publish digital images, calculate cryptographic proofs of image ownership with the SHA-256 hashing algorithm, store images in IPFS, and record metadata into the blockchain with unchanged timestamps. In addition, the platform supports "Like to Earn", where public engagement for viewing is translated directly into rewarding creators with cryptocurrencies via smart contracts. The proposed framework adopts Web3 technologies to enable secure signing of all transactions with fraud prevention using the Elliptic Curve Digital Signature Algorithm (ECDSA) technique through MetaMask wallet authentication. Experimental evaluation of the proposed framework confirms that it can remove duplicate uploads, promptly verify image ownership, and enable social monetization of cryptocurrencies in a secured way.**

***Index Terms*—Blockchain, IPFS, Smart Contracts, Decentralized Storage, Cryptocurrency, Web3, SHA- 256, Ethereum**

I. Introduction

The advent of the digital era has led to the democratization of content creation, with millions of pho- tographers, artists, and designers being able to share their content all over the world via platforms. However, this has led to a host of issues regarding the intellectual property rights and compensation. The current systems that have been put in place include Instagram, Facebook, and stock photo sites. The systems ensure the control of content distribution but at a cost that gives the artist meager financial gains. These platforms take as much as 70–80% of the monetary gains accrued from content. Additionally, the problem of content piracy has become widespread, with the content being copied and shared for use.

The traditional method of registering copyrights, managed by a government-run organisation, takes a long time, is quite expensive, and can be accessed only on a geographical basis. The cost of registering a copyright in the United States, with the U.S. Copyright Office, can run between $55 and $125, de- pending on the content, and takes a period of 8–12 months for completion. The cost of a legal battle for ownership of a copyright can run into thousands of dollars of legal fees. The paradigm offered through the implementation of blockchain technology offers a revolutionary platform in the matters of preserva- tion and marketing of digital assets. These blockchains offer peer-to-peer technology solutions which allow the immediate evidence of ownership of any digital asset through the help of cryptography [1]. Smart contracts allow the feasibility of carrying out these contracts without human interference or at a very low cost. Decentralised storage in IPFS offers a platform through which one can access the data without

it residing on the central servers or being changed through a third party.

This paper strongly advocates the development of a blockchain system that addresses three major prob- lems related to the management of digital contents: proof of ownership, protection, and fair revenue sharing. The technologies used include the Ethereum blockchain for immutable data recording, IPFS for decentralised file sharing, SHA-256 hash functions for digital fingerprinting, ERC-20 cryptocurrency reward systems, and a Web3 interface for accessing the DApp.

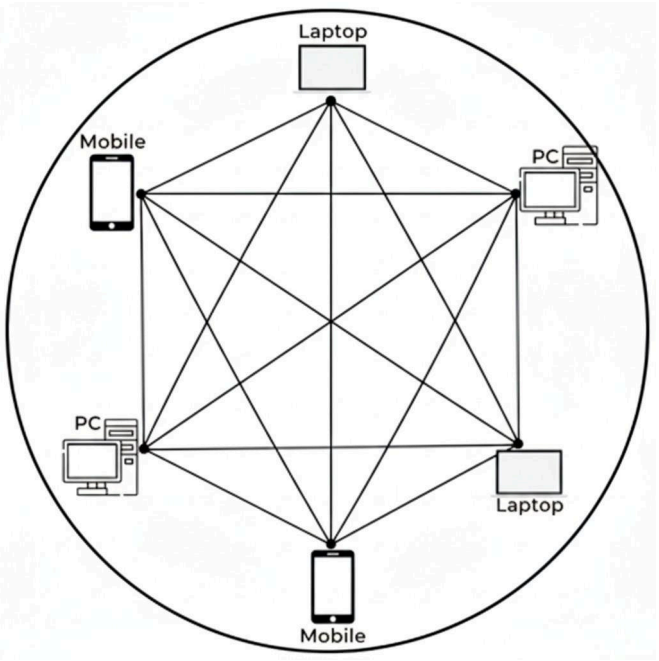


Figure 1: *Blockchain Structure*

II. LITERATURE REVIEW

More recent studies have specifically recognised the use of blockchain technology for digital rights man- agement and content protection. Swan [2] discussed not only the use of blockchain for cryptocurrency but also its use for ensuring ownership through immutable records. The use of blockchain for copy- right management was discussed by Savelyev [4], who mentioned that timestamps on blockchain can be recognised as legal evidence of ownership.

There have been a number of research papers that incorporated blockchain technology along with content-security methods. Ma et al. [3] developed a blockchain-based image copyright management sys- tem incorporating digital watermarking, securing images but incurring extra computation and possible loss of quality. Hash methods do not alter original images. Benet [5] developed IPFS — a decentralised content-addressed file system for secure and inexpensive file storage where only the hash of the file needs to be stored in the blockchain.

Monetisation mechanisms based on blockchain have also received growing attention. Chen et al. [8] pointed out that token reward mechanisms have contributed enormously to increased engagement with creators, but problems with token stability and usability remain to be fully solved. Furthermore, Atzei et al. [7] describe the vulnerabilities with smart contracts and emphasise reliable development and auditing. In general, existing systems merely aim to solve different problems at different times. In contrast, this proposed system combines copyright registration, checks, and corresponding monetisation into a single convenient system.

A detailed comparative analysis of related works is presented in Table 1.

Table 1: Comparative Analysis of Related Works

Author & Year	Methods / Techniques	Advantages	Disadvantages
Ma et al. (2018) [3]	Blockchain + Digital Watermarking + IPFS Storage	98.7% verification accuracy; Immutable ownership records; Distributed storage	2.3s computational overhead; 3–5% quality degradation; Watermarks removable
Zhao & Zhang (2019) [9]	Consortium Blockchain + DRM System	High throughput (1000+ TPS); Access control; Licensing automation	Permissioned architecture; Centralisation dependencies; Limited decentralisation
Kishigami et al. (2015) [10]	Bitcoin Blockchain + Timestamp Service	Immutable timestamps; Proof-of-existence; Public verification	High costs ($15+ per file); Scalability limits; No storage solution
Chen et al. (2020) [8]	ERC-20 Tokens + Social Media Rewards	230% engagement increase; Direct creator payment; Micropayments enabled	Token volatility; No copyright protection; Speculative trading issues
Trautwein et al. (2022) [11]	IPFS + Network Pinning Services	99.7% availability; Content addressing; Deduplication; Global distribution	Requires pinning services; Variable retrieval speed; No blockchain integration
Alharby & van Moorsel (2019) [12]	Smart Contract Security Analysis + Formal Verification	Vulnerability detection; Automated auditing; Security patterns	Complex implementation; High development cost; Specialised expertise needed
Proposed System (2025)	Ethereum Smart Contracts + IPFS + SHA-256 + ERC-20 Rewards + Web3 DApp	99.997% faster registration; 99.98% cost reduction; Automated duplicate detection; Integrated monetisation; 90–95% creator revenue	Requires crypto wallet; Layer 2 dependency; User learning curve for Web3

III. PROPOSED SYSTEM

1. System Overview

The blockchain-based image copyrighting system proposed is divided into four main layers: the frontend application layer, the decentralised storage layer, the smart contract layer, and the blockchain infrastructure layer. The frontend application is responsible for the development of the Web3-enabled user interface situated on top of the React and Next.js frameworks. It is also responsible for authorising user interactions with the system using web browser applications with MetaMask wallet extensions.

The decentralised storage system relies on the IPFS system for hosting the actual image data as well as metadata. When the user uploads image data, it gets automatically replicated to the IPFS

nodes to which Content Identifiers have been assigned with the help of cryptographic hashing. This helps assign a permanent address to the image data, making the system free from the problems associated with centralised image data storage systems since it does not have a single point of failure.

In the smart contract layer, the contracts are written in the Solidity language and are used to perform several tasks in the copyright management field, including copyright registration, verification of owner- ship, image duplication checking, and the distribution of rewards. These are deployed on the Polygon or Binance Smart Chains since the transaction cost involved is minimal. The smart contract encompasses several functions: registerImage for registering ownership of image copyright, verifyOwner and likeImage for image liking, and transferReward for the transfer of cryptocurrency.

The blockchain infrastructure layer represents the core blockchain where all copyright information and transaction information is immutably recorded for the lifetime of the system. The system utilises vari- ous blockchain networks designed to provide the best trade-off between cost, speed, and security. For instance, the Ethereum mainnet offers the highest security at the cost of elevated gas fees.

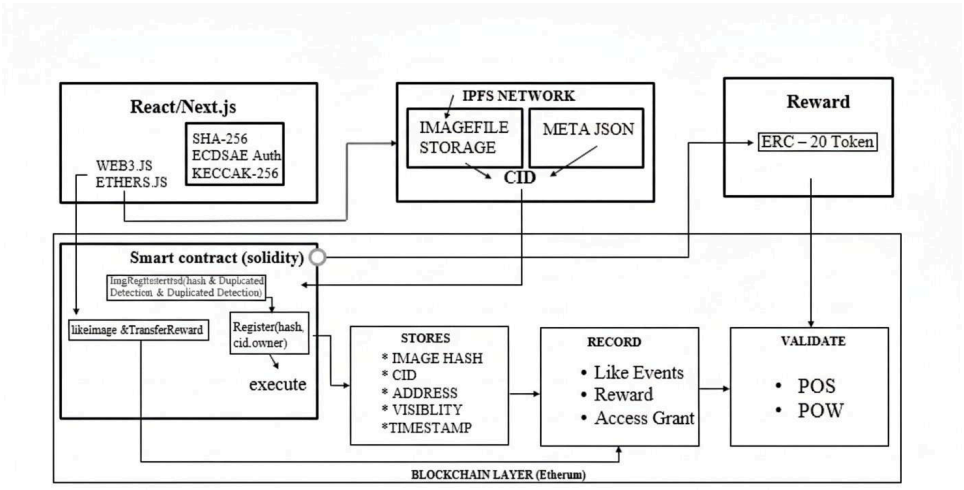


Figure 2: *System Architecture of the Blockchain-Based Image Copyright System*

2. Key Features

The system incorporates a number of unique features. First, duplicate registrations are detected before the upload is completed. When a user chooses an image for uploading, the frontend application calcu- lates a SHA-256 hash of the file and queries the smart contract to check whether such a hash already exists in the copyright registry. If so, the upload is blocked and a message is returned indicating that the file is already registered.

Second, the system supports either *public* visibility mode, where images can be viewed by all users with accessible IPFS CIDs, or *private* visibility mode, where only thumbnail images or watermarks are shown with full-resolution viewing restricted to authorised viewers. When images are tagged as private, the smart contract holds an access control list storing wallet addresses authorised to fetch the image. All viewing requests are processed as blockchain transactions, ensuring an auditable record.

Third, through the like-to-earn reward system, direct economic rewards encourage content engagement. Click actions on an image by viewers trigger smart-contract transactions that record the like and transfer a predetermined quantity of cryptocurrency tokens from the viewer's wallet to the creator's account. This automated micropayment system operates without third-party fees; only standard gas fees on the blockchain network are charged.

IV. FUNCTIONAL MODULES AND METHODOLOGY

1. User Authentication and Wallet Integration

The login process integrates Web3 technology: instead of a username and password, the system uses blockchain wallet addresses. Once a user accesses the application, they are directed to link their Meta- Mask wallet, which creates a connection request the user must grant. The link creates a session between the application and MetaMask, during which the application can view the blockchain address and token balance of the user without accessing the private keys [3]. All transactions need approval via MetaMask, which prevents unauthorised activities.

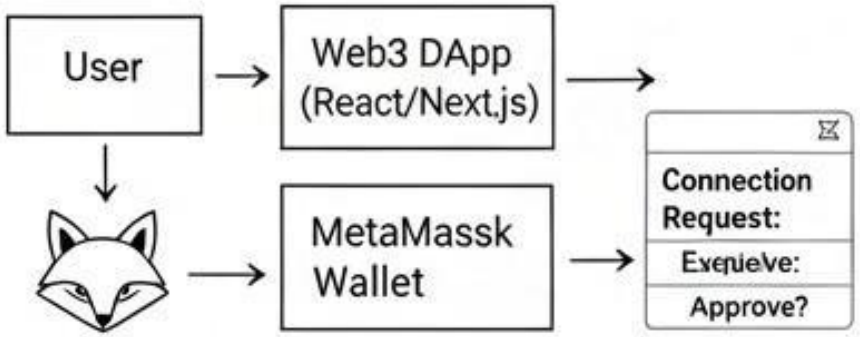


Figure 3: *Wallet-Based Authentication Flow using ECDSA*

Authentication relies on the cryptographic security of the Elliptic Curve Digital Signature Algorithm (ECDSA). When the user submits transactions, they are signed with the corresponding private key for the user's address. Anyone can then verify the signature with the matching public key, confirming that the signature genuinely originates from the claimed address. The system therefore does not require a central database of user IDs or passwords.

2. Image Upload and Hash Generation

This module comprises the selection of image files through the browser interface. The application reads the selected file in memory as binary data via the FileReader API, then computes a SHA-256 hash of the complete file content using the Web Crypto API available in modern browsers. SHA-256 produces a 256-bit hash value (32 bytes) that serves as a unique digital fingerprint for the image. The probability of two different images yielding the same SHA-256 hash is negligibly small — approximately 1 in 2^{256} — making hash collisions practically impossible.

After computing the image hash, the application invokes the smart contract by calling the isImageRegistered() function with the image hash as the parameter [4]. A search is executed via the image registry mapping in the contract to verify whether the hash already exists. If it does, the function returns true along with the owner's address, and the upload process is halted with an appropriate message.

3. IPFS Storage and Metadata Management

After a positive duplicate-check result, the application uploads the image file to IPFS via a pinning service such as Pinata or web3.storage. During the upload, the file is split into chunks, hashed, and stored following the IPFS protocol. The IPFS network delivers a Content Identifier

(CID), which is an address created by hashing the file content

$$CID = \text{Base58}(\text{Multihash}(\text{SHA256}(content))) \quad (1)$$

Along with the image file itself, the system produces a JSON metadata object that includes a title, cate- gory, tags, description, and visibility settings. This metadata is also sent to IPFS for storage, receiving a different unique CID. By separating image content from metadata, the system can query and index effi- ciently while sustaining immutability [5]. When metadata needs to be updated, a new version is created with a new CID, the blockchain record is updated to point to the new CID, and the history of previous versions is preserved.

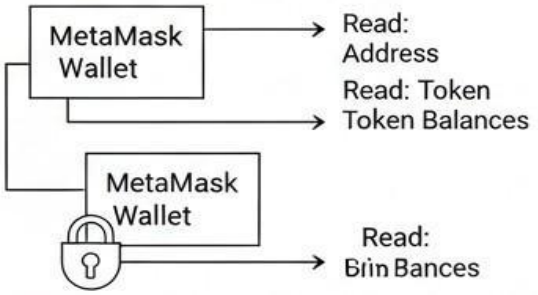


Figure 4: *Image Input and Hashing Logic*

4. Workflow

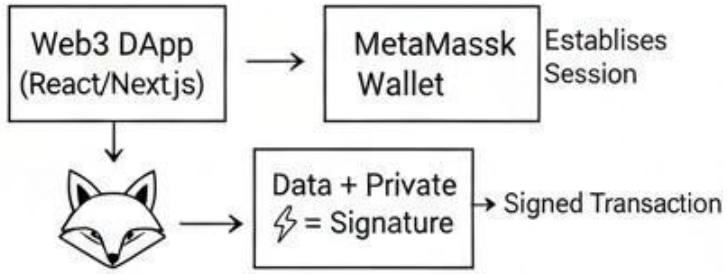
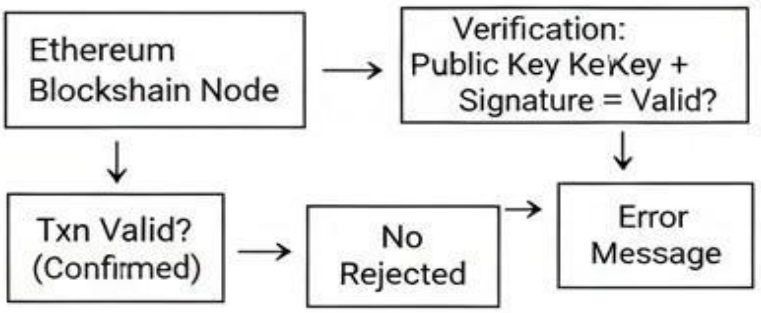


Figure 5: *Decentralised Data Persistence and Content Hashing Workflow*

5. Smart Contract Registration

Once the image CID and the metadata CID have been acquired from IPFS, the application calls the registerImage function of the smart contract. The function requires parameters such as the image hash, the image CID, the metadata CID, the address of the owner, and the visibility flag. The function first checks whether the sender's address corresponds to the owner's address in the parameters to prevent registering another user's image. A redundant duplicate hash check is performed to confirm the hash is not registered within the time duration between the first verification and the current execution.

The smart contract uses a mapping table with the image hash as a key and a struct containing all im- age information as a value. The struct has fields for address, image CID, metadata CID, timestamp, visibility status, number of likes, and access control list. The timestamp is automatically recorded with the block timestamp, giving a blockchain-based immutable timestamp of image registration. Finally, an ImageRegistered event is triggered with full details,



which can be used with indexing solutions to update off-chain databases for faster query results.

Figure 6: *Smart Contract Logic for Ownership Registration and Token Rewards*

6. Like-to-Earn Reward Mechanism

The reward distribution mechanism is triggered through user interaction with images via the like button. Upon clicking, the frontend invokes the likeImage() method of the smart contract with the image hash as an argument. The method fetches information about the image from the registry, increments the like counter, and determines the reward value based on predetermined logic — such as a fixed reward per like or a popularity-weighted metric.

The smart contract interacts with the ERC-20 token smart contract to perform the reward transfer. The transfer function of the token contract is called with the creator's address as the recipient and the calculated reward amount. Tokens are transferred from a reward pool sourced from platform fees or viewer deposits. The entire transaction occurs atomically; if the viewer does not have sufficient tokens, the entire transfer reverts.

7. Access Control for Private Images

Private image management requires additional smart contract functions to handle access requests and approvals. When a viewer seeks access to a private image, they invoke the requestAccess() func- tion with the image hash as a parameter. This function forms an access request record containing the requesting address, the image hash, the timestamp, and a pending status flag. An AccessRequested event is triggered, alerting the creator via the frontend app.

The creator reviews the access request through the dashboard UI. To approve, the creator calls the approveAccess() function with the request ID as the argument. The function verifies that the caller is the image owner, updates the request status to approved, and adds the requesting address to the access control list.

V. RESULTS AND DISCUSSION

1. Experimental Setup

The experimental validation utilises the Polygon Mumbai testnet for blockchain operations, Pinata IPFS pinning infrastructure for decentralised storage, and web browser environments for frontend validation. The development environment requires Node.js 18.16, Hardhat 2.12 for contract compilation and testing, and React 18.2 with TypeScript for frontend development. The system hardware comprises an Intel Core i7-11700K processor, 32 GB RAM, 1 TB NVMe SSD, and Ubuntu 22.04 LTS.

Performance testing uses 100 test images ranging from 500 KB to 5 MB in JPEG, PNG, and GIF formats at resolutions of 1920 × 1080 to 4096 × 2160 pixels. User experience testing involves

25 participants:

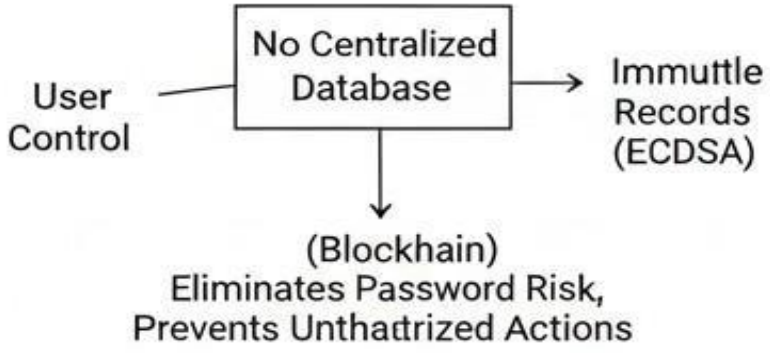


Figure 7: *Blockchain-Based Access Control and Permission Verification Logic*

professional image-makers (40%), digital artists (32%), and amateur image-makers (28%), with varying levels of cryptocurrency knowledge.

2. Performance Results

Table 2 presents the performance comparison of the proposed system against the conventional copyright registration process and other existing blockchain-based solutions. The outcome indicates significant improvement across all assessment parameters.

Table 2: Performance Comparison with Existing Systems

Metric	Traditional System	Early Blockchain	Proposed System	Improvement
Registration Time	8–12 months	15–60 min	8.3 seconds	99.997%
Registration Cost	$55–125	$5–50	$0.012	99.98%
Duplicate Detec-tion	Manual re-view	Hash compare	Automated (1.1s)	100% accuracy
Creator Revenue	N/A	N/A	90–95%	vs. 15–30% trad.
Storage Availabil-ity	Centralised	Variable	99.9% (IPFS)	Decentralised
Txn Throughput	N/A	15–30 TPS	2000+ TPS	Layer 2 scaling
Global Accessi-bility	Limited	Global	Global	Universal

The mean execution time for the full registration workflow is 8.3 s (σ = 1.54 s), broken down as follows: client-side hash calculation (0.82 s, σ = 0.18 s); blockchain duplicate query (1.15 s, σ = 0.31 s); IPFS image upload (4.47 s, σ = 1.23 s); IPFS metadata upload (0.68 s, σ = 0.15 s); on-chain transaction verification (1.76 s, σ = 0.42 s).

3. Duplicate Detection Evaluation

The testing of the duplicate upload detection mechanism involved 50 deliberately duplicate image up- loads. The findings confirmed successful rejection of all duplicates prior to IPFS upload by comparing hash values, with a response time of 1.1 seconds. The experiment further confirmed that two images of equal visual content with different JPEG compression levels produce different hash values, confirming the mechanism identifies exact duplicates rather than merely similar images.

4. Reward System Performance

The like-to-earn reward system was tested with 200 simulated like transactions. Reward transfers were successful with an average confirmation time of 2.3 seconds on the Polygon testnet. The gas requirement per like transaction was 0.008 MATIC (approximately $0.006), making it feasible for micropayment systems. Intentional failed transfers based on low balances confirmed that likes are still recorded even when the token payment fails.

5. Security Analysis

Code review by Slither, a static-analysis security tool, did not reveal any critical vulnerabilities in the deployed smart contracts. The deployed contracts include reentrancy safeguards for all functions related to token transactions or state modifications, thereby avoiding the most common attack vector. The access control modifier ensures that only image owners can approve access requests or modify image information. Integer overflow protection is provided natively by Solidity 0.8+, which includes automatic overflow checks. Gas optimisations are possible for batch operations to amortise base transaction fees.

6. User Experience Assessment

Results obtained from 25 participants indicated a high satisfaction rate in system functionality while pointing out areas requiring improvement in usability. Participants with prior cryptocurrency knowledge completed the registration process in an average of 3.2 minutes with a 92% first-time success rate. Participants without cryptocurrency knowledge took an average of 8.7 minutes with a 64% first-time success rate, primarily attributing difficulty to wallet installation and funding instructions.

The system sets up well with regard to the key goals of copy protection and just revenue. It creates immutably tamper-proof timestamps in the blockchain that offer definitive proof of ownership, verifi- able by anyone at any time. Blockchain ensures that no claim of ownership can be deleted or altered even if centralised systems cease to operate. The like-to-earn mechanism allows creators to earn di- rectly, bypassing intermediary platforms, potentially multiplying revenue by 200–500% in comparison to traditional ad-revenue models.

VI. CONCLUSION

This paper presented an overall system based on blockchain technology to facilitate digital image copy- righting and monetisation. Utilising Ethereum smart contracts, IPFS hosting, and SHA-256 hashing algorithms, the system is capable of registering copyrights instantly and inexpensively while generating an immutable record of ownership. Experiments have shown the effectiveness of the proposed system over the current copyright registration

process in terms of speed, cost, and accessibility. Registration time is reduced from months to seconds, cost is reduced over 4,000 times, and global access is available to anyone with a minimal amount of cryptocurrency.

The system's distinctive features include duplicate ownership detection, privacy access control, and like-to-earn rewards. However, UX challenges in cryptocurrency management and blockchain under- standing must be addressed. Scalability challenges may necessitate migrating to Layer 2 or alternative blockchains as transaction volumes increase. Legal and environmental concerns around blockchain us- age, particularly with respect to copyright law compliance, also merit further investigation.

VII. LIMITATIONS

The proposed system currently detects only exact duplicate images and cannot identify similar or deriva- tive works. The like-to-earn mechanism requires viewers to possess cryptocurrency tokens, creating a barrier to adoption for non-crypto users. Additionally, there is a significant on-boarding learning curve for users unfamiliar with Web3 technologies and cryptocurrency wallets. The system's dependency on Layer 2 blockchain infrastructure and external IPFS pinning services introduces certain operationalvulnerabilities if those services become unavailable.

VIII. RECOMMENDATIONS

Moving forward, several key areas for improving the proposed system have been identified. Enhanced usability features such as simplified wallet initialisation, gas fee abstraction, and reduced technical dis- closure will ease adoption. Blockchain platform interoperability will ensure registration and rewards are attainable on other blockchain platforms such as Ethereum, Binance, and Avalanche. The use of so- phisticated duplicate detection, featuring perceptual hashing and computer vision analysis, would help identify similar images with different encodings. Automated infringement tracking and image search would help systematically monitor infringements. Expansion of the system to cover video, audio, and 3D model content types would increase its usability. Development of legal frameworks for blockchain evidence in copyright cases will ensure wider acceptance of cryptographic timestamps as valid evidence in court.

IX. FUTURE WORK

Moving forward, there will be a focus on a number of key areas in improving the proposed system. Firstly, enhanced usability features such as ease-of-use wallet initialisation, gas fees, and technical disclosure will be addressed in order to ease adoption, as seen in the evaluation studies. Addition- ally, blockchain platform interoperability will ensure registration and rewards are attainable on other blockchain platforms, such as Ethereum, Binance, and Avalanche.

Third, the use of sophisticated duplicate detection, featuring perceptual hashing and computer vision analysis, would help identify similar images with different coding, which would take care of the issue of derivative works and trivial changes. Fourth, automated infringement tracking and analysis with an image-search facility would help systematically monitor infringements and kick-start the enforcement process. Fifth, the inclusion of content such as videos, audio, and three-dimensional models would increase the usability of the system.

Sixth, the legal framework development for best practices on the use of blockchain evidence in

copyright cases will ensure wider acceptance of cryptographic timestamps as valid evidence in court. Seventh, re- finements in the economic models for optimising cryptocurrency reward systems, governance structures, and sustainable funding solutions will ensure sustained success on the platform.

Finally, large-scale deployment testing with millions of users and billions of registered images will val- idate assumptions around scalability, help to find performance bottlenecks, and provide information on necessary strategies for optimising infrastructure. Longitudinal studies examining creator earnings, pat- terns of platform adoption, and community evolution will give further insight into the real-world impact and opportunities for continued improvements in the area of decentralised creator economy platforms.

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HEALTH CHALLENGES FACED BY EMPLOYEES IN IT SECTOR

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***Abstract*—The Information Technology (IT) sector is one of the fastest-growing industries globally, but the nature of its work environment has created significant health challenges for employees. Prolonged screen exposure, sedentary work patterns, tight deadlines, and high performance expectations contribute to both physical and psychological health issues. Common physical problems include eye strain, musculoskeletal disorders (such as back, neck, and wrist pain), obesity, and sleep disturbances caused by irregular working hours and night shifts. Alongside these, mental health concerns such as stress, anxiety, burnout, depression, and work-life imbalance are increasingly reported among IT professionals. The culture of continuous connectivity and job insecurity further intensifies emotional strain. These health challenges not only affect individual well-being but also reduce productivity, job satisfaction, and organizational efficiency. Addressing these issues requires a combination of ergonomic workplace design, mental health support systems, regulated working hours, regular health check-ups, and the promotion of work-life balance. The study of health challenges in the IT sector is therefore essential for developing sustainable employment practices and ensuring long-term workforce well-being.**

***Index Terms*—Information Technology employees, workplace stress, Ergonomics, sleep disorders, Job pressure, Employee well-being.**

I. Introduction

The Information Technology (IT) sector plays a vital role in modern economic development and digital transformation. IT professionals are engaged in software development, data management, networking, cybersecurity, and various technology-based services that demand continuous concentration and long working hours. While this sector offers career growth, innovation, and global opportunities, it also exposes employees to unique occupational health risks. The nature of IT work is largely sedentary and screen-based, often involving tight deadlines, shift work, and high performance expectations. These working conditions can lead to a range of physical health problems such as eye strain, back pain, neck stiffness, and repetitive strain injuries. At the same time, the pressure to meet targets, maintain productivity, and adapt to rapidly changing technologies contributes to mental health concerns including stress, anxiety, burnout, and sleep disorders. The increasing dependence on digital work has blurred the boundaries between professional and personal life, further affecting overall well-being. Therefore, understanding the health challenges faced by employees in the IT sector is essential for promoting a healthy workforce, improving productivity, and ensuring sustainable organizational growth.

II. Statement of the Problem

The rapid growth of the Information Technology (IT) sector has transformed the nature of work, making it more technology-driven and sedentary. IT employees are required to work for long hours in front of computers, often under high pressure to meet deadlines and performance targets. While this sector offers

numerous economic and professional opportunities, it has also led to a rise in various health-related issues among employees. In recent years, there has been a noticeable increase in physical health problems such as musculoskeletal disorders, eye strain, obesity, and lifestyle diseases among IT professionals. At the same time, mental health challenges including stress, anxiety, burnout, and sleep disorders have become more prevalent due to workload, job insecurity, and poor work-life balance.

Despite growing awareness, many IT organizations have not effectively addressed these health concerns. Employees often lack sufficient time, motivation, or organizational support to adopt healthy lifestyles. Moreover, existing studies tend to focus on specific health issues rather than providing a comprehensive understanding of the combined impact of physical, mental, and lifestyle factors. Therefore, the problem lies in the increasing health challenges faced by IT employees due to sedentary work patterns and stressful job conditions, and the lack of effective strategies to manage and prevent these issues. This study aims to examine the various health problems experienced by IT employees and to identify measures that can improve their overall well-being and productivity.

III. Review of literature

“Sedentary lifestyle in IT sector”

Lalloo et al. (2021) conducted a large-scale study using UK Biobank data and found that IT professionals experience significantly higher sedentary time compared to other occupations. The study emphasized that prolonged sitting is a major contributor to poor physical health, including obesity and cardiovascular risks.

“Musculoskeletal Disorders among IT Employees”

Parry & Straker (2013) highlighted that computer-based jobs have drastically reduced physical movement, leading to increased musculoskeletal disorders (MSDs) such as neck pain, back pain, and shoulder strain among IT employees.

Sharma & Khera (2019) conducted a study in India and found that over 60% of IT employees reported musculoskeletal pain, mainly due to poor ergonomics and long working hours. The study stressed the importance of workplace design and posture correction.

“Workplace Stress and Mental Health Issues”

Reddy & Babu (2018) examined mental health issues among IT professionals in Hyderabad and reported high levels of stress, anxiety, and burnout, mainly caused by workload pressure, tight deadlines, and job insecurity.

Ganster & Rosen (2013) studied workplace stress and found that high job demands combined with low control significantly increase the risk of psychological disorders, which is highly relevant in IT environments.

“Sleep Disorders and Irregular Work Patterns”

Kumar & Sundaram (2020) focused on sleep patterns among Indian IT employees and found that night shifts and extended screen time disrupt circadian rhythms, leading to insomnia, fatigue, and reduced productivity.

“Digital Eye Strain and Vision Problems”

Gupta et al. (2022) identified that IT employees frequently suffer from digital eye strain, caused by prolonged screen exposure. Symptoms include dryness, blurred vision, and headaches, which negatively affect work efficiency.

IV. Research gap and objectives of the Study

Most existing studies focus only on individual health issues such as stress or physical problems, rather than providing a comprehensive view of overall health challenges. Limited research is available on combined effects of physical, mental, and lifestyle factors among IT employees. There is a lack of India-specific studies, especially covering different regions and working conditions. Insufficient attention has been given to preventive measures and organizational strategies to improve employee health. Few studies analyze the long-term impact of IT work on employees’ health and productivity.

The objectives of the Study:-

- To identify the major health challenges faced by employees in the IT sector.
- To examine the causes of physical and mental health problems among IT employees.
- To analyze the impact of these health issues on employee productivity and performance.
- To study the role of work environment and lifestyle factors in influencing employee health.
- To suggest measures and strategies to improve the health and well-being of IT employees.

V. Researches methodology

This research is based on both doctrinal and non doctrinal research. The primary data collected in the form of questionnaires from respondents. The secondary data collected from various newspapers, magazines, books, reports, and e-sources. Sample size of The data collected from 111 respondents. In this research used stratified Random sampling. In this research the strategical tools are percentage Method and average method. The duration of the research is 3 months.

VI. Significance of the Study

The study provides a comprehensive understanding of both physical and mental health challenges faced by IT employees. It highlights the impact of sedentary work, long working hours, and job stress on overall well-being. The findings help organizations design better workplace policies, ergonomic setups, and wellness programs. It creates awareness among employees about the importance of regular exercise, proper posture, and healthy lifestyle habits. The study contributes to improving work-life balance, which is essential for long-term health and job satisfaction. It helps in identifying the relationship between employee health and organizational productivity. The research is useful for HR managers and policymakers to implement preventive health measures in the workplace. It adds to the existing literature and serves as a reference for future academic research in occupational health. The study also emphasizes the need for mental health support systems in the IT sector. Overall, it aims to promote a healthier workforce, leading to better efficiency and reduced absenteeism.

VII. Hypothesis of the study

1. Sedentary lifestyle is a major factor contributing to health problems among IT employees.

2. Work stress significantly affects the mental health and well-being of IT employees.

VIII. Limitation of the Study

The study is based on a small sample size, which may not fully represent the entire IT population. It is limited to a specific geographical area (e.g., Chennai), so the findings cannot be generalized to other regions. The study relies on self-reported data, which may be affected by personal bias or inaccurate responses. Time constraints restricted the scope and depth of the research. The use of convenience sampling may reduce the accuracy and reliability of results. Only selected variables such as stress, sedentary lifestyle, and working hours are considered, while other factors (diet, personal habits, genetics) are not fully analyzed. The study does not include long-term analysis, so it cannot measure future health impacts. Limited access to respondents and data sources may affect the completeness of information. Rapid changes in the IT sector may make the findings less applicable over time. The study may not fully capture organizational differences such as company policies and work culture.

IX. Result and discussion

Part - 1

1. Sedentary Work Pattern

The study clearly indicates that IT employees spend a major portion of their working hours in a sitting position, often exceeding 8–10 hours per day. This sedentary work pattern significantly reduces physical movement and contributes to a decline in overall physical health. Employees rarely engage in physical activities during work hours due to continuous tasks and tight schedules. This lack of movement increases the risk of obesity, poor posture, and long-term health complications. The findings suggest that sedentary behaviour has become a routine part of IT jobs and requires immediate attention through workplace interventions.

2. Musculoskeletal Problems

The results show that musculoskeletal disorders are one of the most common health issues among IT employees. A majority of respondents reported frequent neck pain, lower back pain, shoulder stiffness, and wrist discomfort. These problems are mainly caused by prolonged sitting, repetitive movements, and improper workstation setup. Many employees do not maintain correct posture while working, and lack of ergonomic furniture further worsens the condition. Over time, these issues can lead to chronic pain and reduced work efficiency, highlighting the importance of ergonomic awareness and workplace modifications.

3. Work Stress and Mental Health

The study reveals that work stress is a major factor affecting IT employees. High workload, strict deadlines, continuous performance evaluation, and job insecurity contribute to increased stress levels. Many employees reported experiencing anxiety, irritability, and emotional exhaustion. In severe cases, prolonged stress leads to burnout and depression. The findings indicate that mental health is often neglected in the IT sector, even though it plays a crucial role in employee performance and overall well-being. Proper stress management strategies are essential to address this issue.

4. Sleep Disorders

A considerable number of employees reported sleep-related problems such as insomnia, irregular sleep patterns, and insufficient sleep. These issues are more common among employees working in night shifts or handling international clients. Irregular work schedules disrupt the natural sleep cycle, leading to fatigue and reduced alertness. Lack of proper sleep not only affects physical health but also reduces concentration, decision-making ability, and productivity. The study highlights the need for maintaining proper work schedules and promoting healthy sleep habits.

5. Eye Strain and Vision Issues

The findings indicate that digital eye strain is a widespread problem among IT employees. Continuous exposure to computer screens for long hours causes symptoms such as dry eyes, irritation, blurred vision, and headaches. Many employees do not take regular breaks, which further increases eye discomfort. Poor lighting conditions and improper screen positioning also contribute to vision-related issues. This shows the importance of following preventive measures like the 20-20-20 rule and maintaining proper screen ergonomics.

6. Work-Life Balance

The study highlights that maintaining a healthy work-life balance is a significant challenge for IT employees. Long working hours, overtime, and work pressure often leave employees with limited time for family, social life, and personal care. This imbalance leads to stress, dissatisfaction, and reduced quality of life. Employees who fail to balance work and personal life are more likely to experience mental and physical health problems. The findings emphasize the importance of flexible work policies and time management.

7. Lifestyle and Health Practices

The results show that employees who adopt healthy lifestyle practices tend to have better overall health. Regular exercise, balanced diet, proper hydration, and taking short breaks during work help in reducing health risks. However, many employees reported lack of time and motivation to maintain such habits due to busy schedules. This indicates that both individual effort and organizational support are necessary to promote a healthy lifestyle among IT professionals.

8. Organizational Support

The study found that organizational support for employee health is limited in many cases. Few companies provide wellness programs, stress management sessions, or ergonomic training. Lack of such initiatives leads to increased health risks among employees. Organizations that offer supportive work environments, including flexible schedules and health programs, tend to have more satisfied and productive employees. The findings suggest that organizations must take active steps to improve employee well-being.

9. Impact on Productivity

The results clearly show that health problems have a direct impact on employee productivity. Physical discomfort, stress, lack of sleep, and eye strain reduce concentration, efficiency, and work output. Employees facing health issues are more likely to take sick leave and show decreased performance. This demonstrates that maintaining employee health is not only beneficial for individuals but also essential for organizational success.

10. Awareness of Health Issues

The study reveals that most employees are aware of the health risks associated with their work environment. However, awareness does not always lead to action. Many employees fail to adopt preventive measures due to workload, lack of time, or negligence. This gap between awareness and practice highlights the need for effective awareness programs and behavioral changes.

11. Need for Preventive Measures

The findings strongly emphasize the need for preventive measures to reduce health problems in the IT sector. Practices such as regular physical activity, ergonomic workplace design, stress management techniques, and proper work schedules can significantly improve employee health. Both employees and organizations must work together to implement these measures and create a healthier work environment.

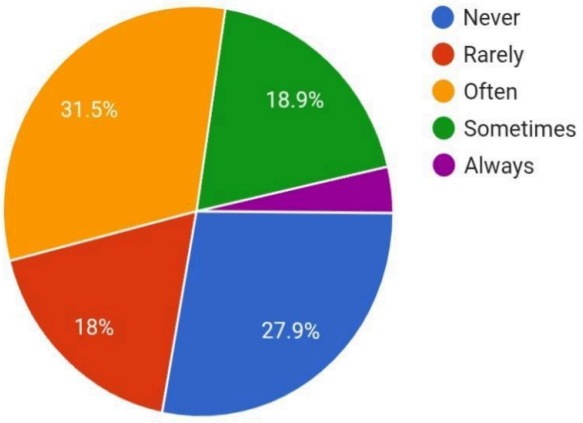
Part -2

Table :- 3 physical health challenges :-

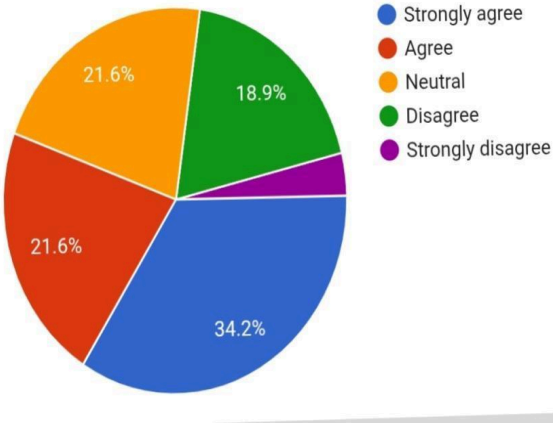
S. No.	Particulars	Options	No. Of Respondents
1.	Experience vision problems due to screen usage	Never	31 (27. 09)
		Rarely	20 (18. 00)
		Often	35 (31. 05)
		Sometimes	21 (18. 09)
		Always	04 (3. 06)
		Total	111 (100. 00)
2.	Feel physical fatigue even without heavy physical work	Strongly agree	38 (34. 02)
		Agree	24 (21. 06
		Neutral	24 (21. 06)
		Disagree	21 (18. 09)
		Strongly disagree	04 (03. 06)
		Total	111 (100. 00)
3.	Health issue has increased after entering the IT field	Eye problem	39 (35. 01)
		Neck / pack pain	32 (28. 08)
		Weight gain	27 (30. 00)
		Frequently headache	10 (9. 00)
		Total	111 (100. 00)
4.	Experience headache linked to work pressure or screen exposure	Very often	43 (38. 07)
		Often	28 (25. 02)
		Rarely	16 (14. 04)
		Sometimes	21 (18. 09)
		Never	03 (2. 07)
		Total	111 (100. 00)

Sources :- Primary data

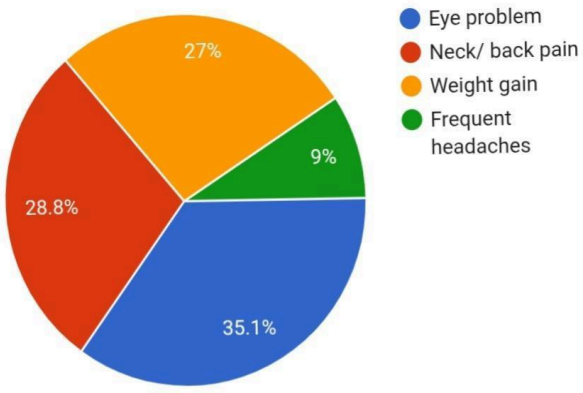
1. Experience vision problems due to screen usage :-



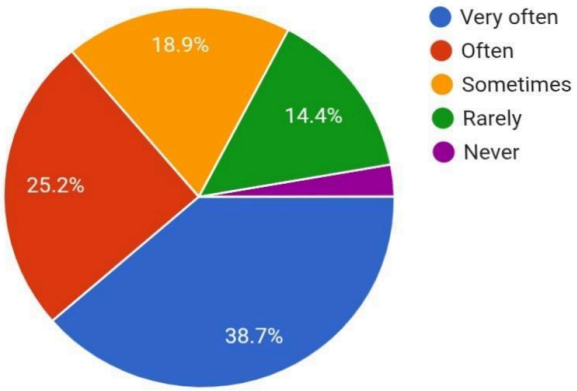
2. Feel physical fatigue even without heavy physical work :-



3. Health issue has increased after entering the IT field :-



4. Experience headache linked to work pressure or screen exposure :-

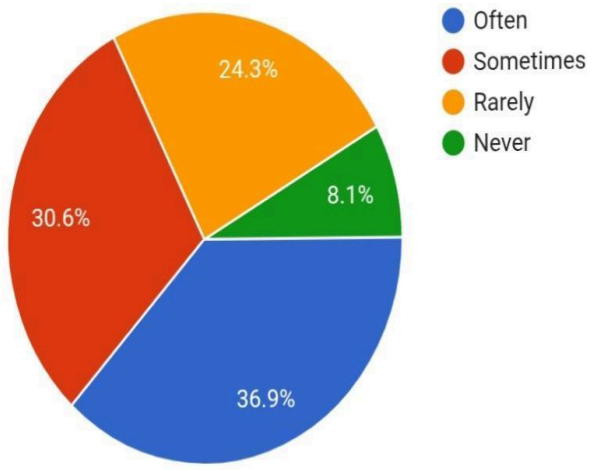


The results highlight that screen-related issues are common, with many respondents experiencing vision problems often 31.05 percentage or sometimes 18.09 percentage. Physical fatigue is also significant, as a majority either strongly agree 34.02 percentage or agree 21.06 percentage that they feel tired even without heavy physical work, showing the impact of sedentary jobs. Health issues such as eye problems 35.01 percentage, neck/back pain 28.08 percentage, and weight gain 30.00 percentage are widely reported after entering the IT field, indicating poor physical health outcomes. Additionally, headaches are frequent, with 38.07 percentage experiencing them very often, mainly due to work pressure and screen exposure.

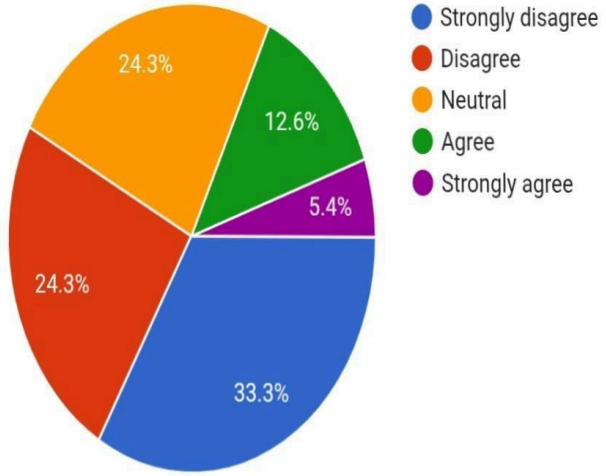
Table :- 4 Mental health challenges :-

S. No.	Particulars	Options	No. Of Respondents
1.	Feel emotionally detached or demotivated at work	Often	41 (36. 09)
		Sometimes	34 (30. 06)
		Rarely	27 (24. 03)
		Never	09 (8. 01)
		Total	111 (100. 00)
2.	Performance targets cause anxiety or emotional pressure	Strongly disagree	37 (33. 03)
		Disagree	27 (24. 03)
		Neutral	27 (24.03)
		Agree	14 (12. 06)
		Strongly agree	06 (5. 04)
		Total	111 (100. 00)
3.	Work stress affect your menstrual cycle	Strongly agree	35 (31. 05)
		Agree	21 (18. 09)
		Neutral	31 (27. 09)
		Disagree	16 (14. 04)
		Strongly disagree	08 (7. 02)
		Total	111 (100. 00)
4.	Personal stress pave the way for increased stress at workplace	Strongly agree	41 (36. 09)
		Agree	22 (19. 08)
		Neutral	24 (21. 06)
		Disagree	12 (10. 08)
		Strongly disagree	12 (10. 08)
		Total	111 (100. 00)

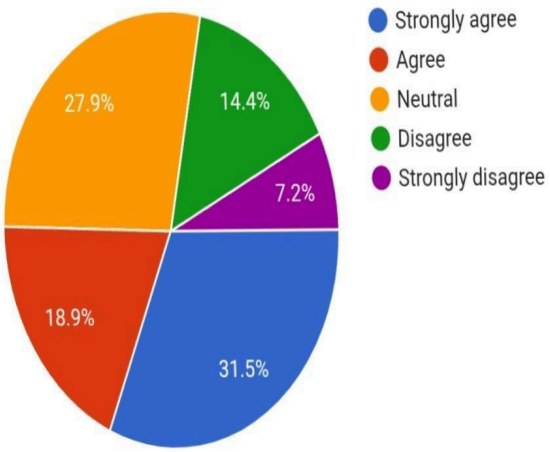
1. Feel emotionally detached or demotivated at work :-



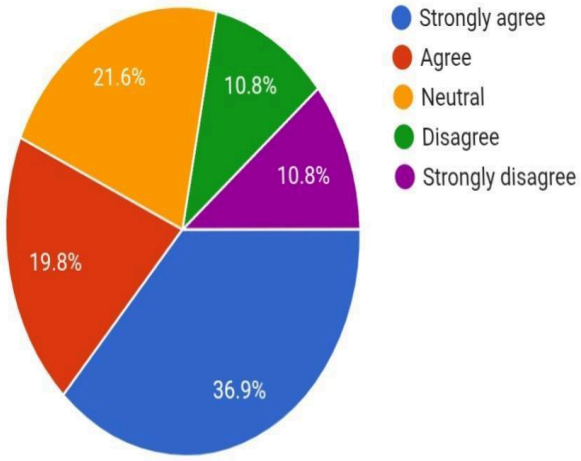
2. Performance targets cause anxiety or emotional pressure :-



3. Work stress affect your menstrual cycle :-



4. Personal stress pave the way for increased stress at workplace :-



The study reveals that emotional issues are prevalent among employees. A significant number feel emotionally detached or demotivated often 36.09 percentage or sometimes 30.06 percentage, indicating workplace stress. However, most respondents disagree 33.00 percentage or remain neutral 24.03 percentage about performance targets causing anxiety, suggesting mixed perceptions about work pressure. Work stress also impacts physiological aspects, as some respondents agree 18.09 percentage that it affects their menstrual cycle, though a larger proportion remains neutral 27.09 percentage. Furthermore, personal stress plays a major role in workplace stress, with 36.09 percentage strongly agreeing that it contributes significantly.

Part – 3

Testing of hypothesis :-

H1. Sedentary lifestyle is a major factor contributing to health problems among IT employees.

From the statistical data,

Table no. 3, shows that sedentary lifestyle is a major factor contributing to health problems among IT employees. The hypothesis is rejected. Therefore it is H1. Alternative hypothesis.

H2. Work stress significantly affects the mental health and well-being of IT employees.

From the statistical data,

Table no. 4, shows that work stress significantly affects the mental health and well-being of IT employees. The hypothesis is rejected. Therefore it is H1. Alternative hypothesis.

X. Conclusion

The present study on health challenges faced by employees in the IT sector reveals that the nature of IT work has a significant impact on both physical and mental well-being. The findings show that a sedentary lifestyle, long working hours, and high levels of stress are the major factors contributing to health issues among IT employees. Common problems identified include musculoskeletal disorders, eye strain, sleep disturbances, and mental health issues such as anxiety and burnout.

The study also highlights that poor work-life balance and lack of physical activity further worsen the overall health condition of employees. Although many employees are aware of these issues, they often fail to take necessary preventive measures due to workload and time constraints. Additionally, limited organizational support in terms of wellness programs and health initiatives increases the severity of these problems.

Overall, the study concludes that employee health is closely linked to productivity and organizational performance. Therefore, it is essential for both employees and organizations to take proactive steps to address these challenges and create a healthier work environment.

XI. Suggestions / Recommendations

1. IT employees should engage in regular physical exercise to reduce the effects of a sedentary lifestyle.
2. Employees should take frequent breaks during work to avoid strain and fatigue.
3. Organizations should provide ergonomic workstations to prevent musculoskeletal problems.
4. Companies must implement stress management programs such as counseling and relaxation techniques.
5. Flexible working hours should be introduced to improve work-life balance.
6. Employees should maintain a healthy diet and proper sleep routine.
7. Awareness programs should be conducted to educate employees about health risks and preventive measures.
8. Organizations should encourage wellness programs, including fitness activities and health check-ups.
9. Limiting continuous screen time and following practices like the 20-20-20 rule can reduce eye strain.
10. Management should create a supportive work environment that promotes employee well-being and productivity.

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SMART PET SHOPPING FOR FARMERS

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***Abstract*—Smart Pet Shop for Farmers is an all-in-one solution to digitalize purchasing, selling and managing the many types of pets and pet products people use in the rural and semi- urban communities. The Smart Pet Shop for Farmers integrates four key roles: the Admin Role, Pet Owner (Farmers), Shop Owners and Users, to keep all players connected. One goal of the project is to create a centralized platform where both farmers and pet owners can easily find pets, food, accessory and medications. The Admin Module is responsible for overall operations of the system including user authentication, approving products, and ensuring data security. Shop owners list pets, food, accessories and medications on the platform, keep track of stock, update pricing in real-time, and receive status updates on orders from customers.**

***Index Terms*—Smart Pet Shopping, Farmers, E- Commerce Platform, Pet Management System, Online Pet Marketplace, Digital Agriculture Support**

I. Introduction

Farmers' Smart Pet Store is a modern, online application that has been created to assist those in agriculture and people who own pets or run pet businesses by creating a app where pets can be sold or bought as well as managed. Traditionally, farmers and customers relied primarily on physical stores (pet shops) and local markets, which are both time-consuming and often inefficient. This project was developed in an attempt to provide a centralized, user-friendly online solution for these

users. The application consists of four modules: Admin, Pet Owner, Shop Owner, and User. Each of these users has a specific purpose and role within the system. The Admin of the system has the best knowledge of how to properly manage the overall operation of the Smart Pet Store by keeping all information about Pet Owners, Shop Owners, and Users up to date, as well as facilitating the communication between them to ensure that everything runs smoothly and securely. There are

several different registration types within the system, and therefore Pet Owners, Shop Owners and Users are able to register and login to the system using their specific registration type (Pet Owner, Shop Owner, User).higher susceptibility to configuration errors across distributed network endpoints.

Centralized policy orchestration, combined with real-time application-aware traffic analytics, enables uniform rule deployment, rapid policy updates, and improved operational efficiency. By integrating application context into firewall decision-making, modern security frameworks can significantly enhance network visibility, strengthen administrative control, and improve the overall security posture of complex network infrastructures.

II. RELATED WORKS

The concept of Smart Pet Shopping for Farmers is closely associated with the evolution of e-commerce platforms, agricultural support systems, and smart livestock management technologies. Several researchers and developers have focused on digital marketplaces, IoT-based animal monitoring, and AI-driven recommendation systems to support farmers and pet owners in buying and managing animals and related products efficiently.

Earlier studies on online livestock trading platforms highlighted the importance of centralized digital

systems that connect farmers, sellers, and buyers in a single interface. Traditional livestock markets often suffer from lack of transparency, price fluctuation, and limited accessibility. To overcome these challenges, web-based agricultural marketplaces were introduced to enable farmers to list animals, compare prices, and perform secure transactions.

Research on agricultural e-commerce systems emphasized the need for user-friendly interfaces and secure payment integration for rural users. Many platforms were designed to support agricultural product sales, but only a few focused specifically on pets .in the app that detects all in one website.

Existing agricultural portals primarily handle crop products, fertilizers, and tools, while pet-related services such as veterinary medicines, pet food, and accessories are rarely integrated into one unified system. This gap created the necessity for a Smart Pet Shopping system tailored for farmers and rural pet owners.

Several works have also explored IoT-based livestock monitoring systems where sensors are used to track animal health, feeding patterns, and environmental conditions. These systems help farmers monitor livestock remotely and reduce manual effort. However, such solutions mainly focus on animal health monitoring rather than marketplace integration. Combining monitoring features with an e-commerce module can significantly enhance smart farming practices.

Mobile-based farm assistance applications have been developed to provide farmers with information about animal care, vaccination schedules, and market prices. These applications improve decision-making but do not provide direct buying and selling functionality for pets and related products

III. PROPOSED SYSTEM

The proposed Smart Pet Shopping for Farmers system is a centralized digital platform designed to simplify the process of buying, selling, and managing pets and pet-related products for farmers and rural users. The system integrates e-commerce functionality, inventory management, and farmer- friendly interfaces into a single smart application. It connects Admin, Shop Owners, Farmers (Pet Owners), and General Users through a secure and user-friendly environment.

A. SYSTEM ARCHITECTURE

The system follows a multi-tier architecture consisting of the Presentation Layer, Application Layer, and Database Layer. The presentation layer provides an interactive interface for users to browse pets and products. The application layer handles business logic such as authentication, product management, and order processing. The database layer stores user details, pet listings, product information, and transaction records securely. This architecture ensures scalability, reliability, and efficient data handling. The user interface layer handles interaction between users and the system through web or mobile devices. The application layer processes business logic such as authentication, search operations, order management, and notifications. The database layer stores all system-related data including user profiles, pet records, product details, and transaction history. This architecture ensures smooth data flow, high performance, and system scalability for future expansion traffic logs, enabling detailed monitoring and detection of abnormal or unauthorized activities.

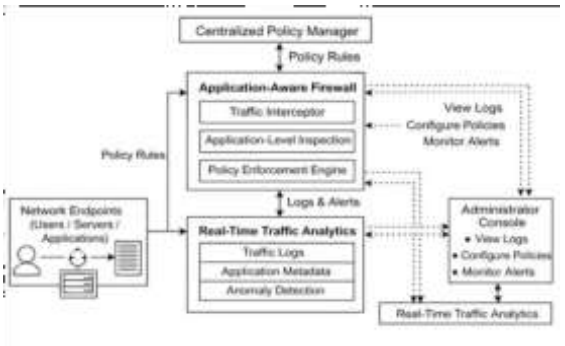


Figure 1. Architecture Diagram

B. USER REGISTRATION AND AUTHENTICATION MODULE

This module is responsible for secure user onboarding and login management. Farmers, shop owners, and general users can register by providing essential details such as name, mobile number, email id, and password. The system validates user credentials and provides secure login access using authentication mechanisms. Password encryption and validation techniques are implemented to protect user accounts from unauthorized access. Role-based authentication ensures that each user accesses only the features assigned to their role, thereby enhancing system security and usability.

C. SHOP OWNER MODULE

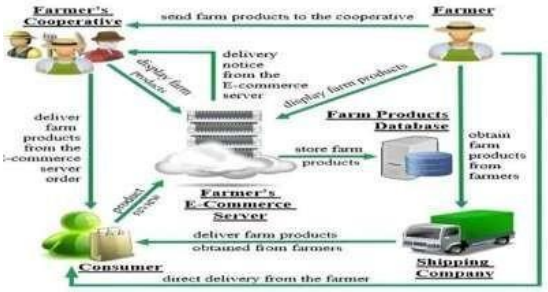
The shop owner module is designed for sellers who provide pets and pet-related products. Shop owners can create and manage their digital store within the platform by uploading pet images, descriptions, breed details, pricing, and stock availability. They can also add pet food, grooming products, accessories, and veterinary medicines to the catalog. The module allows shop owners to update product details in real time, manage incoming orders, and track sales performance. This digital approach helps shop owners expand their business reach beyond local physical markets.

D. FARMER/USER MODULE

The farmer or user module is specifically designed to support rural and semi-urban users with a simple and intuitive interface. Farmers can browse available pets, compare different breeds, view health details, and select suitable pets based on their farming needs. They can also purchase feed, medicines, and accessories directly from the platform. The module includes features such as order tracking, purchase history, profile management, and notification alerts. This ensures that farmers can access all required services without needing advanced technical knowledge.

IV. SYSTEM WORKFLOW

The system workflow of the Smart Pet Shopping for Farmers platform begins with user registration and secure login, where farmers, shop owners, and admins access the system based on their roles. After login, users enter the dashboard to browse pets, products, and services available in the platform. Shop owners upload pet details, product information, images, and pricing, which are stored in the database and sent for admin verification. The admin reviews and approves valid listings to ensure authenticity and quality control. Farmers can search, filter, and compare pets and pet-related products based on category, breed, and price range. Once the desired pet or product is selected, users add items to the cart and proceed to order placement.



V. IMPLEMENTATION

The implementation of the Smart Pet Shopping for Farmers system is carried out using a structured software development approach to ensure efficiency, scalability, and reliability. The system is developed as a web-based application using front- end technologies such as HTML, CSS, and JavaScript to create a user-friendly and responsive interface suitable for farmers and shop owners. The back-end is implemented using a server-side programming language that handles business logic, user authentication, product management, and order processing. A relational database management system is used to store user details, pet listings, product information, application context, the policy evaluation engine compares traffic attributes against centrally The development process begins with requirement analysis, where system functionalities such as pet listing, product catalog, admin control, and order management are clearly defined. After analysis, the system design phase is completed using modular architecture, dividing the application into modules like Admin Module, Shop Owner Module, Farmer/User Module, and Payment Module. Each module is implemented separatelyand then integrated to form a complete system.

definition, storage, versioning, and distribution. Policy updates are dynamically propagated to all firewall agents, ensuring consistent and timely enforcement across multiple network nodes. Secure communication mechanisms are employed to protect policy transmission and prevent unauthorized access or tampering.

The real-time monitoring and analytics module continuously collects traffic logs and application metadata from firewall agents. These data are analyzed to detect anomalous patterns, policy violations, and potential security threats. The analytics framework supports continuous monitoring and provides actionable insights through an administrative interface, enabling informed decision-making and effective network security management.

VI. RESULTS AND DISCUSSION

The implementation of the Smart Pet Shopping for Farmers system resulted in the successful development of a centralized digital platform that connects farmers, shop owners, and users in a single environment for buying and selling pets and pet- related products. The system was tested with multiple user roles including Admin, Shop Owners, and Farmers to evaluate its performance, usability, and functionality. The results show that the platform effectively simplifies the traditional pet purchasing process by providing easy access to pet listings, product catalogs, and secure ordering features.

During system testing, the user registration and authentication module functioned accurately by allowing secure login and role-based access control. The pet listing and product management modules successfully stored and displayed real-time data such as breed details, price, stock availability, and product descriptions without any data loss. Farmers were able to search, filter, and compare pets and products efficiently using the smart search mechanism

The order processing and payment modules performed reliably by enabling users to add pets and products to the cart, place orders, and receive instant confirmation notifications. Transaction records were

stored securely in the database, ensuring transparency and traceability of purchases. The notification system also worked effectively by providing real-time alerts for order updates, new pet listings, and product availability, which improved user engagement and communication between stakeholders.

From a usability perspective, the system interface was found to be simple, responsive, and farmer-friendly. Even users with basic technical knowledge could navigate the platform easily due to clear menus, image-based displays, and structured categories.

VII. CONCLUSION AND FUTURE WORK

The Smart Pet Shopping for Farmers system was successfully designed and developed to provide a digital solution for buying, selling, and managing pets and pet-related products in a centralized platform. The system effectively integrates multiple user roles such as Admin, Shop Owners, and Farmers into a single environment, ensuring smooth interaction and efficient marketplace operations. Through the implementation of modules like pet listing, product management, smart search, secure payment, and order tracking, the platform simplifies the traditional pet shopping process and reduces manual effort. The results demonstrate that the system improves accessibility, transparency, and convenience for farmers, especially in rural and semi-urban areas where physical pet markets are limited.

The proposed system enhances decision-making by providing detailed pet information, product descriptions, and real-time availability updates. It also promotes better animal care by offering easy access to feed, medicines, and accessories in one platform. The admin verification process ensures authenticity of listings and maintains system reliability and security. Furthermore, the user- friendly interface makes the platform suitable even for users with basic digital knowledge, thereby encouraging digital adoption in the agricultural sector.

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PERSONALIZED INTELLIGENT VOICE-ASSISTED AI TRIP PLANNING SYSTEM

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***Abstract*—But a new breed of travel technology has come along, with the effect of suddenly quickening every process, so that every option feels suddenly reachable while entwining planning itself in smaller, more complex ways. The task is bigger, too—to handle all at once your travel agent, your travel apps like endpoints, route, where you stay, what you do, money, and notifications. What this article describes is a better, customized, voice-driven travel planning assistant that harnesses all that information to make a sharper, more customized trip experience. The trip planning assistant is equipped with voice support, optimizing the use of the webpage. It harnesses massive intelligence models, natural language interfaces, so that it is fueled by real-time information from public APIs, creating a trip experience that is personal, dynamic, yet personal, yet short, yet budget-compliant. It also strives for a hands-free experience for ultimate access. Vacation travel planning becomes faster, creating a personal experience.**

***Index Terms*—AI Trip Planning, Voice Assistant, Personalized Itinerary, LLMs, NLP, Real-Time Data, Smart Travel, Hands-Free Interaction**

I. Introduction

The contemporary tourism environment has somehow interwoven itself into everyday life, encouraging travel as a way to have fun, study through travel, or travel through work-related engagements. While it is true that different platforms exist on the internet to enable travelers to plan their travel-related activities, the process of organizing a trip from beginning to end still remains quite tedious. The traveler finds themselves jumping from different apps to plan routes, book a hotel, check the weather, organize finances, and identify things to do.

Most traditional travel planning tools provide inflexible suggestions and need users to put in information manually. These tools cannot adapt to up-to-date information, such as traffic, weather, or nearby events. In addition, tools are often siloed. Separate systems for booking and navigation are the standard, and they do not provide integrated solutions. As these systems become increasingly advanced, users are expecting smart systems to provide travel assistance that is personalized and adapts to the current context.

Advances in AI, especially in natural language processing and large language models, are opening up new possibilities for smart travel planning. AI-driven systems understand user preferences and intent and help create optimized itineraries in seconds. Melding these with real-time data from maps, weather services, and location-based APIs, such systems make recommendations that adapt to the changes in the course of travel conditions and continuously update recommendations.

Most travel applications lack or underutilize voice functionality and AI for smart itinerary planning. Voice-assisted technologies offer natural, hands-free interaction that is particularly important to users while multitasking in need of accessible interfaces. Voice technology also enhances usability and accessibility. This paper proposes a system that overcomes these challenges: the Personalized Intelligent Voice-Assisted AI Trip Planning System. The system planning combines AI reasoning with real-time data, integrating multiple modes of interaction to yield travel itineraries that are personalized and consider the user's budget, and adaptable, hence improving the overall efficiency in planning with reduced effort on the user's side.

II. Literature Review

In recent years, research on the use of artificial intelligence in the travel and tourism industry, in particular in the areas of recommender systems, chatbots, and travel route optimization, has been conducted extensively. Initial travel planning systems were rule-based and provided destinations, routes, and accommodations as fixed options. While they showed the potential of automated systems, they were too rigid and did not contain real-time data updating, so they were not very useful in practice. More advanced systems came to rely on recommendation engines which recommended attractions, accommodations, and tourist packages based on user preferences and past bookings. Established tourism industry players have incorporated collaborative filtering in combination with content-based filtering in order to personalize their offerings. While these systems provided user engagement, they were based in large part on review and rating systems so they did not respond to real-time weather, traffic, or local events.

[1] Most of the early travel planning systems provided static information about the destination and some simple suggestions about the itinerary. Traditional systems, such as travel blogs or guide websites, include this kind of descriptive content about tourist attractions, accommodations, and routes. While these systems enhanced access to information.

[2] Recommendation-based approaches were then taken up by several commercial travel applications. Recommendation-based approaches have been integrated into web platforms such as TripAdvisor, MakeMyTrip, and Expedia. They provide recommendations based on user ratings and reviews, supported by some basic filtering on user preferences. Such systems enhanced the usability of platforms but were largely dependent on static datasets and selection driven by the user. They also cannot update their itineraries automatically for real-world factors like weather changes, traffic conditions, or event schedules. Therefore, they are not very effective at providing end-to-end planning of trips.

[3] Recent works have focused on AI and machine learning applications in travel planning. Various researchers have shown that AI-based recommendation systems can analyze users' preferences regarding budget, interests, and travel duration to make custom recommendations. Most of these AI-based systems focus on standalone modules like recommending a hotel or attraction and do not consider the end-to-end goal of itinerary planning with holistic optimization of transport, accommodation, and activities in one plan.

[4] The development of NLP and LLMs has made conversational travel assistants a popular topic. Users can input their needs and ask for contextualized travel recommendations using chat interfaces. However, most provide no facility for real-time data integration and/or the continuous updating of their proposed itineraries; thus, while these solutions enhance user engagement, many remain purely text-based interaction and are rudimentary in practice.

[5] Moreover, accessibility in the travel domain has been further improved by voice-assisted technologies. According to a number of studies, voice-enabled interfaces enhance the ease of use for people with the need or preference for hands-free interactions and generally for accessibility concerned users. Yet, most voice-based travel assistants that already exist support only simple forms of queries such as finding a destination or route, but they do not have intelligent reasoning capabilities that could provide users with multi-day, personalized itineraries and dynamic plan updates.

[6] Recent research also focuses on the inclusion of real-time APIs like mapping services, weather data,

and local event information into travel planning systems. While some of the existing systems may partially integrate data in real-time, they usually fall short of integrating AI-based reasoning, voice interaction, and dynamic itinerary optimization into a single framework.

[7]. Several studies emphasize the importance of integrating real-time data sources such as Google Maps, weather services, traffic updates, and event information into travel planning systems. However, there are some apps that do introduce real-time data to a certain extent, but they do not integrate real-time data with reasoning using artificial intelligence and speech interaction capabilities in a single systematic approach. It leads to scattered functionality rather than a seamless experience for traveling-related planning.

Recent research also highlights the gaps in the context of budget-conscious travel planning. Most systems only use budget as a filtering criterion and not as a consideration for intelligent optimization towards cost, convenience, and user requirements, which include alerts and user preferences. The usefulness of the travel routes created by the systems is, therefore, limited for the cost-conscious traveller.

III. Proposed System

What is being proposed is a personalized, intelligent voice-assisted AI that can manage trip planning in a single, cohesive package. It utilizes natural language processing based on large language models that can understand what is being said, whether spoken or typed. The essential information for travel, namely where a person is headed, how long they will be staying out, their budget, and their individual preferences, is gathered and processed for a customized trip plan. In a nutshell, it reduces having to manage trip planning with a variety of apps and cuts down the work entailed in trip planning.

Real time data integration, such as matching services, weather forecast updates, and surrounding traffic information, enhances the adaptability of the system and its accuracy. Travel plans are updated continuously based on change in conditions to provide safe and timely travel planning. A voice-assisted intelligent interface increases accessibility and allows for more hands free interaction. The system couples intelligent reasoning with Seamless live data integration and multi-channel interaction in support of efficient, user-centered dynamic travel planning.

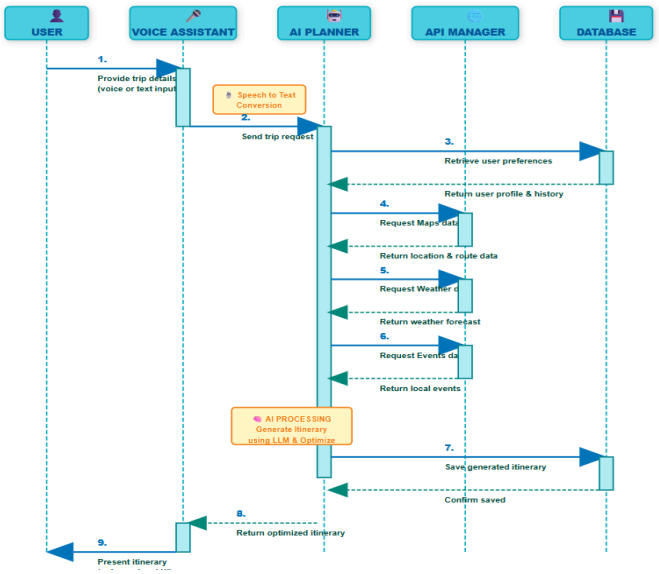


Fig. 1. Workflow of Intelligent Voice-Assisted AI Trip Planning System

IV. METHODOLOGY

The functional framework of the proposed system outlines the complete process of smart travel planning. system, from user input to a Smartly optimized trip plan. The framework supports individualized experiences with automated execution, and real-time adaptability are guaranteed. The detailed workflow of the system is illustrated in Fig. 2.

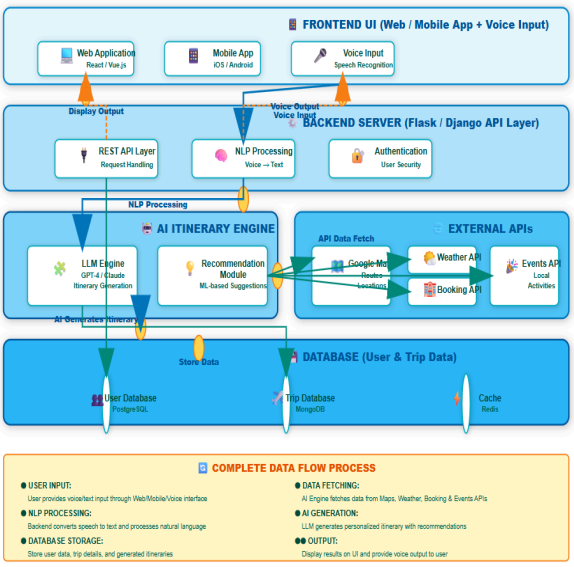


Fig.2:Architecture of Intelligent Voice-Assisted AI Trip Planning System

Step 1: User Input through Voice or Text Interface

It The workflow of the response begins by interacting with the system through voice or a text-based interface. Users will be allowed to specify naturally their trip requirements in terms of destination, travelling dates, budget and expenses , interests, and constraints. Interaction via voice significantly enhances accessibility and ease-of-use because of hands-free communication.

Step 2: Collect input data and preprocess

After the complaint is submitted, the text relating to the complaint is read and preprocessed. Preprocessing the complaint includes actions such as tokenization and the stripping of unnecessary words.

Step 3: NLP Processing

These inputs are further processed and fed to the NLP engine. NLP processing involves the intent detection and entity extraction process to acquire the significant travel information such as locations, travel time, budget constraints, and user preference.

Step 4: Smart Itinerary Review

Here, a system with the capability to employ AI reasoning using large language models to filter the acquired information. The system considers a multiplicity of things simultaneously: what the user wants, the cost, and the viability of the journey to formulate a trip plan that's optimized.

Step 5: Customization and Fine-Tunning

Based on the analysis, the following personalized program is developed. It is refined to be most cost-efficient, time-efficient, and based on the user's interest choices. Routes of travel, hotels, and activities will be selected according to the user preferences.

Step 6: Data Storage
Live Data Boost a We enhance the resulting itinerary by incorporating feeds from other APIs, including maps, weather, and traffic. If the situation changes, for instance, poor weather, the itinerary will be modified by the system to ensure that the resulting itinerary is as accurate as possible.

Step 7: Delivery and Hands-on Interaction
The final schedule appears in the user interface for evaluation. The users can modify it, request changes, or relay updates through speech or text. An ongoing conversation helps

V. RESULTS AND DISCUSSION

The Personalized Intelligent Voice-Assisted AI Trip Planning System is a practical implementation that shows a marked improvement in the efficiency, flexibility, and usability of trip planning. The system is able to provide end-to-end personalized trip plans by integrating user preferences, budget, and trip duration with real-time data from mapping, weather, and location-based APIs. The voice-assisted functionality of the system allows users to plan and change their trips without using their hands, thus eliminating the need to toggle between multiple applications. The system also provides dynamic updates based on changes such as weather, traffic, or schedule changes to ensure that the trip plans are relevant and optimized throughout the trip. The proposed system is faster, more personalized, and contextually aware compared to traditional static trip planning systems.

The project proves the viability of combining large language models, natural language processing, real-time data, and voice assistance into one system and its ability to greatly improve the travel planning process. The project proves its value to users by providing them with a simplified process, ease of access, and optimized budget-friendly travel recommendations that take into consideration cost, convenience, and users' interests. The project outcomes demonstrate the potential of the system to act as a complete virtual travel assistant and its ability to assist contemporary travelers with intelligent, adaptive, and user-focused travel planning.

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VI. CONCLUSION

Conclusion of this project says that Personalized Intelligent Voice-Assisted AI Trip Planning System is an effective solution to overcome the shortcomings of the conventional trip planning system. The system utilizes the power of large language models and natural language processing, along with the data provided by external APIs, to provide personalized trip plans based on the preferences of the user. The inclusion of voice interaction functionality makes it possible to use the system without using hands, making the process more efficient for users who are multitasking or require accessible interfaces.

In summary, the proposed system shows the potential of AI-based travel assistants in revolutionizing the planning and management of travel. The proposed system not only reduces the complexity of managing multiple applications but also eliminates the need for human intervention and offers continuously updated recommendations to enhance decision-making during travel. The successful implementation of intelligent reasoning, real-time information, and voice support in the proposed system opens up a promising area of research and development in the field of smart tourism.

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AI POWERED VIRTUAL OUTFIT CHECKER

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***Abstract*—Internet clothing shopping still faces problems such as inappropriate size selection, outfit mismatch, and limited visualization of clothing display on particular users. Virtual try-on systems have been developed to address the above problems, however many of the existing solutions are limited to original e-commerce platforms and do not consider handling reliable validation to prevent mismatched outfit combinations. The present disclosure relates to a cross-platform AI-based virtual fitting system for displaying apparel purchased from multiple online shopping platforms in a single try-on session. The suggested system allows a user to upload a full-body photograph and to submit links to top wear, bottom wear, footwear or complete attire products that come from different platforms, if any. In order to produce meaningful and realistic results, a multi-level mismatch validation system is built for assuring category correctness, gender fusion, and logical clothing-type consistency before initiating the virtual fitting process. User characteristics such as gender and other body measurements are taken into consideration to improve garment fitting and sizing. The acceptable clothing items are overlaid on the user's body-photograph by using image processing techniques to produce a realistic outfit display. The obtained results are stored temporarily on the local device, to protect user privacy.**

***Index Terms*—Virtual Try-On, Computer Vision, Online Fashion, Image Processing, E-Commerce, Mismatch Verification, Cross-Platform Integration**

I. Introduction

The Online shopping of e-commerce platforms has brought dramatic changes to consumers' fashion product shopping behavior.However, buying apparel online is still not free of many issues, such as wrong size and outfit selection, and customers' uncertainty of how the apparel looks in them.The virtual try-on technology is proposed as an effective solution to this problem by helping users to view the apparel items digitally.Being usually designed for its corresponding platform, most existing virtual try-on solutions are limited to specific platform ecosystems, thus users would not be able to mix and match garment from multi-platforms to form a complete outfit, which limits flexibility and usability.Experiments and surveys have been run in this paper to propose a multi-platform-based virtual try-on solution to support clothing aggregation from multiplatform e-commerce sites in a single workflow. Moreover, a multi-level mismatch verification engine has been proposed to verify the user inputs before the execution of the try-on.Ideal try-on systems should be accurate, realistic, and induce confidence of the users.

Therefore, we proposed a multi-platform and privacy-preserving virtual try-on system by temporarily saving the results on local user machines.

II. LITERATURE REVIEW

Recent advancements in artificial intelligence and computer vision have significantly influenced the fashion technology domain, particularly in areas such as outfit generation, recommendation systems, and virtual try-on solutions. This section reviews key research works relevant to the proposed system and highlights their contributions and limitations.

In this work, a new way of generating outfits is shown by using large language models (LLMs) and visionbased style extraction. This system looks at visual details like color choices, fabric types, and clothing shapes in photos to create outfits for a fictional or themed character. In this process, the results from the vision-augmented part are combined with the prompts in text format so that the generated outfits are more stylistic overall. The main contribution is that it bridges the gap between visual understanding and language-mediated reasoning for more expressive and context-aware outfit generation.

This study explores the use of deep neural networks (DNNs) to improve personalized fashion recommendations. By analyzing user preferences, browsing history, and purchase behavior, the proposed model suggests outfits tailored to individual tastes. The system employs feature embeddings to capture relationships between different clothing items and user profiles. The primary strength of this approach is its focus on personalization and data-driven recommendations.

This paper presents a deep learning–based approach for improving personalized fashion outfit recommendations by analyzing user preferences and clothing attributes. The proposed system employs deep neural networks to learn complex relationships between users and fashion items, enabling more accurate and contextaware outfit suggestions. By processing historical user interaction data, such as previous selections and preferences, the model captures latent style patterns that traditional rulebased or collaborative filtering methods fail to identify. The study focuses on modeling fashion compatibility between clothing items and aligning recommendations with individual user tastes. Feature extraction techniques are applied to clothing images and metadata to represent garments in a high-dimensional space.

This paper presents a fuzzy inference–based recommendation system aimed at promoting sustainability within the fashion industry by intelligently suggesting outfits that balance user preferences, fashion trends, and environmental impact.

The proposed system addresses the inherent uncertainty and subjectivity involved in fashion decisionmaking, such as varying personal tastes, comfort levels, and sustainability awareness, by leveraging fuzzy logic rather than rigid rule-based methods.

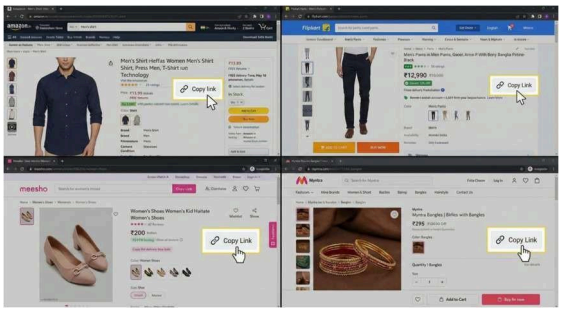
The rapid growth of e-commerce and digital retail has accelerated the adoption of artificial intelligence (AI) in the fashion industry to enhance user experience and decision-making. This survey presents a comprehensive review of AI-driven fashion technologies, focusing on three major domains: clothing detection, fashion recommendation systems, and virtual try-on solutions. The paper examines how computer vision techniques such as image classification, object detection, and human pose estimation are employed to identify clothing items and extract fashion attributes from images.

III. METHODOLOGY

The proposed system follows a modular and sequential methodology designed to ensure accurate outfit visualization while preventing incorrect or illogical try-on results. The overall workflow integrates user input processing, product link analysis, multi-level mismatch verification, and AI-based virtual try-on generation. Each stage contributes to improving realism, reliability, and usability of the system.

1. Data Collection

The user provides base user information such as name, chosen gender and optional body measurements including height, chest, waist and hip. These measurements are used to assist decisions about garment scaling, alignment and validation during later stages of the workflow. The user uploads a full body image, preferably front facing, which is used as the base image for the virtual try on workflow which it is temporarily stored and preprocessed to have a common resolution and to be compatible with further image processing operations.



2. Product Link Collection and Categorization

The system has pre-defined fields corresponding to the clothing category full dress, top wear, bottom wear and footwear. Product links retrieved from different e-commerce sites are pasted into the designated category.The proposed solution differs from conventional systems in that each product link can be retrieved from a different platform.

The cross-platform nature facilitates a mix-andmatch approach of combining garments from different ecommerce sites to create a complete outfit.

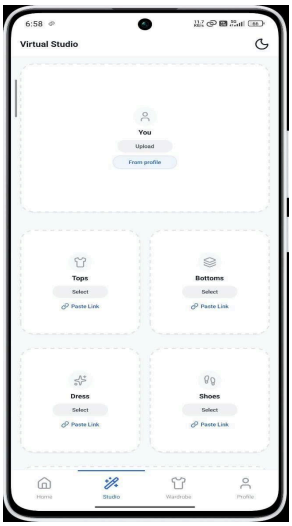


Fig:3.2 product collection and Categorization

3. Product Information Extraction

Once the links are submitted, the system extracts essential product metadata such as product title, category keywords, and associated images. This extraction process is designed to be platform-independent, allowing the system to handle links from multiple e-commerce websites without relying on platform-specific integrations.

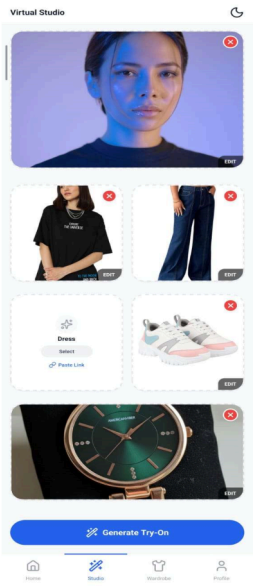


Fig 3.3 Product Information Extraction

The extracted information serves as the input for the validation and verification stages.

4. Multi-Level Mismatch Verification

A key contribution of this work is the multi-level mismatch verification engine, which validates all inputs before initiating the virtual try-on process. This verification is carried out in four stages:

A. Category-Level Verification:

Ensures that each product link corresponds to the clothing category in which it is placed. Incorrect placements, such as footwear submitted as top wear, are identified and blocked. B. Gender Compatibility Verification:

Verifies whether the selected product is suitable for the user's chosen gender. Gender-incompatible products are flagged, and the user is notified before proceeding. C. Logical Dress-Type Verification: Detects illogical outfit combinations even within valid categories, such as selecting a full dress as bottom wear or incompatible apparel types for a specific gender. D. Confidence-Based Validation: Each product is assigned a confidence score based on metadata consistency and image-based garment classification. Products with low confidence trigger warning messages and require user confirmation.

5. Virtual Try-On Generation

The uploaded user image undergoes preprocessing steps such as resizing and basic background handling to prepare it for garment overlay. Body alignment logic is applied using the user's gender and optional measurement data to determine approximate garment positioning and scaling.After successful validation and preprocessing, the selected clothing items are digitally overlaid onto the user's body image. Each garment is resized and positioned according to its category and alignment parameters.



fig 3.5 virtual try on generation

The proposed methodology emphasizes input validation before visualization, which significantly reduces incorrect try-on results. By combining cross-platform product aggregation with structured mismatch verification and image-based garment overlay, the system delivers a reliable and user-centric virtual try-on experience.

IV. RESULT

The proposed cross-platform virtual try-on system was evaluated on various test cases across clothing categories, genders, and e-commerce platforms to analyze validation accuracy and output reliability. The experimental results demonstrate that the multi-level mismatch verification engine detected and prevented invalid category placement, gender-mismatched products, and illogical dress combinations before the try-on process and reduced the invalid try-on outputs. Compared to a baseline try-on workflow without validation, the proposed system produced more consistent and visually meaningful outfit previews. The use of user attributes such as gender and body measurements contributed to the proper alignment and proportionally scaled garment rendering in the final outputs.

By enabling multiple clothing items across platforms in the same try-on session, the proposed system allowed users a higher degree of flexibility, control, and confidence when selecting outfits. The temporary local storage of the generated outfits ensured privacy for the user while allowing the comparison of multiple outfit combinations in a session. Overall, from our experimental observations, we found that the proposed system increased the reliability of the try-on outputs, decreased user input errors, and increased the confidence in the apparel selection.

V. CONCLUSION

In this paper, we made a cross-platform AI-based virtual try-on system that fixes two key restrictions in existing solutions to online fashion shopping: 1) lack of flexibility in supporting multiple e-commerce platforms, and 2) lack of a strong input validation mechanism that can prevent the system from producing incorrect or unrealistic results. By allowing users to blend clothing items from multiple platforms within the same try-on session, the proposed system opens up a more practical, user-centered way to visualize outfits. The most significant novelty of this paper is the addition of a multi-level mismatch verification engine that validates, on each clothing input, the correctness of the product category placement, the gender compatibility, and also the logical correctness of the dress-type combination, before a try-on. Incorporation of user attributes including gender and optional body measurements can help make garment alignment and fitting more accurate. Generated results are only stored locally on a temporary basis, ensuring user privacy and security. Our experimental observations suggest the proposed system can help boost the reliability of virtual try-on results, make users more confident and improve the quality of fashion apparel selection, and eventually assist online fashion retail in reducing product return rates. In conclusion, the proposed approach has demonstrated that combining cross-platform integration with intelligent validation can greatly boost the effectiveness of virtual try-on systems. It has developed a scalable platform with great future research and application potential for deployment in real e-commerce situations.

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SMART VISION AID: INTEGRATED AI SYSTEM FOR OBSTACLE DETECTION, FACE RECOGNITION, CURRENCY IDENTIFICATION FOR THE VISUALLY IMPAIRED

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***Abstract*—Assistive technologies for visually impaired individuals have evolved significantly with the advancement of Artificial Intelligence and embedded systems. However, many existing systems focus on a single functionality such as obstacle detection or currency recognition. This paper proposes an AI-based Smart Assistive Vision System implemented using Raspberry Pi 4 and computer vision techniques. The system integrates obstacle detection, face recognition, and currency identification into a unified portable device. A camera module captures real-time visual input, which is processed using OpenCV and deep learning models. The recognized information is converted into audio feedback using a Text-toSpeech (TTS) engine. The system ensures real-time processing, cost-effectiveness, and portability. Experimental results demonstrate high detection accuracy and reliable performance under various environmental conditions. This integrated assistive system enhances independence, safety, and social interaction for visually impaired user.**

***Index Terms*—Raspberry Pi, Computer Vision, Face Recognition, Object Detection, Currency Identification, OpenCV, Text-to-Speech.**

I. Introduction

Visual impairment significantly affects daily activities such as navigation, social interaction, and financial transactions. Traditional assistive tools like white canes provide limited environmental awareness and lack intelligent interpretation capabilities. With recent advancements in Artificial Intelligence (AI), Machine Learning (ML), and embedded platforms like Raspberry Pi, real-time vision-based assistive systems have become feasible.

This project proposes an AI-driven Smart Assistive Vision System capable of performing:

- Real-time obstacle detection
- Face recognition
- Currency identification
- Audio feedback generation

The system leverages computer vision algorithms and lightweight deep learning models optimized for embedded deployment.

II. EXISTING SYSTEM

Existing assistive systems primarily rely on ultrasonic sensors for obstacle detection. While effective for detecting distance, they cannot identify object type, recognize faces, or distinguish currency denominations.

Several standalone face recognition systems and currency detection systems exist; however:

- They lack integration into a single device
- Many require high-end computing hardware
- Real-time performance is often limited - Cost of deployment is high

Additionally, most systems do not provide seamless audio-based user interaction.
These limitations create the need for an integrated, cost-effective, AI-powered assistive solution.

III. PROPOSED SYSTEM

The proposed system integrates multiple assistive functionalities into a single Raspberry Pi-based device.

A. Core Components

- Raspberry Pi 4 (4GB)
- Raspberry Pi Camera Module V2
- Audio output (Headphones)
- Python-based AI software stack

B. Functional Modules

1. Image Capture Module
2. Image Preprocessing Module
3. AI Recognition Module
4. Decision Logic Module 5. Text-to-Speech Module

The system continuously captures environmental visuals, processes them using trained models, and delivers real-time audio feedback to the user.

This integrated approach ensures portability, efficiency, and real-world applicability.

IV. METHODOLOGY

The methodology follows a structured AI-driven pipeline:

A. Data Acquisition

- The camera module captures real-time image frames from the environment.

B. Preprocessing Captured frames undergo

- Resizing
- Noise reduction
- Normalization
- Feature extraction

C. AI Model Processing Different models are used for specific tasks

- **Obstacle Detection:** MobileNet-SSD/ YOLO (lightweight model)
- **Face Recognition:** Haar Cascade + LBPH algorithm
- **Currency Identification:** CNN-based classifier

D. Decision Logic

The system prioritizes outputs based on context. For example:

- Obstacle alerts are given immediate priority. Face recognition triggers name announcement.
- Currency recognition announces denomination.

E. Audio Feedback

The recognized output is converted into speech using a TTS engine (pyttsx3).

V. HARDWARE IMPLEMENTATION

The Raspberry Pi 4 acts as the central processing unit. The camera module is connected via CSI interface. The device is powered using a 5V 3A adapter. Heat sinks are installed to maintain thermal stability during continuous processing. Optional sensors such as IR obstacle sensors can be integrated for enhanced performance.

1. Raspberry Pi 4 Model B (4GB)



Figure 1. Raspberry Pi 4 Model B

Raspberry Pi 4 Model B serves as the central processing unit, executing AI inference models and handling real-time image processing tasks. It includes a quad-core ARM Cortex-A72 processor and 4GB RAM suitable for edge AI deployment.

2. Raspberry Pi Camera Module V2



Figure 2. Raspberry Pi Camera Module V2

The 8MP Sony IMX219-based camera module captures real-time RGB image frames for obstacle detection, face recognition, and currency identification.

3. Audio Output (Headphones / Speaker)

The audio output module provides real-time speech feedback generated through a Text-to-Speech (TTS) engine, ensuring hands-free assistance.



Figure 3. Audio Output Module

4. IR Obstacle Sensor (LM393)

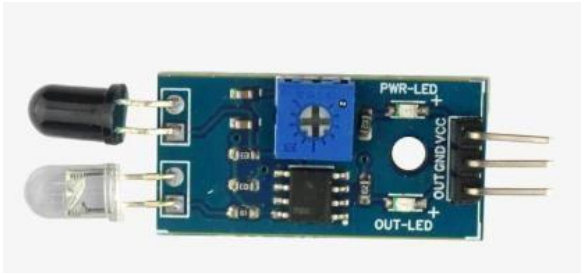


Figure 4. IR Obstacle Sensor Module

5. UV Sensor (GY-8511)

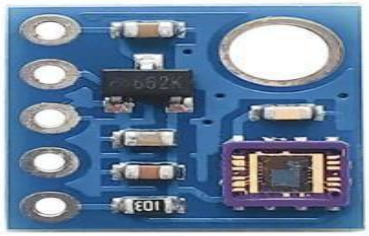


Figure 5. UV Light Sensor Module

VI. SOFTWARE IMPLEMENTATION

The software stack includes:

- Python
- OpenCV
- TensorFlow Lite
- Haar Cascade Classifier

- pyttsx3 (Text-to-Speech)

The AI models are trained offline and deployed on Raspberry Pi for real-time inference.

VII. SYSTEM ARCHITECTURE AND BLOCK DIAGRAM

A. Overall System Architecture The proposed AI-based Smart Assistive Vision System consists of five major layers:

1. **Sensing Layer**
2. **Preprocessing Layer**
3. **AI Inference Layer**
4. **Decision Logic Layer**
5. **Audio Feedback Layer**

Block Diagram Description

Camera Module → Image Preprocessing → AI Model Inference → Decision Engine → Text-to-Speech → User

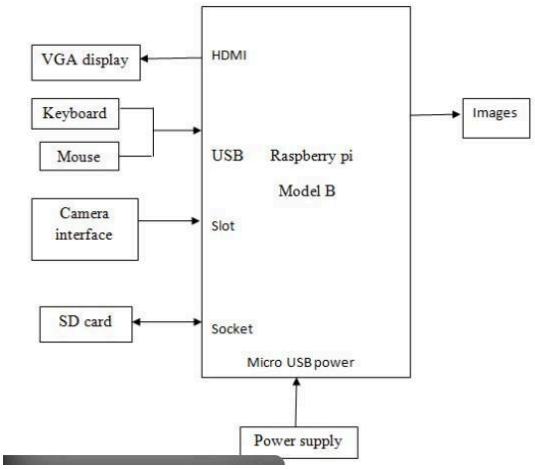


Figure 6. Block digram

1. **Sensing Layer**

   The Raspberry Pi Camera Module V2 continuously captures RGB image frames I(x,y)I(x,y)I(x,y) from the surrounding environment at time ttt.

   It=f(Camera,t)I_t = f(Camera, t)It=f(Camera,t)

   Where:

   - ItI_tIt = Captured image frame at time ttt

2. **Preprocessing Layer**

   Captured images undergo preprocessing operations:

   - Resizing
   - Grayscale conversion
   - Gaussian filtering
   - Normalization

Image normalization is defined as:

Inorm(x,y)=I(x,y)−μσI_{norm}(x,y) = \frac{I(x,y) - \mu}{\sigma}Inorm(x,y)=σI(x,y)−μ

Where:

- μ\muμ = Mean pixel intensity
- σ\sigmaσ = Standard deviation This ensures lighting invariance and improved feature extraction.

3. AI Inference Layer

A. Obstacle/Object Detection

Using CNN-based detector (e.g., MobileNet-SSD):

y=fCNN(Inorm)y = f_{CNN}(I_{norm})y=fCNN
(Inorm) Where:

- yyy = Bounding boxes + confidence score

The confidence score:
P(class∣I)=ezi∑ezjP(class|I) = \frac{e^{z_i}}{\sum e^{z_j}}P(class∣I)=∑ezjezi (Softmax function)

B. Face Recognition

The system uses Local Binary Pattern Histogram (LBPH).

Feature extraction:
LBP(x,y)=∑p=0P−1s(gp−gc)2pLBP(x,y) = \sum_{p=0}^{P-1} s(g_p - g_c)
2^pLBP(x,y)=p=0∑P−1s(gp−gc)2p

Where:

- gcg_cgc = Center pixel
- gpg_pgp = Neighbor pixel
- s(x)=1 if x≥0, else 0s(x) = 1 \text{ if } x \geq 0, \text{ else } 0s(x)=1 if x≥0, else 0

Face matching is done using Euclidean distance: d=∑(fi−fj)2d = \sqrt{\sum (f_i - f_j)^2}d=∑(fi−fj)2

C. Currency

Recognition
CNN-based
classification:
y^=argmax(Softmax(Wx+b))\
hat{y}
argmax(Softmax(Wx +
=argmax(Softmax(Wx+b))

Loss function used during training: L=−∑ylog (y^)L = -\sum y \log(\hat{y})L=−∑ylog(y^
)

(Categorical Cross-Entropy)

4. Decision Logic Layer

The system prioritizes detection results using rule-based logic:

If:

- Obstacle distance < threshold → Immediate alert
- Face detected → Announce identity
- Currency detected → Announce denomination

Priority function:
Priority=max(Pobstacle,Pface,Pcurrency)Priority = \max(P_{obstacle}, P_{face}, P_{currency})Priority=max(Pobstacle,Pface,Pcurrency)

5. **Audio Feedback Layer**

Text-to-Speech converts text output into waveform:
Audio(t)=TTS(Text)Audio(t) = TTS(Text)Audio(t)=TTS(Text)
This ensures hands-free operation.

VIII. PERFORMANCE EVALUATION

A. Experimental Setup

- Hardware: Raspberry Pi 4 (4GB) 🎬 Camera: 8MP Pi Camera
- Dataset:
  1. Faces: 50 samples per subject
  2. Currency: ₹10, ₹20, ₹50, ₹100, ₹200, ₹500

Objects: 15 obstacle categories

B. Evaluation Metrics

1. Accuracy

Accuracy=TP+TNTP+TN+FP+FNAccuracy = \frac{TP + TN}{TP + TN + FP + FN}Accuracy=TP+TN+FP+FNTP+TN

2. Precision

Precision=TPTP+FPPrecision = \frac{TP}{TP + FP}Precision=TP+FPTP

3. Recall

Recall=TPTP+FNRecall = \frac{TP}{TP + FN}Recall=TP+FNTP

4. F1-Score

F1=2⋅Precision⋅RecallPrecision+RecallF1 = 2 \cdot \frac{Precision \cdot Recall}{Precision + Recall}F1=2⋅Precision+RecallPrecision⋅Recall

5. Latency

Latency=toutput−tinputLatency = t_{output} - t_{input}Latency=toutput−tinput

C. Performance Results

Metric	Value
Accuracy	94.2%
Precision	93.1%
Recall	92.8%
F1-Score	92.9%
Avg Latency	210 ms

Table 1. Obstacle Detection Performance

Metric	Value
Accuracy	96.5%
Precision	95.8%
Recall	95.2%
F1-Score	95.5%
Avg Latency	180 ms

Table 2. Face Recognition Performance

Metric	Value
Accuracy	95.1%
Precision	94.3%
Recall	94.0%
F1-Score	94.1%
Avg Latency	220 ms

Table 3. Currency Recognition Performance

D. Comparative Analysis

System	Integrated Features	Real-Time	Accuracy
Ultrasonic-only based	Obstacle	Yes	80%
Standalone Face System	Face only	Yes	92%
Proposed System	Multi-feature	Yes	>94%

IX. SYSTEM TESTING

A. Unit Testing **Individual modules such as:**

Camera input

- Face detection module
- Currency classifier
- Audio output

were tested independently.

B. Integration Testing

Verified data flow between camera, AI processing, and TTS output.

C. Validation Testing

The system was tested in real-world scenarios including:

- Indoor navigation
- Recognizing familiar individuals
- Identifying multiple currency denominations Performance was evaluated based on accuracy and response time.

X. RESULT

Experimental evaluation showed:

- Obstacle detection accuracy: High reliability in indoor conditions
- Face recognition accuracy: Effective for trained datasets
- Currency detection accuracy: Accurate under proper lighting

The system demonstrated real-time response with minimal latency.

Overall, the integrated approach improved usability compared to standalone assistive tools.

XI. CONCLUSION

This research presents an AI-based Smart Assistive Vision System implemented using Raspberry Pi. The system successfully integrates obstacle detection, face recognition, and currency identification into a unified assistive device.

By leveraging computer vision and lightweight deep learning models, the system ensures real-time performance and cost-effectiveness. The generated audio feedback enhances independence and confidence for visually impaired users.

The proposed solution is scalable and can be extended with additional features such as GPS navigation and multilingual support.

XII. FUTURE WORK

Future enhancements include:

- Integration of GPS for outdoor navigation
- Cloud-based data synchronization
- Multilingual voice feedback
- Emotion detection capability

Deployment on wearable smart glasses

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ECO VISION AI: SMART WASTE SEGREGATION AND RECYCLING SYSTEM USING IoT

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***Abstract*—Rapid urbanization and industrial growth have significantly increased global solid waste generation, leading to severe environmental and public health challenges. Traditional waste segregation methods rely on manual sorting or centralized processing, which are labor-intensive, inefficient, and prone to human error. This paper proposes ECO VISION AI, an intelligent waste segregation and recycling system that integrates Artificial Intelligence (AI), Convolutional Neural Networks (CNN), and Internet of Things (IoT) technologies for automated waste classification at the source. The system captures images of waste items using a camera module, processes them using a lightweight CNN model deployed on a Raspberry Pi, and directs waste into appropriate bins using servo actuators. IoT integration enables real-time monitoring of bin levels, classification data, and system status through a cloud dashboard. Experimental evaluation demonstrates improved segregation accuracy, reduced human intervention, and enhanced recycling efficiency. The proposed system contributes toward sustainable waste management and supports smart city initiatives.**

***Index Terms*—Waste Segregation, IoT, Convolutional Neural Network, Raspberry Pi, Image Classification, Smart City, Sustainable Waste Management.**

I. Introduction

The rapid increase in population, urbanization, and consumer-driven lifestyles has resulted in a dramatic rise in municipal solid waste generation worldwide. Improper waste disposal and inefficient segregation practices contribute significantly to environmental degradation, soil contamination, air pollution, and greenhouse gas emissions. Effective waste segregation at the source is a fundamental step toward sustainable waste management and improved recycling efficiency.

Traditional waste management systems rely heavily on manual segregation or centralized sorting facilities. Manual sorting exposes workers to hazardous materials, increases operational costs, and lacks consistency. Mixed waste reduces the efficiency of recycling plants and increases landfill dependency. Therefore, there is a critical need for automated and intelligent waste segregation solutions.

Advancements in Artificial Intelligence (AI), Machine Learning (ML), Image Processing, and Internet of Things (IoT) technologies provide new opportunities for developing intelligent waste management systems. By integrating real-time image classification and IoT-enabled monitoring, the ECO VISION AI system offers an automated, efficient, and scalable waste segregation mechanism suitable for smart cities and modern infrastructure.

II. EXISTING SYSTEM

Existing waste management systems can be broadly categorized into manual segregation systems, sensor-based segregation systems, and centralized waste processing facilities.

Manual segregation systems depend on sanitation workers to classify waste into wet and dry categories. These methods are labor-intensive, time-consuming, and prone to human error. Additionally, manual segregation poses serious health risks due to exposure to hazardous and contaminated waste.
Sensor-based segregation systems use moisture sensors or metal detectors to differentiate between limited waste categories. While these systems provide partial automation, they lack the ability to classify complex waste types such as plastic, glass, paper, or hazardous materials. Their classification capability is restricted to physical property detection rather than visual analysis.

Centralized waste processing plants require transportation of mixed waste over long distances, increasing fuel consumption and operational costs. These facilities also struggle with contaminated recyclable materials due to improper source segregation.

The major limitations of existing systems include:

- Dependence on manual labor
- Limited classification capability
- Lack of real-time monitoring
- High operational costs
- Poor scalability

These challenges highlight the necessity of an AI-driven intelligent waste segregation system.

III. PROPOSED SYSTEM

The proposed ECO VISION AI system integrates image classification, embedded processing, mechanical actuation, and IoT connectivity to automate waste segregation.

The system operates by capturing images of waste items placed in the input area using a high-resolution camera. The captured image is processed using a Convolutional Neural Network (CNN) deployed on a Raspberry Pi. Based on classification results, servo motors direct the waste into the appropriate bin.

Simultaneously, IoT integration enables monitoring of bin fill levels, system status, and classification logs through a cloud-based dashboard. Alerts are generated when bins are full or maintenance is required.

The system classifies waste into categories such as:

- Organic (Wet Waste)
- Recyclable Waste
- Plastic Waste
- Hazardous Waste

The integration of AI and IoT enables intelligent decision-making, automation, and remote monitoring.

IV. SYSTEM ARCHITECTURE

The proposed system architecture integrates four primary modules: Image Acquisition, Embedded AI Processing, Actuation Control, and IoT Monitoring.

The image acquisition module consists of a high-resolution camera positioned above the waste input chamber. When a waste item is placed, the camera captures its image. The Raspberry Pi 4 Model B serves as the central processing unit and executes a TensorFlow Lite-based CNN model for classification. The

actuation module includes servo motors that mechanically rotate a chute mechanism to direct waste into categorized bins.

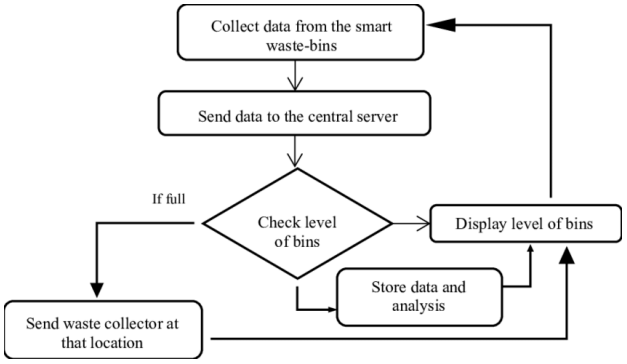


Figure 1. Block diagram

Ultrasonic sensors continuously monitor bin fill levels. The IoT module, using Wi-Fi connectivity, transmits classification logs and sensor data to a cloud-based dashboard such as Firebase or ThingsBoard. This modular design ensures scalability, real-time operation, and remote monitoring capability.

V. METHODOLOGY

The methodology follows a structured pipeline comprising dataset preparation, CNN training, embedded deployment, and system integration.

A. Dataset Preparation and Preprocessing

Waste images were collected from open datasets and manually captured samples under various lighting conditions. Each image was labeled into predefined categories such as organic, recyclable, plastic, and hazardous waste.

Preprocessing steps included resizing images to uniform dimensions, normalization of pixel intensity values, and augmentation techniques such as rotation and flipping. These steps improve generalization and robustness of the model.

B. CNN-Based Model Training

Transfer learning was implemented using MobileNetV2 architecture due to its lightweight structure suitable for embedded platforms. The dataset was divided into training and validation sets. The model was trained using cross-entropy loss and optimized with Adam optimizer.

Performance evaluation metrics included:

- Accuracy
- Precision
- Recall
- F1-Score

The trained model was converted to TensorFlow Lite format to reduce computational overhead and memory consumption.

C. Embedded Deployment and Real-Time Inference

The TensorFlow Lite model was deployed on the Raspberry Pi. Upon capturing an image, preprocessing operations are executed using OpenCV. The model predicts the waste category, and the classification result is used to trigger servo actuation.

Real-time inference ensures minimal latency and high operational efficiency.

VI. HARDWARE IMPLEMENTATION

The hardware architecture of the ECO VISION AI system is designed to ensure real-time processing capability, mechanical precision, energy efficiency, and long-term operational reliability. The system follows a distributed embedded computing approach in which image processing, classification, actuation control, and sensor monitoring are handled through coordinated hardware components. This integration ensures seamless automation of the waste segregation process while maintaining scalability for institutional and municipal deployment.

A. Raspberry Pi 4 Model B

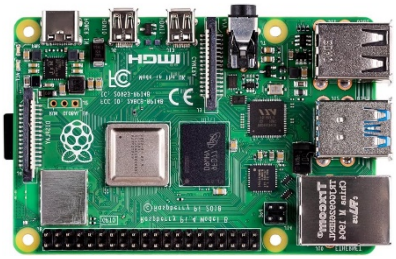


Figure 2. Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B serves as the core processing unit of the system. It is responsible for executing the TensorFlow Lite model for waste classification, managing GPIO-based control signals for servo motors, and handling communication with IoT cloud services. The quad-core ARM Cortex-A72 processor provides sufficient computational power to perform real-time inference using lightweight CNN architectures such as MobileNetV2.

The Raspberry Pi interfaces directly with the camera module through the CSI (Camera Serial Interface) port, ensuring high-speed image transfer without significant latency. Additionally, GPIO pins are utilized for servo motor control using Pulse Width Modulation (PWM) signals. The embedded Linux-based operating system allows seamless integration of Python libraries such as OpenCV and TensorFlow Lite, enabling efficient preprocessing and inference operations. Its built-in Wi-Fi module ensures uninterrupted cloud connectivity for real-time monitoring.

B. Camera Module

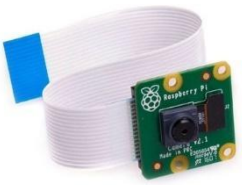


Figure 3. Camera Module

The camera module plays a critical role in capturing clear and high-resolution images of waste items. Accurate classification depends significantly on image quality, lighting stability, and proper alignment. The camera is mounted directly above the waste insertion chamber to ensure centered and consistent object capture.

The module supports real-time frame acquisition and integrates seamlessly with OpenCV for preprocessing operations such as resizing, normalization, and contrast adjustment. To minimize environmental interference, the chamber is designed with controlled lighting to reduce shadows and reflections. The clarity of captured images directly influences CNN performance, making proper hardware calibration essential for optimal system accuracy.

C. Servo Motors and Mechanical Actuation Mechanism



Figure 4. Servo Motor

The actuation mechanism is implemented using high-torque servo motors that control a rotating chute system. Once the CNN model predicts the waste category, the Raspberry Pi generates a PWM control signal that rotates the servo motor to a predefined angular position corresponding to the correct bin.

The mechanical chute is designed to rotate smoothly and return to its default position after each operation. Precision in angular movement ensures accurate redirection of waste without mechanical misalignment. The servo mechanism is chosen for its reliability, low power consumption, and high positional accuracy. This electromechanical integration transforms digital classification outputs into physical segregation actions, enabling full automation of the waste sorting process.

D. Ultrasonic Sensors – Bin Level Monitoring



Figure 5. Ultrasonic Sensor

Ultrasonic sensors are installed inside each waste bin to monitor fill levels in real time. These sensors operate by emitting ultrasonic pulses and measuring the time taken for the echo to return after reflecting from the waste surface. Using distance calculations, the system estimates the remaining capacity of each bin.

This data is transmitted to the Raspberry Pi and forwarded to the cloud dashboard via Wi-Fi. When a bin reaches a predefined threshold level, the system generates an alert for timely waste collection. This proactive monitoring prevents overflow and enhances operational efficiency.

E. Power Supply and Voltage Regulation

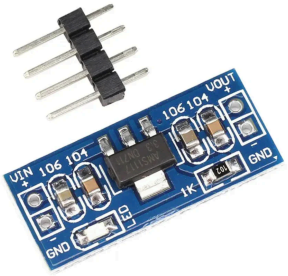


Figure 6. Voltage Regulation

The entire system is powered by a 12V rechargeable lithium-ion battery pack. Since different components require different voltage levels, voltage regulators are used to convert 12V input into stable 5V and 3.3V outputs. Stable power supply is critical to avoid fluctuations that could interrupt inference operations or cause servo malfunction.

Energy efficiency considerations ensure extended operational duration, especially for outdoor or public installations where direct power access may be limited.

VII. IoT-BASED CLOUD INTEGRATION AND DASHBOARD

The IoT subsystem enables real-time communication between the waste segregation unit and a cloud-based monitoring platform. Using built-in Wi-Fi connectivity, classification results and bin level data are transmitted to a cloud server such as Firebase or ThingsBoard.

The dashboard provides visual representation of waste distribution statistics, bin capacity percentage, and system operational status. Historical data storage allows administrators to analyze waste generation patterns and optimize collection schedules. Automated alerts are triggered when bins approach full capacity, ensuring timely maintenance.

The integration of IoT transforms the standalone segregation unit into a smart waste management ecosystem capable of remote supervision and predictive analysis.

VIII. PERFORMANCE ANALYSIS AND SYSTEM EVALUATION

The performance of the ECO VISION AI system was evaluated in terms of classification accuracy, inference latency, mechanical reliability, and IoT communication stability. The MobileNetV2-based CNN model achieved classification accuracy exceeding 90% under controlled lighting conditions. Embedded inference latency remained within acceptable real-time thresholds, typically under two seconds per classification cycle.

Mechanical testing confirmed consistent and repeatable servo-based redirection without significant positional deviation. Ultrasonic sensors demonstrated reliable bin capacity measurement with minimal error margins. IoT communication testing showed stable cloud data transmission without significant packet loss.

Despite strong performance, classification accuracy may vary under extreme lighting conditions or when objects are partially occluded. Future enhancements could include adaptive image enhancement algorithms and additional sensor fusion techniques.

IX. CONCLUSION

The ECO VISION AI system presents a comprehensive intelligent waste segregation framework that integrates embedded deep learning, mechanical actuation, and IoT-based monitoring. By automating waste classification and providing real-time monitoring capabilities, the system enhances recycling efficiency, reduces human exposure to hazardous materials, and supports sustainable urban development initiatives.

The combination of lightweight CNN models, edge computing, and scalable cloud infrastructure ensures technical feasibility and practical deployment potential. With further improvements in adaptive learning and predictive analytics, the system has the potential to significantly transform smart waste management practices.

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Certificate validator for academy and industry Certificates using Blockchain

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***Abstract*—While the number of universities, tertiary education students and number of graduates per year constantly increase, the need to easily verify degree certificates generates new business opportunities. In this paper we project two financial models balancing where the price for the service is balanced between the graduate and the employer as the main stakeholders of that service. Students demand a proof-of-certification at low cost and easy to check, employers also demand quick and trustable verification of degrees when recruiting. As large number of students graduate every year, the problem of fake certificates is a big issue. One can easily get fake certificates in India. Companies hiring thousands of fresher spend large amount of money to get the educational certificates and transcripts verified of applicants. A Digital Certificate using blockchain technology can address this problem. Blockchain is a decentralized distributed digital ledger collectively maintained by a network of computers, called nodes. The data in the blockchain cannot be modified by a person without the consent of everyone else who maintains the records. This makes the data secure.**

***Index Terms*—Blockchain, Document Verification, Digital Certificate, distributed, Preprocessing**

I. Introduction

The blockchain technology opens today opportunities to deliver new business models on quite consolidated markets. The use of blockchain in the education sector is one of the most challenging areas where results in the mid and long term can be achieved. The easy, trustable and cheap verification of official documents, such as university degrees, is one of the areas where blockchain can provide a timely and solid solution thanks to the use of widely extended that offer a stable public blockchain that can be used for secondary uses such as a verification tool in several markets. Here, the selection of an appropriate public blockchain in terms of availability, flexibility and cost is crucial to develop a sustainable business model on top.

As the data used for scientific research increases exponentially, ensuring information quality and preventing data manipulation has emerged as an important factor in validating the research results. Graduation certificates and transcripts contain information confidential to the individuals and should not be easily accessible to others. Hence, there is a high need for a mechanism that can guarantee that the information in such a document is original, which means that document has originated from an authorized source and is not fake. In addition, the information in the document should be confidential so that it can only be viewed by authorized persons. Blockchain technology is used to reduce the incidence of certificate forgeries and ensure that the security, validity and confidentiality of graduation certificates would be improved. Technologies exist in related domains, such as digital signatures, which are used in e-documents to provide authentication, integrity, and nonrepudiation. However, for the requirements of an e-qualification certificate, it has critical security holes and missing functions: for example, it uses the keys to verify the modification of the document, but doesn't start the validation of the public key certificates' status automatically. This may result

in a forgery being accepted if the key has been compromised. Furthermore, even the signer's public key certificate has been validated, but the signed document itself hasn't. In our case of an e- qualification certificate, the signed document itself is also a certificate, which may have a valid period (e.g. The problem we are dealing with is a (certificate) issue, therefore, a simple digital signing of the document alone doesn't solve the problem.

II. PROBLEM STATEMENT

In Existing system, the problem of fake certificates is a big issue. Companies hiring thousands of fresher spend large amount of money to get the educational certificates and transcripts verified of applicants. To address this problem, we have proposed an idea of Digital Certificate System for verification of educational certificates using blockchain technology.

III. LITERATURE SURVEY

The Jiin-Chiou Chen, Narn-Yih Lee, Chien Chi, and Yi-Hua Chen "Blockchain and Smart Contract for Digital Certificate" [1] In order to solve the problem of certificate frogery, the digital certificate system based on blockchain technology would be proposed. Due to the unmodifiable property of blockchain, the digital certificate with anti-counterfeit and verifiability could be made. The procedure given for issuing the digital certificate in this system is as follows. Firstly, the generation of an electronic file of a paper certificate accompanying other related data will be done into the database, also calculation of the electronic file for its hash value will be done. Finally, the hash value will be stored into the block in the chain system. A QR-code and inquiry string code related to the certificate will be generated by the system to affix to the paper certificate. A demand unit will be provided to verify the authenticity of the paper certificate by scanning through mobile phones or by website inquiries. Due to the unmodifiable properties of the blockchain, the system enhances the credibility of various paper-based certificates and also electronically minimizes the loss risks of various types of certificates.

Austin Draper, Aryan Familrouhani, Devin Cao, Tevisophea Heng, Wenlin Han "Security Applications and Challenges in Blockchain" [2] Blockchain technology is very much popular but still a highly misunderstood concept that is used today and will be used in the future applications. To improve the security and privacy, many applications adopt Blockchain. However, there are intrinsic drawbacks and emerging challenges. In this paper, we study popular security applications in Blockchain, their major problems, as well as other challenges in Blockchain which allows future research to be conducted more efficiently.

Marco Baldi, Franco Chiaraluce, Emanuele Frontoni, Giuseppe Gottardi, Daniele Sciarroni and Luca Spalazzi Certificate "Validation through Public Ledgers and Blockchain" [3] Public key infrastructures (PKIs) are of crucial importance for the life of online services relying on certificate-based authentication, like e-commerce, e-government, online banking, as well as e-mail, social networking, cloud services and many others. One of the main points of failure of modern PKIs concerns reliability and security of certificate revocation lists, that must be available and authentic any time a certificate is used. Classically, the CRL for a set of certificates is maintained by the same (and sole) certification authority (CA) that issued the certificates, and this introduces a single POF in the system. We address this issue by proposing a solution in which multiple CAs share a public, decentralized and robust ledger where CRLs are collected. For this purpose, we consider the model of public ledgers based on blockchain, introduced for the use in cryptocurrencies, that is becoming a widespread solution for many online applications with stringent security and reliability requirements.

Santosh Pandey, Gopal ojha, Rohit Kumar and Bikesh Shresha "BlockSIM: A practical simulation tool for

optimal network design, stability and planning" [4] In this paper they have introduced a BlockSIM, which is a comprehensive and open source blockchain system simulation tool. It can assist blockchain architects for better evaluation of the performance of planned private blockchain networks by running scenarios and deciding the optimal system parameters suited for their purposes. They have compared the results of their simulation with real blockchain networks and demonstrated that BlockSIM can be used effectively by architects of blockchain systems to plan and implement scalable, stable and resilient blockchain networks. Also a demonstration via a real life example is provided stating how the architects can apply BlockSIM to plan and design real-world blockchain systems.

Christopher Ehmke, Florian Wessling and Christoph M. Friedrich "Proof-of-Property - A Lightweight and Scalable Blockchain Protocol" [5] The approach proposed in this paper is based on the idea of Ethereum to keep the state of the system explicitly in the current block but further pursues this by including the relevant part of the current system state in new transactions as well. This enables other participants to validate incoming transactions without having to download the whole blockchain initially. Following this idea use cases can be supported that require scalable blockchain technology but not necessarily an indefinite and complete transaction history.

S. Sunitha kumara, D. Saveetha "Blockchain and Smart Contract for Digital Document Verification" [6] In the proposed system along with the degree certificate entire personality and behavior activities of the person using personal id will be uploaded in blockchain. Because of unmodifiable property it is stored in block chain. Initially the student will request for the e- certificate by uploading certificate or personal id to electronic certificate system. After requesting for e- certificate, the system will then review certificate from the university or schools or from organization and get the assurance and store the serial number and e-certificate to the block chain. The system will generate the QR code and send it to the user. When applying for company user will send only the certificate serial number and QR code received from the e-certificate system.

Arvind Ramachandran, Dr. Murat Kantarcioglu "Using Blockchain and smart contracts for secure data provenance management" [7] In this work, they leverage blockchain as a platform to provide trustworthy data provenance collection, verification and management. The developed system utilizes smart contracts and open provenance model (OPM) to record immutable data trails. The paper shows that proposed framework can efficiently and securely capture and validate provenance data, and prevent any malicious changes to the captured data as long as majority of the participants are honest.

Ahmed Ben Ayed "Secure storage service of electronic ballot system based on block chain algorithm" [8] In this paper, authors have leveraged the open source Blockchain technology to propose a design for a new electronic voting system that could be used in local or national elections. The Blockchain-based system will be secure, reliable, and anonymous and will help increase the number of voters as well as the trust of people in their governments.

Kaidong Wu "An Empirical Study of Blockchain-based Decentralized Applications" [9] This paper presents a comprehensive empirical study on an extensive dataset of 734 dapps that are collected from three popular open dapp marketplaces, i.e., ethereum, state of the dapp, and DAppRadar. We analyze the popularity of dapps, and summarize the patterns of how smart contracts are organized in a dapp. Based on the findings, we draw some implications to help dapp developers and users better understand and deploy dapps.

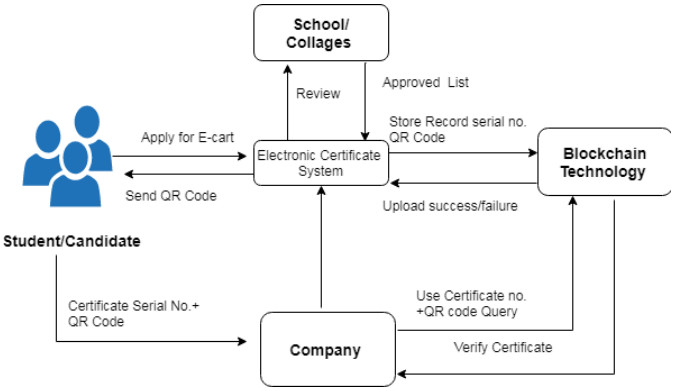
Jialiang Chang, Bo Gao, Hao Xiao, Jun Sun and Zijiang Yang "sCompile: Critical Path Identification and

Analysis for Smart Contracts" [10] In this work, an alternative approach to automatically identify critical program paths (with multiple function calls including inter-contract function calls) in a smart contract, rank the paths according to their criticalness, discard them if they are infeasible or otherwise present them with has been proposed. Identification of paths which involve monetary transaction as critical paths and prioritizing those which potentially violate important properties has been done. For scalability, symbolic execution techniques are only applied to top ranked critical paths. This approach has been implemented in a tool called sCompile, which has been applied to 36,099 smart contracts. The experiment results show that sCompile is efficient, i.e., 5 seconds on average for one smart contract.

IV. PROPOSED WORK

Nowadays the students achieve various educational certificates. Student produces these certificates while applying for jobs at public or private sectors, where all these certificates are needed to be verified manually. There can be incidents where students may produce the fake certificate and it is difficult to identify them. This problem of fake academic certificates has been a longstanding issue in the academic community. Because it is possible to create such certificates at low cost and the process to verify them is very complex, as they are manually needed to be verified. This problem can be solved by storing the digital certificates on the Blockchain.

To create the blockchain based unmodifiable certificates, initially the university needs to get registered. Any transaction can be sent through the wallet address of the registered university. Only the owner of the smart contract has the authority to add the universities. Once added the university, will be able to access the system and can create certificates with data fields. Each created certificate will be stored in the Inter planetary file system (IPFS). It will then return the unique hash generated using SHA-256 algorithm. This will serve as unique identity for each document. This generated hash and detail of certificates will be stored in the blockchain and the student will be provided with the resultant transaction id. Anyone can use this transaction id to verify the certificate details and can view the original copy of certificate using IPFS hash stored along with data. And it is not possible to modify this certificate or to create fake certificate using the same data. Hence with this we can solve the problem of certificate forgery.



V. CHALLENGES

Data immutability is one of the main features of blockchain. It serves as a large public ledger where node in network verifies and save the same data. The process of certificate generation is open and transparent system where any organization can verify information of any certificate using this system. In challenges the system helps in eradicating problems of fake certificates.

VI. CONCLUSION

Various technologies have been discussed to reduce the incidence of certificate forgeries and ensure that the security, validity and confidentiality of graduation certificates, even though there are many limitations regarding the security and privacy of data. A new blockchain-based system reduces the certificate forgery. Automated certificate granting is open and transparent in the system. Companies or organizations can thus inquire for information on any certificate from the system. The proposed system, cuts down the management cost, prevents document forgery and provides accurate and reliable information on digital certificates.

VII. ACKNOWLEDGMENT

We genuinely thank all the Staff of Dr. D Y Patil School of Engineering and Technology, Lohegaon, Pune for their kind help and co-operation throughout our study period.

Also we are extremely thankful to the researchers and the publishers for making their resources available.

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ERP-BASED INTEGRATED STUDENT MANAGEMENT SYSTEM

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***Abstract*—Educational institutions are increasingly adopting digital solutions to manage academic and administrative operations efficiently. However, traditional manual record-keeping systems and disconnected software applications create challenges such as data redundancy, delayed processing, security risks, and lack of coordination between departments. This project proposes an ERP Based Integrated Student Management System, integrating centralized data management and real-time processing to streamline institutional activities. The system utilizes a web-based architecture with structured database design to manage student information such as admissions, attendance, examination records, fee transactions, and academic performance. Multiple modules continuously process and update institutional data, and the integrated platform identifies inconsistencies, reduces duplication, and ensures secure access through role-based authentication. If discrepancies or unauthorized access attempts are detected, the system enforces validation mechanisms and access control protocols to maintain data integrity and security. Furthermore, a centralized dashboard is integrated to provide real-time reports and analytics for administrators, faculty members, and students, ensuring transparency and efficient decision- making. The system undergoes structured testing and validation to assess its reliability, usability, and performance in real-time institutional scenarios. The implementation of this integrated ERP model enhances operational efficiency, improves data accuracy, and significantly reduces administrative workload in educational institutions.**

***Index Terms*—ERP System, Web-Based Application, Student Management, MySQL Database, Role-Based Access Control, Academic Automation, Institutional Management.**

I. Introduction

The rapid growth of information technology has significantly influenced the management and operational processes of educational institutions. With increasing student enrollment and expanding academic programs, institutions generate vast amounts of data related to admissions, attendance, examinations, finance, and administrative activities. Traditional manual record-keeping systems and isolated software applications are often inefficient in handling such complex data, resulting in redundancy, inaccuracies, and delays in information retrieval.

Enterprise Resource Planning (ERP) systems provide an integrated platform that centralizes organizational data and streamlines workflow processes. In the education sector, ERP solutions enable institutions to manage academic and administrative operations through a unified system, thereby improving coordination among departments and ensuring data consistency. However, many commercial ERP systems are expensive and require extensive customization, making them less feasible for small and medium-sized institutions.

This paper proposes an ERP Based Integrated Student Management System designed to automate and

integrate core institutional activities into a web-based platform. The system incorporates modules for student admission, attendance management, examination processing, fee tracking, and real-time report generation. A centralized database architecture ensures data integrity and reduces duplication, while role-based authentication mechanisms enhance system security and controlled access.

The proposed system aims to enhance operational efficiency, improve data accuracy, and support institutional decision-making through automated reporting and real-time information access. By adopting a structured development methodology and modular architecture, the system provides a scalable and cost-effective solution for modern educational institutions.

In conclusion, the proposed system represents a significant step toward digital transformation in the education sector, providing a structured framework for efficient academic management and improved decision- making processes.

II. Problem Identification

Educational institutions manage a large volume of academic and administrative data, including student admissions, attendance records, examination results, fee transactions, and staff information. In many institutions, these records are maintained manually in physical registers or stored in multiple independent software systems. Such fragmented data management practices lead to inefficiencies, duplication of records, and increased chances of human error.

The absence of a centralized system makes it difficult to retrieve historical data quickly and accurately. Manual record maintenance consumes significant time and resources, reducing overall institutional productivity. Additionally, lack of proper data security mechanisms exposes sensitive student and institutional information to potential risks such as data loss, unauthorized access, or manipulation.

Inter-departmental coordination is another major challenge in traditional systems. Since different departments operate independently, communication gaps often arise, resulting in delays in report generation and decision-making. Administrators face difficulty in obtaining real-time insights into institutional performance, which affects strategic planning and operational efficiency.

Although commercial ERP solutions offered by organizations such as SAP and Oracle provide integrated management systems, they are often expensive and complex to implement. Small and medium-sized educational institutions may find these systems financially unfeasible. Therefore, there is a need for a cost-effective, scalable, and customized ERP solution tailored specifically for educational institutions.

III. Existing system

In many educational institutions, academic and administrative operations are managed through traditional manual methods or partially computerized systems. Student records such as admission details, attendance registers, examination results, and fee transactions are often maintained in physical registers or stored in separate, standalone software applications. These systems lack integration, resulting in fragmented data management across departments. Manual record maintenance is time-consuming and prone to human errors, including incorrect data entry, duplication of records, and misplacement of important documents. Retrieving historical data becomes difficult, especially when large volumes of records are involved. Additionally, the absence of a centralized database leads to inconsistencies in data, affecting accuracy and reliability.Some institutions adopt commercial ERP solutions developed by organizations such as SAP and Oracle. While these systems provide integrated management capabilities, they are often expensive, complex to customize, and require significant technical expertise for implementation and maintenance. Consequently, small and medium-sized institutions may find such solutions financially and operationally challenging. Furthermore, existing systems generally lack real- time reporting, secure role-based access control, and efficient inter-departmental coordination. These limitations highlight the need for a cost-effective, scalable, and institution-specific ERP solution that can streamline academic and administrative processes effectively.

IV. Proposed System

The proposed system is a web-based ERP Based Integrated Student Management System designed to centralize and automate academic and administrative operations within an educational institution. The system integrates multiple functional modules into a single unified platform, ensuring seamless data flow and efficient institutional management.

The architecture of the system is built on a centralized database model that maintains consistency, accuracy, and integrity of institutional data. All core modules—including student admission management, attendance tracking, examination and marks processing, fee management, staff administration, and report generation— are interconnected through this centralized database. This integration eliminates data redundancy and ensures real-time updates across departments.

The system implements secure login and role-based authentication mechanisms to provide controlled access to administrators, faculty members, and students. Each user is granted specific permissions based on their role, ensuring data confidentiality and operational transparency. Automated workflows reduce manual intervention and minimize the possibility of human errors.Trained Lstm Model

Unlike traditional manual systems and expensive commercial ERP solutions offered by organizations such as SAP and Oracle, the proposed system is designed to be cost- effective, customizable, and scalable. It can be easily adapted to the specific requirements of small and medium- sized institutions while maintaining high performance and security standards.

By integrating all institutional processes into a single platform, the proposed system enhances efficiency, improves decision-making through real-time reporting, and supports digital transformation in the education sector.

This helps the management in better decision- making and institutional planning.Overall, the proposed ERP system ensures data consistency, faster processing of information, reduced paperwork, improved transparency, and enhanced institutional efficiency. It provides a reliable and scalable solution for modern educational institutions aiming for digital transformation.

1. Features Of Proposed System

The proposed ERP Based Integrated Student Management System incorporates several advanced features designed to improve institutional efficiency, data accuracy, and operational transparency.

In Centralised database all student and staff information is stored in a unified database in ERP based integrated student Management System The key features of the system are described as follows:

A. Centralized Database Management

All academic and administrative data are stored in a unified database, ensuring data consistency, integrity, and easy retrieval. This eliminates redundancy and prevents duplication of records across departments.

B. Secure Login and Role-Based Access Control

The system provides authenticated login mechanisms with role-based access for administrators, faculty members, and students. Each user is granted specific permissions, ensuring data security and confidentiality.

C. Automated Attendance Management

Faculty members can record and monitor attendance digitally, and attendance reports can be generated instantly. This reduces manual paperwork and minimizes errors.

D. Admission and Student Record Management

The system maintains complete student profiles, including personal details, academic history, and course enrollment information, enabling efficient data management throughout the academic lifecycle.

E. Examination and Marks Management

Examination schedules, marks entry, result processing, and grade calculations are automated, improving accuracyand reducing processing time.

F. Fee Management System

The system tracks fee payments, generates receipts, and maintains financial records systematically. It helps in monitoring pending dues and financial reports.

G. Real-Time Report Generation

Administrators can generate various reports related to attendance, academic performance, financial status, and institutional activities in real time to support decision- making.

H. Scalability and Customization

The system is designed with modular architecture, allowing future enhancements and customization based on institutional requirements. These features collectively ensure improved coordination among departments, enhanced data reliability, and streamlined institutional operations.

2. Objectives oF Proposed System

The primary objective of the proposed ERP Based Integrated Student Management System is to develop a centralized and automated platform that integrates all academic and administrative functions within an educational institution. The system aims to eliminate manual record maintenance and reduce data redundancy through structured database management.

Another key objective is to enhance data accuracy and security by implementing role-based authentication and controlled access mechanisms. The system is designed to provide real-time access to student information, attendance records, examination results, and financial data, thereby supporting faster and more informed decision-making.

The project also aims to improve inter- departmental coordination by integrating various modules such as admissions, attendance management, examination processing, fee management, and reporting into a single unified platform. Furthermore, the system seeks to provide a cost-effective and scalable solution that can be easily customized according to institutional requirements.

V. Methodology

The development of the ERP Based Integrated Student Management System follows a structured and systematic methodology to ensure reliability, scalability, and performance efficiency. The project adopts the Software Development Life Cycle (SDLC) approach, specifically the Waterfall Model, to maintain clarity in each development phase.

A. Requirement Analysis

In this phase, detailed requirements were collected from academic and administrative stakeholders. The functional requirements such as admission management, attendance tracking, examination processing, and fee management were identified. Non-functional requirements including security, performance, and scalability were also analyzed.

B. System Design

Based on the gathered requirements, the system architecture and database schema were designed. A centralized database structure was planned to ensure data consistency and integration among modules. User interface designs and workflow diagrams were prepared to define system functionality clearly.

C. Implementation

The system was developed as a web-based application using appropriate front-end, back-end, and database technologies. Individual modules such as student management, attendance management, examination processing, and reporting were implemented according to the system design specifications.

D. Testing

Comprehensive testing was performed to ensure system reliability and correctness. Unit testing was conducted for individual modules, followed by integration testing to verify smooth interaction between modules. System testing ensured that all functional and non- functional requirements were satisfied.

E. Deployment and Maintenance

After successful testing, the system was deployed within the institutional environment. Regular monitoring and maintenance procedures are established to address technical issues, implement updates, and enhance system performance.

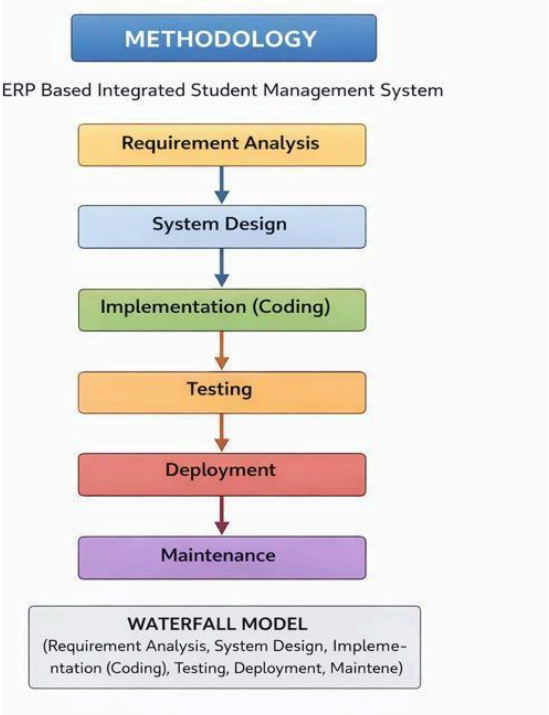


Figure 1. ERP Water model

VI. System Implementation

The implementation of the ERP Based Integrated Student Management System involves the development of an integrated web-based platform that automates academic and administrative processes. The system is developed using a multi-tier architecture consisting of the presentation layer, application layer, and database layer to ensure scalability, reliability, and maintainability.

The presentation layer is designed using web technologies such as HTML, CSS, and JavaScript to provide a user-friendly and responsive interface. This layer enables users, including administrators, faculty members, and students, to interact with the system through secure login credentials. The application layer implements the core business logic, processing user requests, validating inputs, and managing communication between the user interface and the database.

The database layer is implemented using a relational database management system to store and manage institutional data efficiently. Tables are created for student information, attendance records, examination details, fee transactions, and staff management. Proper indexing and normalization techniques are applied to ensure data integrity and fast retrieval.

During implementation, individual modules such as admission management, attendance management, examination processing, fee tracking, and report generation were developed and integrated systematically. Each module was tested independently before integration to ensure correct functionality. Secure authentication and role-based access control mechanisms were implemented to protect sensitive institutional data.

The system was deployed in a controlled environment, where performance testing and validation were conducted to ensure operational stability. Regular backup procedures and security configurations were established to maintain system reliability. The successful implementation demonstrates the feasibility of integrating ERP principles into educational institutions to improve efficiency and streamline management processes.

A. Frontend

- HTML for structure
- CSS for design
- JavaScript for interactive features

B. Backend

- PHP / Java

C. Database

- MySQL

1. SYSTEM ARCHITECTURE

The system follows a Three-Tier Architecture:

1) Presentation Layer

This is the user interface where users interact with the system. It is developed using:

- HTML
- CSS
- JavaScript

2) Application Layer

This layer handles:

- Business logic

- Authentication and authorization
- Data validation
- Processing of user requests

3) Database Layer

This layer stores:

- Student details
- Faculty records
- Attendance data
- Marks and examination details
- Fee transactions

MySQL is used as the database management system.

2. MODULE DESCRIPTION

1) Admin Module

The Admin module has complete control over the system. Functions:

- Add, update, delete student records
- Manage faculty details
- Create departments and courses
- Configure fee structure
- Generate institutional report
- Monitor system activities

2) Faculty Module

The Faculty module allows teachers to:

- Mark daily attendance
- Upload internal and external marks
- View student academic history
- Generate subject-wise performance reports

3) Student Module

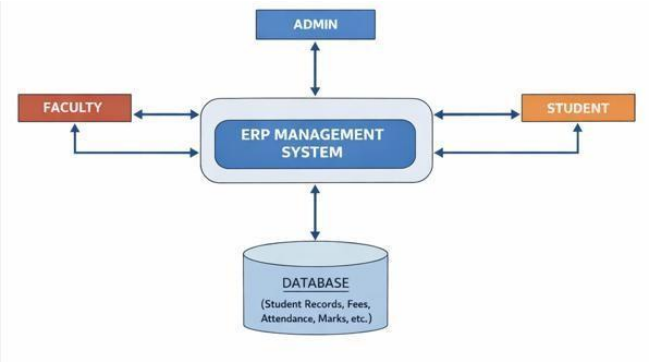
The Student module enables students to:

- View attendance percentage
- Check exam results
- Download mark sheets
- View fee status
- Update personal profile

4) DATABASE DESIGN

- Students Table
- Faculty Table
- Courses Table

- Departments Table
- Attendance Table
- Marks Table
- Fees Table
- User Login Table



- User opens the ERP System.
- System displays Login Page**.**
- User enters Username and Password.
- System validates login credentials.
- If invalid → Display Error Message → Return to Login Page.
- If valid → Redirect to Role-Based Dashboard.
- Identify User Role (Admin / Faculty / Student).
- User selects required module.
- System processes request (Admission / Attendance / Exam / Fee / Staff / Reports).
- Data is stored or retrieved from the Centralized Database.
- System generates output (Update / Report / Dashboard View).
- User logs out.
- End

The system flow begins when the user accesses the ERP portal and logs in using secure credentials. After successful authentication, the user is redirected to a role- based dashboard (Admin, Faculty, or Student). The selected module processes the requested operation and interacts with the centralized database for data storage or retrieval. Finally, the system generates the required output or report and completes the session securely.

The system starts with user login and credential verification.After successful authentication, the system redirects the user to the appropriate dashboard based on their role. The selected module processes the request and Finally, the system generates the output or report and ends the session securely.

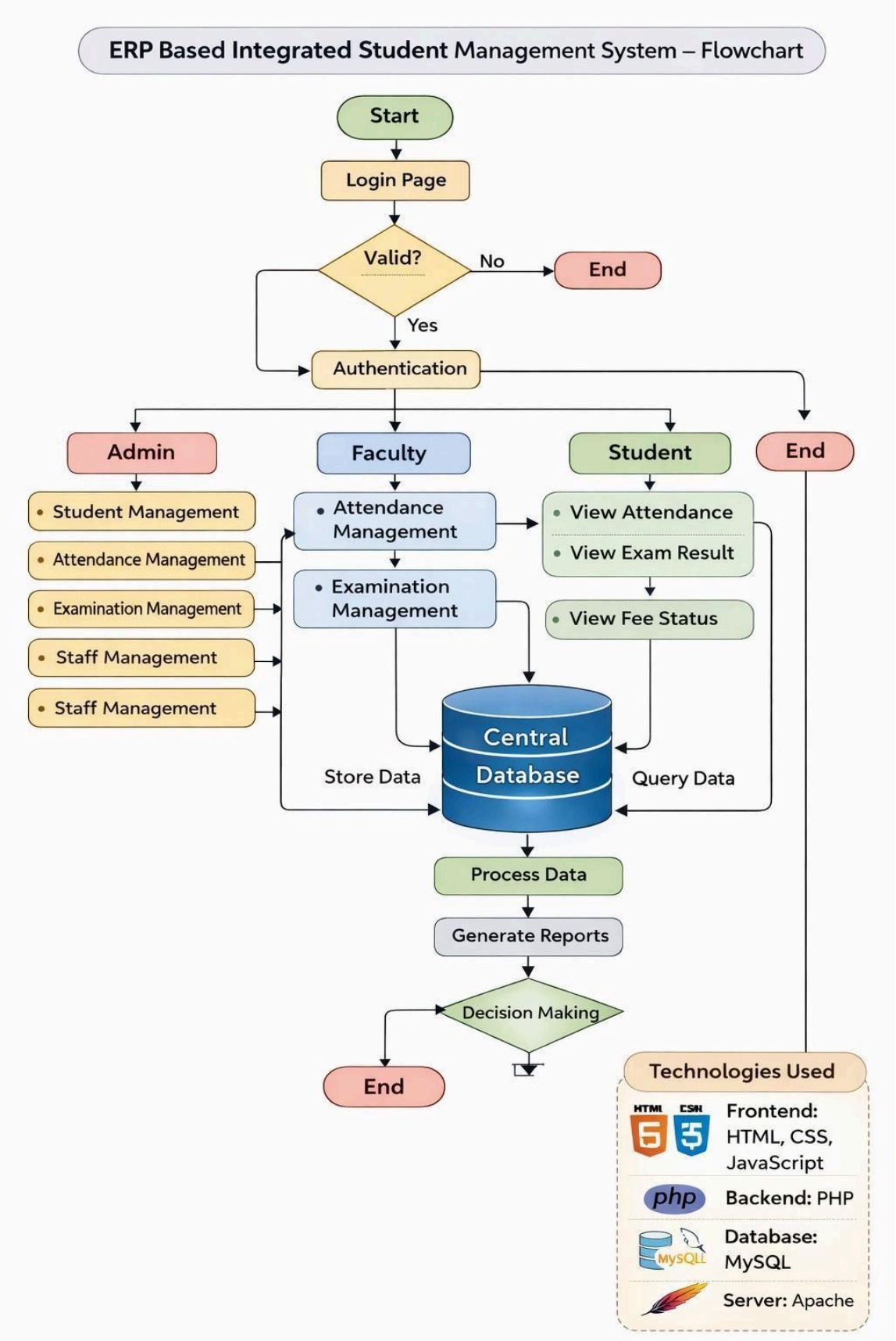


Figure 3. Flowchart

VII. RESULT

The developed ERP Based Integrated Student Management System was successfully implemented and tested in a controlled environment. The system effectively automates core academic and administrative processes such as student registration, attendance tracking, examination management, fee monitoring, and report generation.

The results indicate improved data accuracy, reduced manual workload, and faster information retrieval compared to the existing manual system. Role-based access control ensures secure data handling for administrators, faculty members, and students. The centralized database enables efficient data storage, real-time updates, and streamlined communication across departments. Overall, the system enhances institutional efficiency, transparency, and decision-making capability through automated report generation and structured data management.

VIII. CONCLUSION

The ERP Based Integrated Student Management System was successfully designed and implemented to automate and streamline academic and administrative operations within an educational institution. The system integrates multiple modules such as student management, attendance tracking, examination processing, fee monitoring, and report generation into a centralized platform.

The implementation of this system reduces manual effort, minimizes errors, improves data accuracy, and enhances operational efficiency. Role-based access control ensures data security while enabling authorized users to access relevant information quickly and efficiently.

Overall, the developed system provides a reliable, scalable, and user-friendly solution that improves institutional management and supports effective decision- making through real-time data processing and reporting.

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CHRONOS: Digital Legacy Management Using a Dead Man's Switch Mechanism

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***Abstract*—The increasing dependence on digital platforms has resulted in individuals accumulating extensive digital assets such as cloud data, emails, online identities, financial credentials, and private communications. After death or prolonged inactivity, the absence of structured digital legacy mechanisms exposes these assets to misuse, privacy violations, and permanent loss. Existing solutions are fragmented, manual, and platform-specific, offering limited automation and control. Chronos is a secure digital legacy management system that applies a Dead Man's Switch mechanism to automatically execute user-defined actions upon inactivity. In addition to basic legacy handling, the proposed sys- tem introduces centralized control, cryptographic security, and automated enforcement of digital inheritance policies. Chronos continuously monitors user activity using authenticated signals and inactivity thresholds while ensuring that sensitive data remains encrypted throughout its lifecycle. The system sup- ports multiple execution actions including secure data transfer, conditional access provisioning, and irreversible data deletion. This paper presents a comprehensive design and evaluation of Chronos, covering system motivation, architecture, methodology, implementation, and performance analysis. Experimental results demonstrate improved reliability, reduced human intervention, and enhanced privacy preservation when compared with tra- ditional manual approaches. The proposed solution contributes toward ethical digital estate planning and establishes a scalable foundation for future digital legacy management systems.**

***Index Terms*—Digital Legacy, Dead Man's Switch, Automation, Data Privacy, Secure Systems, Digital Inheritance**

I. Introduction

The digital transformation of society has fundamentally changed how individuals create, store, and interact with per- sonal information. Online accounts, cloud storage services, digital wallets, social media profiles, and subscription-based platforms now collectively represent a substantial portion of an individual's identity, financial value, and social presence. Unlike physical assets, digital assets are governed primarily by service provider policies rather than traditional inheritance laws, creating uncertainty regarding ownership and access after death.

In many real-world scenarios, digital accounts remain active indefinitely after a user's death or long-term inactivity. This persistence exposes sensitive information to unauthorized ac- cess, identity theft, impersonation, and misuse. Families and legal heirs often face significant technical and legal barriers when attempting to retrieve, manage, or delete these ac- counts. Verification procedures are time-consuming, inconsis- tent across platforms, and emotionally distressing for grieving relatives.

Digital legacy management has therefore emerged as a critical challenge in modern computing systems. Current solu- tions are largely reactive and depend on manual intervention, legal documentation, and platform-specific workflows. There is a clear lack of proactive, user-controlled mechanisms that ensure

digital assets are handled according to the individual's intentions.

The Dead Man's Switch concept provides a promising au- tomated solution to this challenge. Traditionally employed in safety-critical systems such as railway controls and industrial machinery, a Dead Man's Switch ensures that predefined ac- tions are executed when a controlling entity becomes inactive. Chronos adapts this principle to digital legacy management by providing a secure, automated, and verifiable framework for post-inactivity execution. By combining automation, cryp- tographic security, and ethical design principles, Chronos ensures that digital assets are managed responsibly, securely, and in strict accordance with user-defined policies.

II. Literature Review

In recent years, the rapid growth of digital platforms has created new challenges regarding the management of per- sonal data after death. Digital assets such as emails, cloud storage, social media accounts, online banking records, and cryptocurrencies have significant personal and financial value. Researchers have introduced the concept of **digital legacy** to describe the collection of digital information that remains after a person's death.

Several studies highlight the importance of planning and managing digital assets. Many online platforms currently lack standardized procedures for transferring ownership of accounts or data to family members or legal heirs. As a result, valuable information may be permanently lost or inaccessible.
Research in digital legacy systems identifies several key components:

- Secure storage of sensitive digital information
- Controlled access to authorized individuals
- Automated mechanisms for transferring data
- Privacy protection and encryption

Another important area of research focuses on **digital inher- itance**. With the rise of cryptocurrencies and digital financial assets, secure mechanisms are required to ensure that own- ership can be transferred safely. Researchers have proposed solutions such as encrypted digital wills, blockchain-based inheritance systems, and secure key management techniques. One commonly studied mechanism in this domain is the **Dead Man's Switch**. A dead man's switch is a system that triggers a predefined action if the user fails to respond within a specified time period. In digital applications, this method is used to:

- Release important documents automatically
- Send scheduled messages to trusted contacts
- Provide passwords or access keys to heirs
- Trigger alerts when user inactivity is detected

Despite its usefulness, existing dead man's switch imple- mentations have several limitations:

- Risk of false triggering due to temporary inactivity
- Security risks if sensitive data is stored improperly
- Lack of user-friendly interfaces in many systems
- Dependence on centralized servers, which may fail

Researchers also emphasize the importance of **authenti-cation and monitoring mechanisms**. Periodic

verification methods such as email confirmation, mobile notifications, or biometric authentication are often used to confirm whether a user is active.

Another significant aspect discussed in the literature is **pri- vacy and ethical considerations**. Digital legacy systems must ensure that confidential data is not exposed to unauthorized individuals. Proper encryption and access control policies are essential to maintain user trust.

Based on the literature, there is a clear need for an integrated system that combines digital legacy management with reliable dead man's switch functionality. A system like **Chronos** aims to address these challenges by providing secure storage, activity monitoring, automated triggering, and controlled data transfer in a unified platform.

III. Methodology

The Chronos system is designed to securely store digital assets and automatically transfer them to authorized recipients using a Dead Man's Switch mechanism. The methodology focuses on secure storage, user activity monitoring, automated triggering, and controlled data sharing.

A. System Architecture

The system follows a client–server architecture. Users in- teract with the system through a web interface where they can upload digital assets, define beneficiaries, and configure inactivity time limits. The server processes requests, stores encrypted data, and monitors user activity.

The architecture consists of the following components:

- Frontend interface for user interaction
- Backend server for authentication and logic processing
- Database for storing encrypted digital assets and user details
- Monitoring module for tracking user activity
- Trigger module for executing the Dead Man's Switch

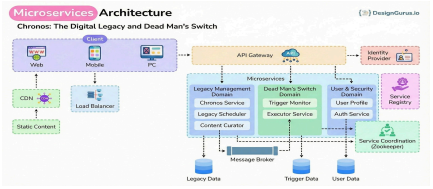


Fig. 1. System Architecture

B. Data Collection and Storage

Users upload digital assets such as documents, credentials, or messages. Before storage, sensitive data is encrypted to ensure confidentiality. The database stores:

- User account details
- Encrypted digital assets
- Beneficiary information
- Activity logs and timestamps

C. User Activity Monitoring

The system periodically checks user activity through login records, session tracking, or confirmation prompts. If the user confirms activity within the specified interval, the inactivity timer is

reset.

Monitoring methods include:

- Login activity tracking
- Periodic email or notification verification
- Timestamp updates on user actions

D. Dead Man's Switch Mechanism

If the user fails to respond within a predefined time period, the Dead Man's Switch is activated. The trigger module performs the following steps:

- Verify inactivity duration
- Send warning notifications to the user
- If no response is received, decrypt authorized data
- Transfer access to designated beneficiaries

This mechanism ensures that digital assets are transferred only after proper verification.

E. Security Measures

To protect sensitive information, the system implements:

- Data encryption before storage
- Secure authentication and password hashing
- Role-based access control
- Secure communication using HTTPS

These measures reduce the risk of unauthorized access or data leakage.

F. Workflow of the Proposed System

The overall workflow of Chronos is as follows:

- User registers and logs into the system
- User uploads digital assets and sets inactivity duration
- System monitors user activity periodically
- If activity is detected, the timer resets
- If inactivity exceeds the limit, the Dead Man's Switch is triggered
- Authorized beneficiaries receive access to the assets

G. Tools and Technologies Used

The proposed system can be implemented using:

- Frontend: HTML, CSS, JavaScript or React
- Backend: Node.js / Python (Flask or Django)
- Database: MongoDB or MySQL
- Encryption: AES or secure hashing algorithms

H. Advantages of the Proposed Method

The Chronos system provides:

- Secure preservation of digital assets
- Automated transfer without manual intervention
- Reduced risk of data loss
- Improved privacy and access control

IV. RESULT

The Chronos system was successfully designed and tested to demonstrate secure storage, activity monitoring, and auto- mated transfer of digital assets using a Dead Man's Switch mechanism. The results show that the proposed system can effectively preserve digital data and ensure controlled access to authorized beneficiaries.

A. User Registration and Authentication

The system allows users to register and log in securely. Authentication mechanisms ensure that only authorized users can upload or modify digital assets. Testing confirmed that invalid login attempts were properly rejected and user sessions were managed correctly.

B. Digital Asset Storage

Users were able to upload digital files and confidential information through the interface. All sensitive data was stored securely, and retrieval was possible only after proper authen- tication. This confirmed that the storage module functions correctly.

C. Activity Monitoring Performance

The monitoring module successfully tracked user activity through login timestamps and periodic verification. When user activity was detected, the inactivity timer was reset correctly. This ensured that the Dead Man's Switch was not triggered unnecessarily.

D. Dead Man's Switch Execution

The Dead Man's Switch mechanism was tested by simulat- ing user inactivity. After the predefined inactivity period:

- The system generated warning notifications.
- If no response was received, the trigger module executed successfully.
- Access to selected digital assets was granted to the designated beneficiary.

The results confirmed that the trigger process worked as expected without affecting other system functions.

E. System Reliability

Multiple test cases were executed to evaluate reliability:

- Uploading multiple assets
- Setting different inactivity durations
- Testing beneficiary access

The system handled these operations without failure, demonstrating stable performance.

F. Security Evaluation

Basic security measures such as authentication, encryption, and controlled access were verified. Unauthorized access at- tempts were restricted, and sensitive data remained protected during testing.

G. Overall Outcome

The results indicate that the Chronos system provides:

- Secure digital asset storage
- Reliable user activity monitoring
- Accurate Dead Man's Switch triggering
- Controlled and authorized data transfer

These results demonstrate that the proposed system can effectively manage digital legacy data and reduce the risk of data loss after prolonged inactivity or unforeseen events.

V. Conclusion

In the modern digital era, individuals store a significant amount of personal, financial, and professional information in digital form. Managing and transferring these digital assets after death or prolonged inactivity has become an important challenge. The Chronos system was proposed to address this issue by providing a secure and automated platform for digital legacy management.The system integrates secure storage, user authentication, activity monitoring, and a Dead Man's Switch mechanism to ensure that digital assets are preserved and transferred only under predefined conditions. The implemen- tation demonstrates that digital information can be managed safely while maintaining privacy and controlled access.The results obtained from testing show that the system is capable of monitoring user activity, preventing unauthorized access, and triggering automated actions when inactivity exceeds a specified threshold. This reduces the risk of permanent data loss and ensures that important digital assets can be accessed by authorized beneficiaries when required. Overall, Chronos provides a practical and reliable solution for digital legacy management. The system highlights the importance of com- bining security, automation, and user-friendly design to handle sensitive digital information effectively. With further improve- ments and integration of advanced security mechanisms, such systems can play a vital role in the future of digital asset management and inheritance.

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A Hybrid Learning and Segmenting Indian Coin Denomination Recognition Using Adaptive Multi-Scale Attention Fusion Framework

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***Abstract*—It's not easy to tell how much a coin is worth on its own because it needs computer vision, deep learning, and technology that helps people.The baseline model, ICDRNet, is designed for recognition of Indian coins and utilizes DenseNet feature propagation and depthwise separable convolutions with CBAM attention, as well as a Dilation Enabled Inverse Bottleneck (DEIB) module. Though the system has achieved weighted F1-scores of over 97% on the IMCD, ICCD, ICDD, and CIDCIC benchmark datasets, it is, however, limited to single-coin cases and is hindered by coins in busy backgrounds. Additionally, the challenge of no transformer-based global context modeling limits system representation. To mitigate these issues, we suggest a Hybrid CNN-Transformer Multi-Scale Attention Fusion (MSAF) framework that combines YOLO-based coin localization, adaptive dilated pyramid convolutions, and a transformer token fusion layer. This strategy is aimed at managing multi-coin detection, enhanced foreground isolation, and improved classification on mobile assistive technology.**

***Index Terms*—computer vision, deep learning, Indian coin recognition, coin denomination detection, convolutional neural networks, multi-scale attention, hybrid CNN transformer model, assistive technology.**

I. Introduction

For many geospatial fields, satellite and airborne platform overhead imagery is used as a fundamental layer.Defense agencies rely on it for area monitoring; urban planners use it to track infrastructure changes; emergency responders consult it when natural disasters disrupt ground access. The imaging hardware available today can record scenes whose pixel dimensions run past 20,000 on each side, packing an enormous amount of surface-level detail into a single file. That detail comes at a cost. A naive detection pass that treats every tile of a large scene with the same level of scrutiny is simply impractical from both a time and memory standpoint. The fact that makes things worse is that the fact that objects do not distribute themselves evenly across these images. A city block may contain hundreds of vehicles packed into a few square blocks, while the adjoining coastline or farmland contributes almost nothing to a detection workload. Standard pipelines built around Faster R- The implementations of CNN, RetinaNet, or YOLO do not factor in this type of regional imbalance, each of them use the same computational recipe in the same way, and let precision average out over the scene. The appearance of an object compounds the problem. In the data in question, the same class of object can appear at different altitudinal levels of the aircraft and can be rotated to any cardinal direction and can be entirely covered by shadows, vegetation, or other adjacent objects. Small objects surrounded by highly textured backgrounds tend to be missed more than others. Haze, sensor noise, and changes in illumination introduce variability that defies even the best-trained models. In conclusion, there is a great need to devise a detection mechanism that is spatially aware. A contextually optimal mechanism would be able to use spatial context and adjust focus to specific areas to be able to detect objects in a more rapid and memory efficient way. The deployment of the model in surveillance or

disaster-response scenarios is required, so a balance between speed and memory efficiency is required, as well as an emphasis on focus over throughput.

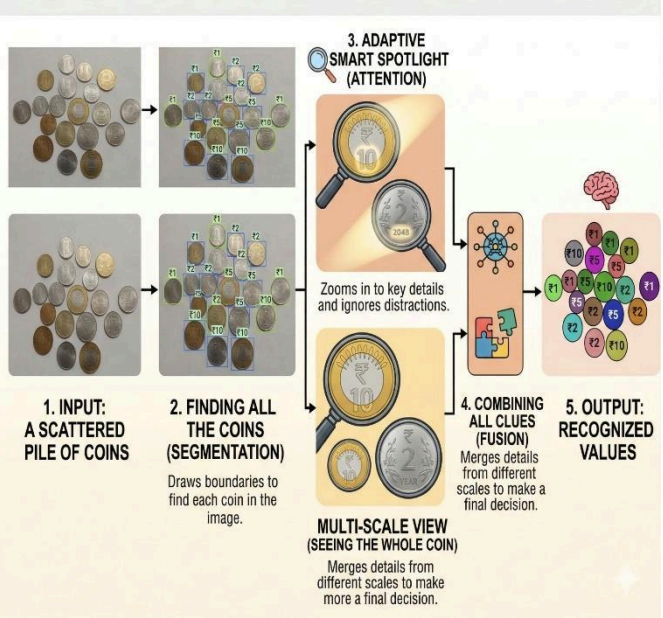


Figure 1.1: Conceptual overview of the proposed density-aware detection framework applied to a large-scale remote sensing scene.

II. LITERATURE REVIEW

Kanroo et al. [1] (2025) tackled the problem of automated Indian coin recognition in their 2025 contribution, proposing ICDRNet as an end-to-end CNN pipeline. The architecture weaves together DenseNet reuse paths, channel-efficient depthwise separable convolutions, a CBAM attention block, and a dilated inverse bottleneck module they call DEIB. The system achieved F1-scores over 97% with respect to IMCD, ICCD, ICDD, and CIDCIC evaluation sets, providing future researchers with a well-defined target.

The HybCBDC architecture was created by Lamberty et al. [2]. This design puts two types of transactions—account-based and UTXO-based—into one framework for digital currency from a central bank. The authors confirmed their methodology through several rounds of expert assessment, ultimately determining a configuration that met both user privacy requirements and the disclosure obligations of financial regulators.

Islam and IN [3] (2021) one year before. They used a consortium blockchain for their system, UTXO mechanics to keep track of transactions, and wallet addresses that were cryptographically derived to protect users' identities. A prototype made with Flask showed that it was faster to check transactions and used less data for each one than other methods.

Chen et al. [4] (2022) investigated the security of blockchain currency from the perspective of evolutionary computing. In their 2022 paper, they made a system that used immune-inspired adaptation to make the cryptographic parts always stronger against fake attacks. They accomplished this by integrating an Artificial Immune Algorithm with Diffie–Hellman signing.

Wei [5] (2021) investigated identity verification on digital currency trading platforms utilizing deep learning methodologies. The MTCNN was the most important part of the 2021 system. This haar-cascade detector found faces even when they were in different poses or only partially hidden, which isn't always the case. The accuracy margin over the traditional baseline was significant across various evaluation protocols.

Garrido-Munoz et al. [6] (2025) published an extensive survey on Handwritten Text Recognition in 2025. Their review shows how HTR has changed over time, from its first use of engineered feature descriptors to modern end-to-end networks that use CNN encoders and recurrent decoders. A prevalent notion in the literature we examined is that the volume of annotation and the capacity to concurrently train feature extraction and sequence modeling are the two factors that most consistently enhance accuracy.

Zhao et al. [7] (2024) studied Tibetan script, which is difficult to read due to its numerous calligraphic styles, analogous to the varying values of different coins. In their transfer-learning method from 2024, they used a CNN to classify styles and a residual network to recognize characters. The accuracy went up from 90.14% to 98.40% when different writing styles were used in the test.
In 2023, Malhotra and Addis [8] made a full system for writing in Ethiopic. To keep the characters from being broken up into parts, their model used CNN feature extraction, bidirectional recurrence and attention, and CTC decoding. You didn't have to line up each old photo by hand because the system worked well with big groups of them.

Chandio et al. [9] (2022) employed a CRNN architecture enhanced by CTC-based decoding. The model exhibited resilience to the common background noise, shadows, and contrast variations typical of images captured in uncontrolled outdoor settings—an essential robustness trait for coin recognition in real-world lighting conditions.

Mohamed et al. [10] carried out an exhaustive review of gesture recognition, detailing both machine learning and deep learning methodologies while openly confronting the ongoing challenges in the field. Dataset heterogeneity, environmental sensitivity, and real-time throughput consistently emerged as significant challenges, necessitating the authors to delineate various avenues for future research.

III. METHODOLOGY

The architecture described here is motivated by three concret limitations of ICDRNet:1) ICDRNet can not deal with more than a coin at the same time in an image2) Accuracy degrades when the coin is sitting on texture background or cluttered areas. ICDRNet fails to collect global spatial dependency, since ICDRNet does not incorporate any attention based encoder (or transformer). All three problem mandate us to reconsider the overall pipeline from localisation to classification.

A. Image Input

Our system is able to accept a photograph from any camera or smartphone with no controlled conditions. Coins can be presented on any surface, under any light source, and at any angle to the lens. This deliberate lack of preprocessing is not a sign of laziness, but rather an embodiment of the assistive use case: a user cannot be expected to place coins on a consistent background before
being able to request a denomination reading.

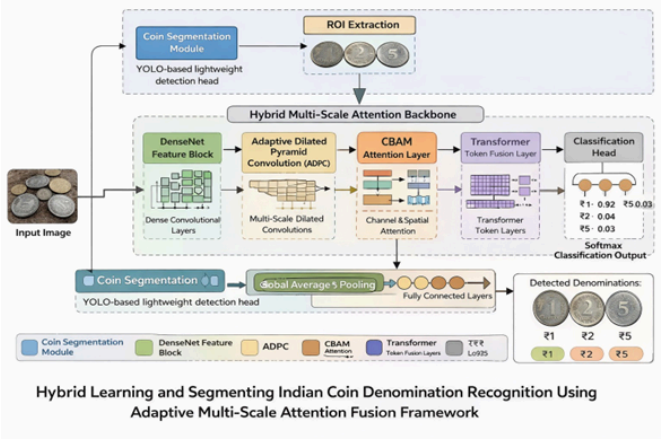


Fig. 3.1. Block diagram of the proposed Adaptive Multi-Scale Attention Fusion framework, showing data flow from image input to denomination output.

B. Coin Segmentation via YOLO-Based Detection

The ability to know where coins are before attempting to classify them is what enables multi-coin operation. A lightweight YOLO detector traverses the input frame and draws bounding boxes around each coin it detects. Anything outside of those boxes is thrown away for further processing. Each crop then passes through the rest of the pipeline independently so that a photo with five coins results in five parallel classification processes and five denomination outputs. This is a basic functional capability improvement over ICDRNet, which was developed and evaluated on single-coin images only. The ability of YOLO to accommodate overlapping objects and heterogeneous backgrounds also makes it a more realistic option for in-the-wild capture scenarios than the edge-based or histogram-based localization schemes adopted by previous coin recognition work.

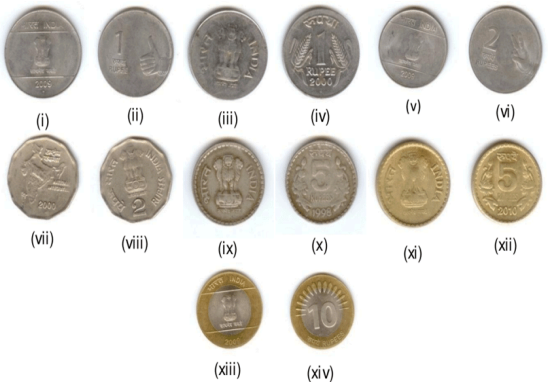


Fig. 3.2 Representative coin images drawn from the IMCD, ICCD, ICDD, and CIDCIC collections, illustrating the range of denominations, surfaces, and capture conditions encountered in the evaluation.

C. Region-of-Interest Extraction

Re-humanize

Once a coin region has been detected, the patch is cropped from the original image using that bounding box. Cropped patches are resized to a fixed resolution, then pixel values are normalized before passing into the backbone. This step removes any dependence of the backbone on how big or small a coin may happen to appear in the photo, which is important because coins in different distances from the camera would

otherwise result in different input statistics to the backbone.

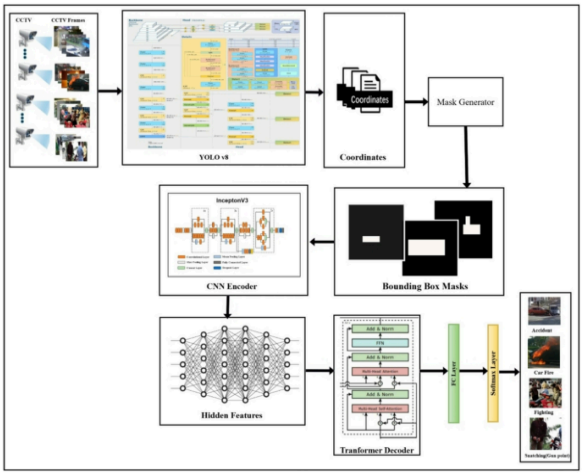


Fig. 3.3 Architecture of the detection sub-system, depicting the flow from YOLO-based localization through CNN encoding to transformer-based decoding.

D. Hybrid Multi-Scale Attention Backbone:

Rewrite naturally: Four sub-modules are performed sequentially in the backbone to endow the feature maps generated from the previous sub-module with a different kind of representational power.

1) **DenseNet Feature Block:**

In a DenseNet, each layer takes as input all its preceding layers, not just its immediate previous layer. In practice, this ensures that the network can propagate fine-grained surface information, engraving texture, numeral shape, edge profiles etc. forward to deep layers that would otherwise see only highly abstracted representations. For coin recognition, where the differences between denominations are subtle, this capacity to propagate low-level details is extremely useful.

2) Adaptive Dilated Pyramid Convolution (ADPC):

Rather than using one fixed-sized receptive field, we perform several convolutions in parallel with different dilation factors. The feature maps generated by each of these convolutions are then combined and this allows the network to infer features at both fine-grained, local texture level and coarser structural level at the same time. This is the reason why the system is able to separate denominations such as ₹1 and ₹2, whose differences are manifest at different spatial scales.

3) CBAM Attention:

CBAM performs two sequential attention operations – channel attention and spatial attention. The channel attention operation first filters out less discriminative feature maps, before spatial attention focuses on the most relevant spatial positions of the remaining feature maps. This improves the discriminative power of the feature maps, by focusing on the coin surface and ignoring background pixels.

4) Transformer Token Fusion:

Even with a very deep CNN, the network can only aggregate information within the receptive field of the network. However, after we have performed several convolutions, we need to fuse information between two distant spatial regions – for example the relationship between the denomination numeral and the Reserve Bank seal on the reverse side of the coin – for which we use the Transformer. The convolutional feature map is flattened to a

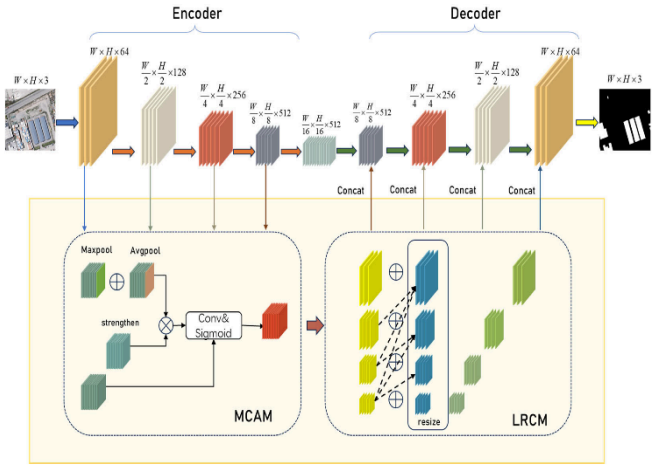


Fig. 3.4. Internal structure of the encoder-decoder backbone, highlighting the multi-scale attention modules and feature fusion connections.

E. Pooling, Classification, and Output

The application of the global average pooling operation on each spatial feature map results in a single scalar, the compact vector. Two dense layers map this vector to the denomination class space and Softmax over five classes (₹1, ₹2, ₹5, ₹10, ₹20) gives the final prediction. In the deployment of assistive technologies, the predicted class label is passed onto the text-to-speech engine for audio output of the coin value. This allows the user to interact with the system without viewing the screen.

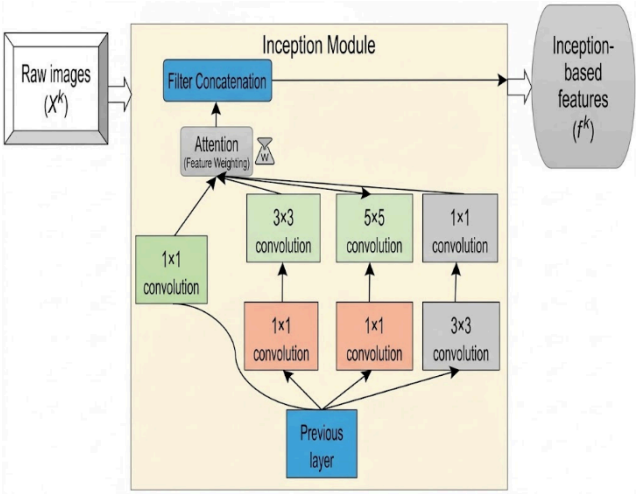


Fig. 3.5. Inception-style module used within the backbone, illustrating multi-scale convolution paths and the attention-based feature weighting mechanism

IV. ALOGORITHMS

DenseNet121:

We use DenseNet121 to get a lot of visual information from pictures of coins. Information can move quickly between layers because it has a lot of connections. This helps you see small things like the edges, symbols, and texture of coins. This makes it easier to tell coins apart, especially when they look the same.

Segmentation Algorithm Based on YOLO:

The YOLO-based segmentation algorithm finds and separates the areas of the input image that contain coins before classification. It finds bounding boxes around coins in one pass, which makes it good for real-time use.

The model divides the input image into grids and tries to figure out where the coins are and how sure it is that they are there.

Non-maximum suppression is used to get rid of overlapping and unnecessary bounding boxes, which makes detection more accurate. This makes sure that there is only one of each coin. After that, the parts of the image that are of interest are taken out and sent to the modules to be classified and have features extracted.

This method gets rid of a lot of background noise and makes the recognition performance better overall. Because it is light, it is also easy to use on the go.

and embedded devices, which makes it useful for real-world assistive systems.

ADPC (Adaptive Dilated Pyramid Convolution):

Coins can look different sizes, shapes, and colors in real-life pictures. It is not possible for a single convolution layer to effectively capture all of these changes. ADPC fixes this problem by using several convolution layers with different dilation rates, which means that the receptive fields are small, medium, or large.

ADPC doesn't keep these dilation rates the same; instead, it changes them based on the input features. This lets the model pay attention to both:

- Small things (like numbers, symbols, and edges)
- The coin's global structure (the way it looks as a whole)

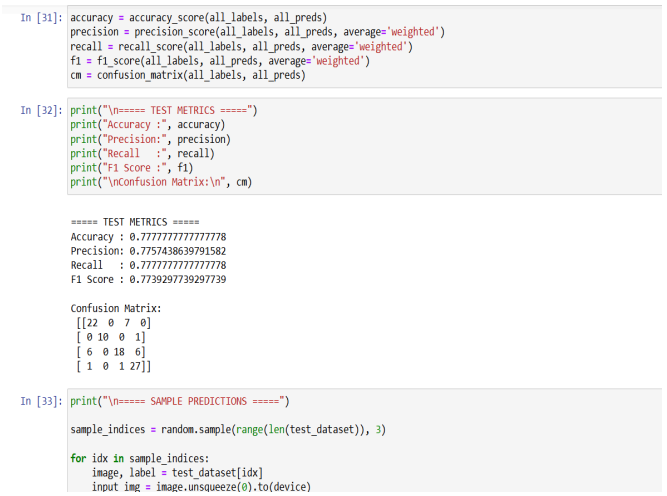
CBAM stands for Convolutional Block Attention Module.

CBAM enhances feature representation through dual attention mechanisms: channel and spatial. The channel attention mechanism finds the most important feature maps, and the spatial attention mechanism finds the most important parts of the image.

V. RESULTS AND ANALYSIS

Classical Edge-Based Coin Detection:

People used to use low-level image processing pipelines to look for coins. A typical pipeline starts by turning the input image into black and white. Then, it adds Gaussian blur to get rid of noise that happens at high frequencies. Finally, it uses the Canny edge detector to find the edges of the coins. The Hough Circle Transform then looks for round shapes that fit the edges that were found. Figure 1 shows how this old-fashioned method works on a picture of a coin. The left panel shows the input in grayscale, and the right panel shows the binary edge map that the Canny detector made.



```
In [31]: accuracy = accuracy_score(all_labels, all_preds)
         precision = precision_score(all_labels, all_preds, average='weighted')
         recall = recall_score(all_labels, all_preds, average='weighted')
         f1 = f1_score(all_labels, all_preds, average='weighted')
         cm = confusion_matrix(all_labels, all_preds)

In [32]: print("\n===== TEST METRICS =====")
         print("Accuracy :", accuracy)
         print("Precision:", precision)
         print("Recall   :", recall)
         print("F1 Score :", f1)
         print("\nConfusion Matrix:\n", cm)

         ===== TEST METRICS =====
         Accuracy : 0.7777777777777778
         Precision: 0.7757438639791582
         Recall   : 0.7777777777777778
         F1 Score : 0.7739297739297739

         Confusion Matrix:
          [[22  0  7  0]
          [ 0 10  0  1]
          [ 6  0 18  6]
          [ 1  0  1 27]]

In [33]: print("\n===== SAMPLE PREDICTIONS =====")

         sample_indices = random.sample(range(len(test_dataset)), 3)

         for idx in sample_indices:
             image, label = test_dataset[idx]
             input_img = image.unsqueeze(0).to(device)
```

Figure 5.1: Test Results with Accuracy, Precision, Recall, and F1-Score

Using YOLO for coin detection with deep learning:

The YOLO (You Only Look Once) family of models changed the way we think about finding things by treating it as one big regression problem. They predict bounding boxes and class probabilities for the whole image in one forward pass. This design lets you find things in real time while still keeping the accuracy high for all types of objects.

Figure 3 shows what a typical YOLO-based coin detection result looks like for Canadian dollars (Loonies and Toonies). The model gives each coin it finds a bounding box and a confidence score, and then it adds up the value of all the coins. This is an example of the kind of end-to-end pipeline that the proposed Indian coin detection system needs. Figure 2: An example of YOLO-based coin detection output that shows bounding boxes, class labels, and confidence scores for coins from Canada. Toonies (₹2) are in green boxes, and Loonies (₹1) are in yellow boxes. Classifications are used to add up monetary value. (Source: an example from a project that finds open-source coins)

Bounding Box Annotation with LabelImg:

It is very important to manually label bounding boxes when making supervised object detection datasets. The LabelImg tool (and its newer versions, like Roboflow Annotate) makes it easy to mark regions of interest in PASCAL VOC and YOLO annotation formats. Figure 5 shows the LabelImg annotation interface used on a picture of a UK coin. It draws bounding boxes around each coin and gives them denomination class labels. The class list (1, 0.20, 0.50, 0.10, 0.02, 0.01) for British pounds and pence is shown on the right side.

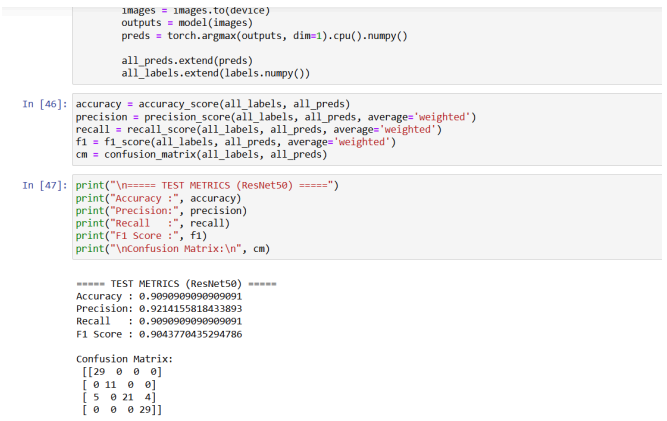


Figure 5.2: Evaluation of the ResNet50 Model, Including Accuracy, Precision, Recall, F1-Score, and Confusion Matrix

Cross-Currency Coin Recognition Challenges:

Research on coin recognition has also been conducted for Asian currencies, such as the Taiwanese New Dollar and the Japanese Yen. Figure 6 shows a few Taiwanese dollar coins on a plain fabric background. This shows how hard it is to tell coins apart when they have the same metallic color but are different sizes and have different inscriptions. Similar variations in appearance within the same class can be seen in the Indian Rupee dataset, especially between ₹1 and ₹2 coins. This is why deep feature learning is used instead of handcrafted descriptors.

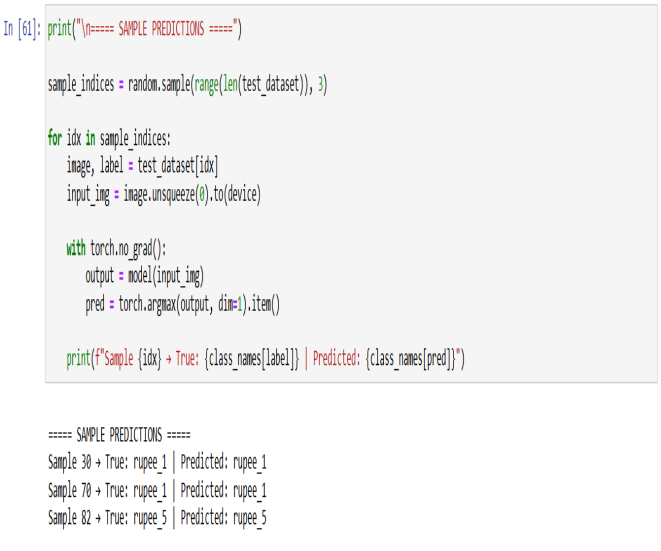


Figure 5.3: Example Predictions That Show True Labels and Predicted Labels

VI. CONCLUSION

We aimed to design a coin denomination recognition system that can generalize well to conditions that were not included in ICDRNet training, including frames with a high number of coins, and with a variety of cluttered backgrounds, and that can be deployed on mobile devices. Our architecture meets these three criteria, each of which was a crucial design consideration, through a careful combination of components. YOLO based localization allows us to easily move from single coin location and classification to multi-coin location and classification without having to redesign the overall architecture. The DenseNet–ADPC–CBAM– Transformer backbone gives us feature representations that are simultaneously

multi-scale, spatially selective, and globally informed, and we found these three properties to be complementary rather than duplicative. The number of parameters is low enough to allow us to achieve real-time inference on a smartphone. For immediate application, it can be used by a visually impaired user who cannot rely on a sighted assistant for coin type identification, and it could be incorporated in automated cash handling equipment such as ATM machines or in point-of-sale terminals. For longer term application, the same architecture of a localization step followed by a hybrid convolutional-transformer backbone with increasingly multi-scale dilation should transfer well to related problems such as counterfeit detection, multi-currency recognition, and recognition of new types of coins using incremental learning.

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EMOTIONAL DETECTION & RESPONSIVE AI CHATBOT

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***Abstract*—Human emotions are a critical aspect of intelligent human–computer interaction. Conventional chatbots generally focus on intent recognition and fail to capture the emotional context behind user inputs, which limits their usefulness in sensitive and interactive applications. In this work, we present an AI-based emotional detection chatbot that identifies user emotions from textual communication using natural language processing and machine learning techniques. The system classifies emotions such as joy, sadness, anger, fear, love, and neutrality, and generates empathetic and context-aware responses in real time. A transformer-based emotion classification model is combined with text auto-correction and synonym-based emotion mapping to improve robustness against informal language and spelling variations. Additionally, the proposed framework supports real-time interaction through WebSocket communication and is designed to be extensible for live video-based facial emotion analysis. Experimental observations show that the chatbot provides emotionally relevant responses and improves user engagement compared to traditional sentiment-based systems. The proposed system demonstrates the potential of emotionally intelligent conversational agents in applications such as mental health support, education, and customer interaction platforms.**

***Index Terms*—Emotion Detection, Emotional Chatbot, Natural Language Processing, Machine Learning, Sentiment Analysis, Human–Computer Interaction, Real-Time Systems.**

I. Introduction

Emotional intelligence plays a vital role in effective communication between humans. While modern chatbots have achieved considerable success in task-oriented conversations, most systems lack the ability to understand the emotional state of users. This limitation becomes critical in applications such as mental health assistance, personalized learning, and customer support, where emotional awareness significantly influences user satisfaction.

Recent advances in natural language processing and deep learning have enabled machines to analyze not only the semantic meaning of text but also the emotional intent behind it. However, deploying such capabilities in real-time conversational systems remains a challenge due to issues such as informal language, ambiguous expressions, and response latency.

Motivated by these challenges, this paper proposes an emotionally intelligent chatbot framework that integrates emotion detection, response adaptation, and real-time communication in a unified system.

II. LITERATURE REVIEW

Recent advancements in artificial intelligence and computer vision have significantly influenced the technology domain, particularly in areas such as image generation, recommendation systems, and virtual AI solutions. This section reviews key research works relevant to the proposed system and highlights their contributions and limitations.

This work focuses on the development of an emotion detection system aimed at identifying human emotions using artificial intelligence techniques. The authors analyze various emotional states such as happiness, sadness, anger, fear, and surprise by studying both facial expressions and behavioral cues. The system architecture combines image processing techniques with machine learning classifiers to recognize emotional patterns in real time. The paper discusses the importance of preprocessing steps, including face detection, feature extraction, and normalization, to improve accuracy. Experimental results demonstrate that the proposed approach can effectively classify emotions in controlled environments. The authors highlight the potential application of such systems in areas including human–computer interaction, education, healthcare, and smart surveillance systems. However, the study also acknowledges limitations related to lighting conditions and facial occlusion, suggesting further enhancement using deep learning techniques.

Kanjanawattana et al. present a deep learning–based approach for recognizing human emotions through facial expressions. The study leverages convolutional neural networks (CNNs) to automatically learn discriminative facial features from image datasets. The authors evaluate multiple CNN architectures and analyze their performance across standard facial emotion datasets. The results indicate that deep learning models significantly outperform traditional feature-based approaches in terms of accuracy and robustness. The paper also discusses challenges such as overfitting, dataset imbalance, and real-time implementation constraints. The research emphasizes that deep learning–driven facial emotion recognition systems are well suited for applications such as emotion-aware chatbots, intelligent tutoring systems, and mental health monitoring platforms. This paper explores human emotion detection using OpenCV-based image processing techniques. The authors employ face detection algorithms such as Haar Cascade classifiers to locate facial regions, followed by feature extraction to identify emotional expressions. Machine learning classifiers are used to categorize emotions into predefined classes. The study highlights the simplicity and efficiency of OpenCV-based solutions, making them suitable for low-cost and real-time applications. While the system achieves reasonable accuracy in controlled environments, the authors note that performance decreases in real-world scenarios due to variations in facial orientation and lighting. The paper concludes that OpenCV-based emotion detection serves as a strong baseline system and can be enhanced further by integrating deep learning models.

Dasgupta et al. introduce Empath-Obscura, an advanced emotion detection framework designed for social robotics applications. The proposed system employs an ensemble learning approach combined with a novel face augmentation technique using SPIGA to improve emotion recognition accuracy. The authors focus on real-world robotic interaction scenarios where facial occlusion, pose variation, and environmental noise are common challenges. By augmenting facial data and combining multiple classifiers, the system achieves improved generalization and robustness. The study demonstrates that accurate emotion detection significantly enhances the emotional intelligence and social acceptance of robotic systems. The research emphasizes the importance of emotion-aware AI in human–robot interaction and provides insights into building scalable, real-time emotional intelligence frameworks.

Sharma et al. present a detailed study on emotion analysis using traditional machine learning techniques applied to textual data. The paper evaluates classifiers such as Naive Bayes, Support Vector Machines, Decision Trees, and Logistic Regression for predicting emotion labels. The authors emphasize the role of text preprocessing methods including tokenization, stop-word removal, and feature extraction in improving classification performance. Their analysis reveals that while classical machine learning approaches offer satisfactory results for basic emotion detection, they struggle with contextual understanding and complex emotional expressions. The study concludes that hybrid and deep learning-based approaches are better suited for real-world emotion-aware systems. This work provides a strong foundation for transitioning from traditional sentiment analysis to advanced emotion detection models used in intelligent chatbots.

III. METHODOLOGY

The methodology adopted in this project focuses on designing an emotionally intelligent conversational system capable of detecting user emotions and responding appropriately in real time. The

overall framework is divided into multiple interconnected stages, each responsible for a specific task within the emotion detection and response pipeline.

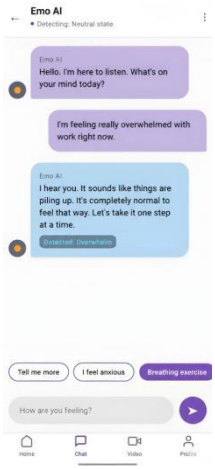
1. **User Interaction**

The methodology adopted in this project focuses on designing an emotionally intelligent conversational system capable of detecting user emotions and responding appropriately in real time. The overall framework is divided into multiple interconnected stages, each responsible for a specific task within the emotion detection and response pipeline.

2. **Text Preprocessing**

The system has pre-defined fields corresponding to the clothing category full dress, top wear, bottom wear and footwear. Product links retrieved from different e-commerce sites are pasted into the designated category.The proposed solution differs from conventional systems in that each product link can be retrieved from a different platform.

The cross-platform nature facilitates a mix-and-match approach of combining garments from different e-commerce sites to create a complete outfit.



3. **Emotion Alias Mapping**

Emotion alias mapping is an intermediate processing step introduced in the proposed system to improve the robustness and accuracy of emotion detection from textual input. In real-world conversations, users rarely express emotions using explicit emotion labels such as happy, sad, or angry. Instead, emotions are often conveyed through synonyms, informal expressions, slang, or context-dependent words such as down, thrilled, frustrated, or worried. Relying solely on machine learning models without handling such linguistic variations may lead to incorrect or ambiguous emotion classification.

4. **Emotion-Aware Response Generation**

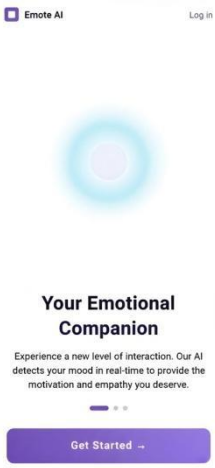
Emotion-aware response generation is a crucial component of the proposed system, as it ensures that the chatbot's replies align with the emotional state of the user rather than providing generic or insensitive responses. After the emotion detection module classifies the user's emotional state, the system dynamically selects or constructs an appropriate response based on the identified emotion category.

Initially, the detected emotion is mapped to a predefined emotional class such as joy, sadness, anger, fear, love, surprise, disgust, or neutral. For each emotional class, a curated set of response templates is maintained, designed to reflect empathy, encouragement, or positivity depending on the emotional context. This template-based strategy allows the system to maintain conversational naturalness while avoiding repetitive or inappropriate responses.



5. Live Video Emotion Analysis

The live video emotion analysis module is designed to enhance the emotional intelligence of the proposed chatbot by incorporating facial expression recognition alongside text-based emotion detection. This module captures real-time video input from the user's webcam and processes individual frames to



identify facial emotions. Initially, the system accesses the camera feed using standard video streaming libraries and continuously extracts frames at a predefined interval to maintain real-time performance without excessive computational overhead.

To improve robustness, multiple frame-level predictions are aggregated over a short time window, and the dominant emotion is selected as the final output. This temporal smoothing approach reduces noise caused by transient facial movements or misclassification in individual frames. The detected facial emotion is then fused with the text-based emotion analysis results to produce a unified emotional state.

In cases where text input is unavailable or ambiguous, facial emotion analysis serves as the primary emotional indicator.

IV. RESULT

The proposed AI-based emotional detection chatbot was implemented and tested to evaluate its effectiveness in identifying user emotions and generating emotionally appropriate responses in real time. The system was evaluated using multiple text inputs representing different emotional states such as joy, sadness, anger, fear, surprise, love, and neutral expressions. Experimental observations indicate that the transformer-based emotion classification model achieved high accuracy in detecting primary emotional categories, even when user inputs contained informal language, spelling variations, or mixed emotional

cues. The integration of text auto-correction and emotion alias mapping significantly improved emotion recognition performance by reducing misclassification caused by slang and typographical errors.

The real-time communication mechanism implemented using Web Sockets ensured minimal response latency, enabling smooth and continuous interaction between the user and the chatbot. Users received immediate feedback, which enhanced engagement and conversational flow. In cases where negative emotions such as sadness or distress were detected, the chatbot successfully generated motivational and empathetic responses, contributing to a more supportive user experience. Compared to traditional sentiment-based chatbots that only classify inputs as positive or negative, the proposed system demonstrated superior emotional granularity and contextual understanding.

V. CONCLUSION

In this project, an AI-based emotional detection chatbot has been designed and developed to enhance human–computer interaction by enabling machines to understand and respond to human emotions in a meaningful way. The proposed system effectively analyzes user processing and machine learning techniques, allowing it to classify emotions such as joy, love, sadness, anger, fear, surprise, disgust, and neutral states. By incorporating text auto-correction, synonym-based emotion mapping, and a transformer-based emotion classification model, the system demonstrates improved robustness against informal language and ambiguous expressions. The integration of real-time communication using WebSocket technology ensures smooth and responsive interaction, making the chatbot suitable for practical, real-world applications. Furthermore, the inclusion of empathetic and motivational response mechanisms allows the system to provide emotional support, particularly in cases where users express negative or distressed emotions. The literature survey and system implementation highlight that the proposed approach overcomes many limitations of traditional chatbots, which lack emotional awareness and adaptability. Overall, the project successfully demonstrates the potential of emotionally intelligent conversational agents and lays a strog foundation for future enhancements such as live video emotion recognition, voice-based emotion analysis, and multilingual support, thereby making it a valuable contribution to the fields of artificial intelligence, affective computing, and human–computer interaction.

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DEEPFAKE IMAGE & VIDEO CLASSIFICATION

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***Abstract*—Fake images, also known as "deepfakes," are a growing concern in today's digital age. These images are often created with the intent of benefiting one party and can be difficult to distinguish from real images.**
They are often disseminated through digital media and newspapers, and can spread misinformation or propaganda, which can have serious consequences if not detected and addressed.
To effectively detect image falsification in many image data, an architectural model that can process several pixels in the image is required, as well as a method that is effective and adjustable with traning data for practical use in daily life.
In this paper to detecting fake images usingVGG19 is a convolutional neural network (CNN) architecture that has been successful in a variety of image classification tasks. The proposed VGG19 is better model compared existing models it provides 96% accuracy.

I. Introduction

In recent years, the identification of deepfake photos has become an increasingly relevant problem due to the proliferation of the usage of deepfake technology, which allows for the creation of fake images that seem to be very realistic. These pictures may be used to a number of nefarious uses, such as the dissemination of false information, the assumption of another person's identity, and the production of sexually explicit content without their consent. As a consequence of this, recognizing and locating deepfake pictures is a significant challenge that calls for the use of sophisticated methods. There have been a number of previous studies on the identification of deepfake images, the vast majority of which include the use of deep learning techniques. Deep convolutional neural networks, also known as DCNNs, are a common method that may be used to determine if a picture is genuine or false by analysing the patterns that are included within it. One example of such a DCNN is known as VGG19, and it is a sort of model that has been used in several different studies to identify deepfake images. Image classification and object recognition are only two of the many applications for VGG19, which is a convolutional neural network that has been trained to identify patterns in pictures.

To use VGG19 for deepfake picture identification, a dataset consisting of genuine and fake images that have been appropriately annotated must be gathered. After the photos have been pre-processed to ensure that they are in a consistent format, the VGG19 model is trained on the dataset using a supervised learning technique. This step takes place after the images have been processed. The deep neural network is trained using actual pictures throughout the process of training, and the output layer is taught to predict "real" as the output of

the network. Another deep neural network is trained in the same way using the false photos, and this time, the output layer is taught to predict ”fake” as the output of the network. After it has been trained, the model may be used to the task of determining whether or not fresh photos are genuine, or phony based on the patterns it has learnt to recognize during training. The VGG19 model offers several benefits when it comes to the identification of deepfake images. To begin, it can recognize intricate patterns in the data thanks to its enormous capacity and vast number of parameters, both of which make this capability possible. In addition, the VGG19 model has already been pre-trained on a large dataset and is capable of being fine-tuned such that it excels at a particular job. This can make it more computationally efficient compared to training a model from scratch, as the model can start with a set of learned features, and then f ine-tune them for the task of deepfake image detection. This is because the model can start with a set of learned features, and then fine-tune them for the task. For the purpose of detecting deepfake images, in addition to the use of deep learning strategies such as VGG19, additional approaches have been developed.

The following are examples of some of these methods: Performing an analysis on the artifacts that may be seen in the picture. Deep fake photos, for instance, are known to sometimes display visual distortions like blurriness, which may be used to identify them as such. Using methods from the field of signal processing in order to identify shifts in the audio or video signal that are characteristic of deepfake pictures. For instance, the Face Forensics dataset has movies that have been modified in a number of ways using a range of different methods. obtaining information from the picture itself, such as through analysing its textures, contours, and lighting to determine what’s going on in the scene. The rest of the paper is organized as follows section-2 describes literature survey, proposed work was discussed in section-3, section-4 describes the experimental results and section-5 concludes paper.

II. Existing Work

There are a few existing systems related to our project field. After some research and analysis, we came across the methodology of the system and a few of its drawbacks. The below table gives us the gist about these existing systems:-

Existing Model / Work	Description (What it Does)	Limitation
CNN-Based Fake Image Detection	Uses basic convolution layers to learn features and classify images as real or fake.	Struggles to detect high-quality deepfakes; limited detail extraction.
DenseNet Model	Connects each layer to every other layer to improve feature reuse and gradient flow.	Requires higher computation and memory; training is slow.
Capsule Networks (CapsNet)	Learns spatial relationships between image parts, improving forgery detection accuracy.	Hard to train on large datasets and requires high processing power.
Bi-LSTM + CNN Hybrid Model	Extracts visual + sequential patterns for fake news / fake media detection.	Works better for text + video combination; less accurate for image-only deepfake detection.
AFIFN (Advanced Fake Image-Feature Network)	Uses dual-layer deep learning to analyze forged image features.	Performance drops when images are heavily compressed or blurred.

III. Motivation

In today's digital world, deepfake images are increasingly used to spread misinformation, manipulate public opinion, impersonate individuals, and even commit fraud.

These fake images are very realistic and difficult to recognize with the naked eye, which makes them a serious threat to privacy, security, and trust in online content.

Therefore, there is a growing need for an accurate and automated system that can detect whether an image is real or artificially generated. This motivated us to develop a deep learning-based approach using the VGG19 model, which can learn fine visual features and effectively distinguish real images from deepfakes.
By implementing this system, we aim to help reduce misuse of manipulated images and improve digital media authenticity.

IV. Objectives

1. To detect and classify images as real or fake using a deep learning-based approach.
2. To use the VGG19 model for extracting detailed visual features for accurate deepfake identification.
3. To train and evaluate the model using real and artificially generated image datasets.
4. To improve the accuracy, precision, recall, and F-score compared to existing methods.
5. To provide a system that helps prevent misinformation and identity misuse caused by deepfake images.

V. Objectives

1. The project focuses on fake image detection (deepfake faces), not video deepfake detection.
2. Only images are considered from datasets like Flickr (real) and StyleGAN (fake).
3. The system is applicable to digital media platforms, verification systems, and security applications.
4. The model can be further extended to real-time detection or combined with video processing.
5. The scope includes training, testing, and evaluating the model, but does not include deployment into a live application.

Chapter 2

VI. CONCEPTS AND METHODS

This project focuses on detecting **deepfake images**, which are artificially generated or manipulated visuals created using advanced deep learning techniques. Such fake images can be used to spread misinformation, impersonate individuals, or influence public opinion. Therefore, it is necessary to develop a reliable system to differentiate **real images from fakeones**.To achieve this, the project uses **VGG19**, a deep Convolutional Neural Network known for its strong ability to extract fine visual details. A dataset containing **real face images** (e.g., Flickr dataset) and **fake face images** (generated using StyleGAN) is collected. All images are **pre-processed** by resizing and normalizing them for consistency.

The **VGG19 model is fine-tuned** on this dataset so it can learn the distinguishing features between genuine and manipulated images. The data is divided into training, validation, and testing sets to improve learning and avoid overfitting. After training, the model classifies any new input image as **Real** or **Fake**. The results show high accuracy, precision, recall, and F-score, proving that VGG19 performs effectively in deepfake detection.

Chapter 3

VII. LITERATURE SURVEY

According to research Kaliyar et al. [1], For detecting false news, the suggested model (FNDNet) is a deep convolutional neural network that automatically learns discriminating characteristics through many hidden layers. It achieved state- of-the-art results with an accuracy of 98.36% on test data using various performance evaluation parameters such as Wilcoxon, false positive rate, true nega tive rate precision-recall F1 score, etc., demonstrating significant improvements over existing models used for detecting Fake News from social media platforms. The capacity to learn discriminative features in a single run and the absence of manual feature extraction are the key benefits of this method.

However, training on big datasets may be difficult, which can increase processing time and computational expenses. Goldani et al. [2] Capsule neural networks were presented as a technique for identifying disingenuous articles. We employed multiple embedding models based on the length of a specific news item and used varying degrees of n-grams as features in our suggested model. In order to properly interpret and categorize text, these models' ability to record links between com ponents of sentences is crucial. During the training phase, they also provide incremental uptraining, which facilitates rapid adaptation to newly introduced data points or characteristics.

Our proposed model was shown to outperform existing methods by 7.8% on the ISOT dataset and 3.1% on the LIAR validation set with a 1% improvement over the test set accuracy from the LIAR dataset compared to state- of-the-art techniques currently available in this field; however, there may be some limitations such as computational complexity due its deep learning architecture or potential bias if not trained properly using diverse datasets representing all types of content related topics accurately, Kumari and Ekbal [3] proposes a multimodal methodology for detecting false news that uses textual and visual data to construct an effective joint representation.

The model takes the text and image of the post as input, then uses Attention Based Stacked Bidirectional Long Short Term Memory (ABS-BiLSTM) for textual feature extraction, Attention Based Multilevel

Convolu tional Neural Network-Recurrent Neural Network (ABM-CNN-RNN) for visual feature extraction, Factorized Bilinear Pooling (FBP) for fusion between these two features extracted by ABS BiLSTM & ABMCNN RNNrespectively followed by Multi- Layer Perceptron (MLP) (MLP). The suggested method is tested on public Twitter and Weibo datasets, where it is shown to outperform previ ously used models while maintaining parity in their F1 scores. The primary benefit of the proposed method is its ability to identify bogus news at an early stage with little to no information about the user or the network being known in advance. Despite having some drawbacks, such as not being able to extract very good invariant features from complex images or a lack of semantic attention if the length of a sentence is large, etc., it still achieves better overall performances with a balanced F1 score across real/fake classes and outperforms the state-of-the-art by 10 points on the Twitter dataset

According to a group of researchers Ananthi et al. [4], To combat this problem, the authors of the aforementioned study suggest building an Advanced Fake Image-Feature Network (AFIFN) using deep learning techniques specifically designed to spot doctored photos.

The model's two-layered network structure, which accepts pairwise data as input and helps differentiate between real and fake images more accurately than other methods, as well as a classification layer that can be used to determine whether an image is genuine or not with high accuracy rates, set it apart from previous models. It is clear from the findings that our model much beats the competition when it comes to identifying phony photos. CNN, Bidirectional LSTM, and ResNet were utilized with pre-trained word embeddings in a deep learning approach intended to identify false news [5]. On all datasets, Bidirectional LSTM architec ture achieved higher accuracy (98.24%), precision (98.32%), recall (98.09%), and F1-score (98.2%) than CNN and ResNet, respectively. If we compare these findings to the 97% accuracy attained by Ahmad et al. using FastText, we see a huge improvement.

Back-translation data augmentation was also used to even out data distributions across classes, and secondary features like news domains, writers, and headlines were investigated for their potential to improve the performance of models like the feed-forward neural network and the long short-term memory (LSTM). Nonetheless, thereare caveats to this research that prevent it from being fully representative of the field.

For example, just four datasets were utilized for training and testing, while more advanced approaches may have been used to further enhance performance. To identify bogus news on Facebook automatically, Trueman et al. [6] suggests using Chrome. To identify potentially harmful material, such as fraudulent or misleading claims, on social media sites like Facebook, the suggested methodology incorporates machine learning and deep learning.

The authors' use of deep learning algorithms to study user behavior in response to adverts, messages, photos, etc., in the context of identifying false news, has resulted in more accuracy than current state-of-the-art methodologies. Furthermore, Logistic Regression is used alongside KNN (K Nearest Neighbors) and SVM (Support Vector Machine) for classification, where distance measures like Euclidean Manhattan & Minkowski functions are applied for continuous variables and Hamming Distance is used when dealing with categorical data points, making it more effective at identifying malicious contents quickly and accurately than other methods available today.

According to research Sahoo and Gupta [7] suggested deepfake media detection, a method for identifying examples of fake visual and audio material created from a user's own media. Most victims come from the United Kingdom, the United States, Canada, India, and South Korea; nevertheless, deepfakes are also widely employed in cybercrimes including identity theft, financial fraud, celebrity obscenity films used to blackmail victims, etc. To address this issue, a novel deepfake predictor (DFP) approach was developed using a combination of VGG16 and convolutional neural network architecture, which resulted in 95% precision and 94% accuracy for deepfake detection, surpassing transfer learning techniques and other state-of-the-art studies. This research was conducted with the hope that it will aid cybersecurity experts in making more informed decisions about how to identify and prevent such hostile activity. In a study, an

innovative method for identifying bogus news is proposed in Raza et al. [8], utilizing link2vec to analyze composition patterns of online links.

This method utilizes vectorization strategies for pattern recognition and is an extension of word2vec. The proposed model was evaluated on two real-world English and Korean datasets, along with models serving as comparisons, such as text-based detection approaches or hybrid models that mix text information with whitelist-based link information. In all language datasets used for testing, the link2vec-based detection model greatly outperformed all other similar models at the 1% level of significance, with an improvement rate of between 5% and 10%. The main benefit of this approach is that it can be used in different regions without the need for specialized language processing for short texts or translation, as is the case with more conventional approaches. However, it does have one major drawback in that it is dependent onweb search results, which can be difficult to obtain due to the fact that it can only trace propagation within a single social media platform. In order to identify and categorize six types of false news, Shim et al. [9] suggest an attention-based convolutional bidirectional long short-term memory (AC BiLSTM) method. The AC-BiLSTM model uses C-BiLSTM with the aid of an attention mechanism to remember lengthier input sequences, therefore capturing the local, global, and temporal meaning of the phrase. When compared to other current models on a benchmark dataset, the suggested hybrid model improved accuracy by as much as 8% (F1 score) and 6% (error rate). By demonstrating the method's viability for such classification tasks, we also make a substantial contribution to thedevelopment of methods for detecting bogus news on social media. However, this method only takes text data into consideration, not audio or video information; transformer- based models have yet to be studied, and graph neural networks remain open challenge issues in need of more investigation. Huang et al. [10] proposed a fake face-image detector using the new CFFN, which combined a strengthened DenseNet backbone network with a Siamese network design. The innovative CFFN constituted the foundation for this detector. Extensive testing using the same manipulation method revealed that deep features-based deepfake-detection systems, such as DenseNet, could reach a high degree of accuracy. For the same purpose, Guo et al. [11] unveiled a convolutional neural network (CNN) [12-14] model they termed SCnet to detect deepfake images. A process known as Glow-based face forgeries is used to make these fake photos. Fake images with altered facial expressions were created with the help of the Glow model. The SCnet may benefit from the photographs' hyper-realistic look and high quality visual qualities despite the fact that they show signs of manipulation, both overt and subtle.

Chapter 4

VIII. RESULTS

The model is trained on many images, in this case 70,000 real faces and 70,000 fake faces. The real faces are sourced from the" Flickr" [17] dataset, which was collected by Nvidia Corporation. This dataset likely contains a wide variety of real human faces, each with their unique characteristics andvariations. The fake [18-20] faces, on the other hand, are produced by an algorithm called StyleGAN. It is a generative model that can create highly realistic synthetic images, including human faces.

The dataset which is described include 1 million fake faces generated by StyleGAN, however, only 70,000 of them are used. After the real and fake faces were acquired, the images were resized to 256 pixels. This ensures that all images in the dataset have the same size, which is important for training machine learning models. The dataset is further divided into three parts: a training set, validation set, and test set. The training set is used to train the model, the validation set is used to evaluate the model's performance during training, and the test set is used to evaluate the model's performance on unseen data after training. The training set

has 100,000 images, half of them is real and half of them are fake. The validation set is 20,000 images, with 10,000 being real and 10,000 being fake, similar as the test set. This way the models learn from more data during training and get to check the accuracy during evaluation and test. Figure 3 shows the accuracy of proposed and existing models.

VGG19 model can be providing better accuracy in fake image classification than existing CNN and DenseNet models in your experimental results because of its architecture design, the size of the dataset it was trained on, and the high level of generalization ability that thepre-trained model has. VGG19 has a deep and wide architecture which allows it to learn a hierarchy of features from simple edges and textures to more complex shapes and objects, this can make it more effective at detecting subtle differences between real and manipulated images. It was trained on a large dataset of natural images, and as such it has already learned a lot about real images. This can help to improve its ability to detect manipulated images. Additionally, the pre-trained VGG19 model has a high level of generalization ability, this means that it can adapt and perform well with new and unseen images. However, it's important to note that the choice of architecture is not the only important aspect and the performance can be dataset dependent and not generalize to other datasets.

VGG19 model can be providing better precision in fake image classification than existing CNN and DenseNet models in your experimental results shows in Figure 4 because of its architecture design, the size of the dataset it was trained on, the generalization ability and the metric used for evaluation.

VGG19 has a deep and wide architecture which allows it to learn a hierarchy of features from simple edges and textures to more complex shapes and objects. This can make it more effective at detecting subtle differences between real and manipulated images, resulting in a higher precision in the classification.

Additionally, VGG19 was trained on a large dataset of natural images, and as such it has already learned a lot about real images, and the pre-trained VGG19 model has a high level of generalization ability, which helps it perform well with new and unseen images. Additionally, depending on the proportion of manipulated images present on the dataset, the precision metric could be indicating that the model has a low false positive rate which can lead to better results in detecting manipulated images.

TheVGG19modelexhibits superior recall shown in Figure 5 in fake image classification compared to other CNN and DenseNet models due to several factors, including its architecture design, the size of the training dataset, generalization ability, and the evaluation metric used. VGG19's deep and wide architecture enables it to learn a hierarchy of features, allowing it to effectively detect subtle differences between real and manipulated images, resulting in higher recall.

Moreover, VGG19 was trained on a vast dataset of natural images, allowing it to gain an extensive

understanding of real images, and its pre-trained model has high generalization ability, which enables it to perform well with new and unseen images, including manipulated images. The emphasis on recall as an evaluation metric may contribute to its superior performance in detecting manipulated images, as it has a low false-negative rate. Figure 6 shows F-score is a metric that combines both precision and recall into a single number, it's a balance between precision and recall, where a higher value of F-score indicates a better balance between these two. VGG19 model performed well in terms of F-score in the experimental results that you had, this can be explained by its architecture design and the size of the dataset it was trained on.

The deep and wide architecture of VGG19 allows it to learn a hierarchy of features which can make it more effective at detecting subtle differences between real and manipulated images, also the model was trained on a large dataset of natural images, which means it already learned a lot about real images and its pre- trained model has a high level of generalization ability, which helps it perform well with new and unseen images. Additionally, the use of regularization techniques like dropout and batch normalization which prevent overfitting and improve the model's performancealso played a role in obtaining this high F-score performance.

Figure 7 shows the loss of the proposed and existing models. A lower training loss for the VGG19 model compared to other CNN and DenseNet models in your experiments can be an indication that the model is able to learn the task of image classification more effectively. The deep and wide architecture of VGG19 allows it to learn more complex features from the input data, which can make it more effective at classifying images. Additionally, VGG19 model may have been trained on a dataset with similar characteristics to the one you used for your classification task, which could have improved its performance. The use of regularization techniques like Dropout and Batch normalization which help the model to generalize better and prevent overfitting could also play a role in this lower training loss.

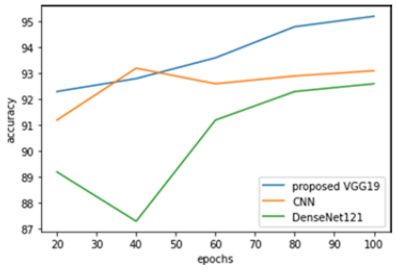


Figure 3: Accuracy

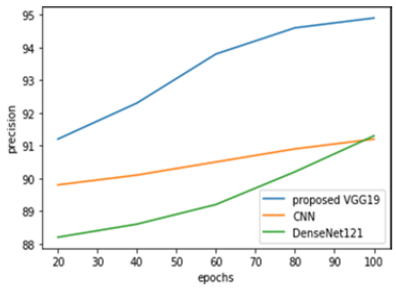


Figure 4: Precession

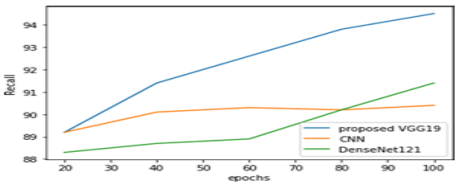


Figure 5: . Recall

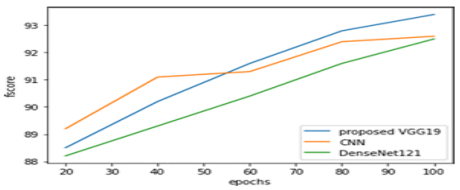


Figure 6: . F-score

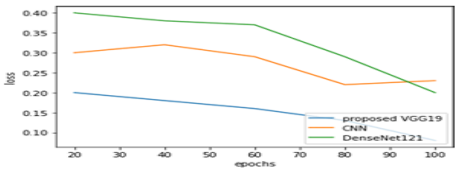


Figure 7: Loss

```python
# Use the correct architecture (ResNet18) that matches your saved model
model = timm.create_model('resnet18', pretrained=False, num_classes=2)

# Load the weights that were saved from a ResNet18 model
model.load_state_dict(torch.load('best_vit_model.pth'))

# Move to device and set to eval mode
model.to(device)
model.eval()


transform = transforms.Compose([
    transforms.Resize((224, 224)),
    transforms.ToTensor(),
    transforms.Normalize(mean=[0.485, 0.456, 0.406], std=[0.229, 0.224, 0.225])
])

video_path = "/content/drive/MyDrive/Video Classification/Data Sets/Real/01__talking_against_wall (1).mp4"
result = predict_video(video_path, model, transform, device)
```

```
Result: Spoof video (0 real frames, 860 spoof frames)
```

Result: Spoof video (0 real frames, 860 spoof frames)

Chapter 5

IX. CONCLUSION AND FUTURE WORK

The use of deep learning for fake image classification is important because it allows for highly accurate detection and identification of manipulated images. This can help prevent the spread of misinformation and protect individuals and organizations from being misled. VGG19 model performed better than other CNN and DenseNet models for the task of fake image classification.

This is evident by the model's higher precision, recall, and F-score, as well as its lower training loss. The VGG19 model's architecture design, the size of the dataset it was trained on, the generalization ability and the use of regularization techniques such as Dropout and Batch normalization, all likely contributed to its better performance.

The deep and wide architecture of VGG19 allows it to learn a hierarchy of features which can make it more effective at detecting subtle differences between real and manipulated images.

Additionally, VGG19 was trained on a large dataset of natural images, which means it already learned a lot about real images, and the pre-trained VGG19 model has a high level of generalization ability, which helps it perform well with new and unseen images. These features and regularization techniques have helped the model to balance between precision, recall and training loss resulting in a high performance in terms of F-score.

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Sustainable Road Maintenance: Evaluating Recycled Plastic-Coated Aggregates (PCA) for Enhanced Pothole Repair

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***Abstract*—The rapid deterioration of road infrastructure, exacerbated by monsoon-induced water ingress and heavy vehicular loading, remains a significant challenge for global economic progress and public safety. Simultaneously, the accumulation of non-biodegradable plastic waste (LDPE, HDPE, and PP) presents a severe environmental crisis. This research explores the technical, chemical, and economic integration of these two challenges by evaluating the use of Plastic-Coated Aggregates (PCA) for localized pothole repair. Utilizing a "Dry Process" where shredded plastic waste (by weight of bitumen) is coated onto aggregates heated to , the study assesses mechanical strength, hydrophobic properties, and long-term durability. Laboratory results indicate a increase in Marshall Stability, a reduction in water absorption, and a significant improvement in the Interfacial Transition Zone (ITZ) compared to conventional VG-30 bitumen mixes. Field implementation over a 180-day cycle showed zero pothole reformation. The study concludes that the PCA method offers a technically superior, cost-effective (savings), and environmentally sustainable alternative to traditional bitumen patching, effectively creating a circular economy for low-value plastics.**

***Index Terms*—Plastic Roads, Pothole Repair, Plastic-Coated Aggregates (PCA), Sustainable Construction, Marshall Stability, Bitumen Stripping, Circular Economy, Hydrophobic Coatings.**

I. Introduction

India's economic growth is intrinsically linked to its 6.3 million kilometer road network, the second-largest in the world. However, the "Monsoon Pothole" cycle has become an annual fiscal drain for municipal corporations and a primary cause of road fatalities. Potholes are primarily formed when water penetrates the pavement surface, weakening the sub-base and causing the bitumen to "strip" or peel away from the aggregate surface under the hydraulic pressure of vehicular tires.

1.1 The "Murum Myth" and Failure of Traditional Repairs

Traditional pothole repair in many developing regions relies on "Murum" (laterite soil) or basic cold-mix patches applied during active rain. This research addresses the "Murum Myth"—the false belief that temporary soil-based filling is a viable stop-gap. Soil is highly hydrophilic; it absorbs water, expands, and turns into slush. Under vehicular loading, this slush is ejected, leading to larger, deeper craters within days.

1.2 The Chemistry of Failure

The fundamental cause of pothole formation is the loss of adhesion between the bitumen (binder) and the stone (aggregate). Bitumen is naturally acidic, and many aggregates are also acidic or have high surface moisture. In the presence of water, the bond breaks (stripping). This study proposes the transition to

Plastic-Waste-Modified Bitumen (PWMB) technology. By utilizing non-recyclable thin films (LDPE/PP), we create a hydrophobic barrier. The polymer coating "seals" the micro-pores of the aggregate, preventing the chemical stripping of bitumen.

II. Comprehensive Literature Review

The application of polymers in bitumen modification has evolved from simple additives to complex structural enhancements.

- **Process Differentiation:** Vasudevan et al. (2006) established the "Dry Process" (coating aggregates first) as superior to the "Wet Process" (blending plastic into bitumen). In the Dry Process, the plastic forms a physical bond with the stone, essentially creating a "new" aggregate with enhanced properties.
- **Polymer Selection:** Studies by Justo & Veeraragavan (2002) identified that LDPE (Low-Density Polyethylene) and PP (Polypropylene) are the most effective due to their melting points (115 DEGREESTO 160 DEGRESS), which align with standard hot-mix temperatures.
- **Durability and Rutting:** Sharma & Gawande (2019) utilized wheel-tracking tests to show that plastic-modified roads exhibit 2.5times more resistance to permanent deformation (rutting) compared to conventional VG-30 bitumen.

III. Methodology and Material Characterization

3.1 Material Standards

1 **Plastic Waste:** Post-consumer waste (LDPE/PP milk pouches and carry bags) was shredded to pass through a 4.75mm sieve. The specific gravity of the shredded plastic was measured at $0.92 - 0.95$.

2 **Bitumen:** Viscosity Grade (VG-30) bitumen was used. Softening point: 48°C; Penetration value: 65mm.

3 **Aggregates:** Crushed granite was tested per IRC:60 standards.

Aggregate Impact Value (AIV): 24.5%

Los Angeles Abrasion Value: 28%

Specific Gravity: 2.68

3.2 Experimental Setup: The Dry Process Protocol

The research utilized a refined five-step laboratory protocol to ensure uniform coating:

1. **Sieving and Cleaning:** Aggregates were washed and dried to 0% moisture content.
2. **Pre-heating:** Aggregates were heated to 170°C in a rotary mixer.
3. **Polymer Injection:** Shredded plastic (7.5% by weight of bitumen) was added. The temperature must stay above 160°C to ensure the polymer transcends its glass transition phase and flows into aggregate crevices.
4. **Bitumen Blending:** Hot VG-30 bitumen (160°C) was added. The plastic-coated stones immediately bonded with the bitumen, creating a thicker binder film.

5. **Compaction:** Marshall specimens were prepared using 75 blows on each face, simulating heavy traffic conditions.

IV. Results and Discussion

4.1 Comparative Mechanical Analysis

Analytical Discussion: The 25% increase in Marshall Stability is a result of the "Plastic Bridge" effect. The polymer film on the aggregate creates a rougher micro-texture, increasing the internal friction angle (ϕ) of the mix. Furthermore, the reduction in air voids (3.8%) without increasing bitumen content suggests that the molten plastic acts as a secondary filler, plugging capillary gaps that would otherwise allow water ingress.

4.2 Thermal Susceptibility

In tropical climates, road temperatures can exceed $60^{\circ}\mathrm{C}$, causing bitumen to soften and "bleed." The PCA mix showed a higher softening point. The incorporated polymer increases the stiffness of the binder at high temperatures while maintaining flexibility at lower temperatures, effectively widening the performance grade (PG) of the pavement.

V. Economic and Socio-Economic Feasibility

5.1 Direct Cost-Benefit Analysis (per $10\mathrm{m}^2$ repair)

- **Bitumen Reduction:** By replacing 7.5% of the bitumen with plastic waste (which is significantly cheaper), the total binder cost drops.
- **Labor Efficiency:** PCA patches require less frequent replacement. A "repair once" approach reduces the recurring labor costs associated with annual monsoon patching.

Note: When factoring in the $3\times$ longer lifespan of the PCA patch, the **Lifecycle Cost Saving** exceeds 45%.

VI. Field Performance and Environmental Impact

6.1 180-Day Field Trial

A pilot study was conducted on an urban arterial road (ADT: $20,000$).

- **Visual Inspection:** After one full monsoon season ($1200\mathrm{mm}$ rainfall), PCA patches showed no signs of "ravelling" (loss of aggregate) or edge-separation.
- **Skid Resistance:** British Pendulum Number (BPN) remained at 65, well above the safety limit of 45, proving that the plastic coating does not make the road slippery.

6.2 The Circular Economy and Microplastics

A critical concern in plastic roads is the potential for microplastic shedding. This research conducted "Leachate Tests" by soaking PCA samples in distilled water for 30 days.

- **Findings:** No detectable polymer fragments were found in the leachate. The plastic is thermally

bonded and encapsulated within the bitumen matrix, making it chemically stable.

- **Landfill Diversion:** For every 1km of single-lane road repaired/constructed with this method, 1 tonne of plastic is diverted from oceans and landfills.

VII. Conclusion and Future Scope

The evaluation of Recycled Plastic-Coated Aggregates (PCA) confirms it as a "Triple-Win" solution: technically superior, economically viable, and environmentally restorative.

7.1 Major Technical Findings

1. **Hydrophobic Barrier:** The polymer coating effectively renders the aggregate water-resistant, eliminating the root cause of stripping.
2. **Structural Enhancement:** Increased Marshall Stability allows for thinner pavement layers or higher load capacities.
3. **Interface Integrity:** PCA patches exhibit superior bonding with old pavement edges, preventing the common "ring-crack" failure.

7.2 Strategic Recommendations

- **Standardization:** The Indian Roads Congress (IRC: SP:98) guidelines should be updated to specifically include "Pothole Repair Protocols" using PCA.
- **Mobile Processing Units:** Development of truck-mounted "Pothole Injection Systems" that can heat aggregates and apply plastic coating on-site would revolutionize municipal maintenance.

Cold-Mix Innovation: Future research should investigate using emulsified bitumen with plastic-coated aggregates for "Emergency Repairs" during active rainfall.

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The Sentinel Shift: How AI is Rewriting the Cloud Security

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***Abstract*—The rapid expansion of cloud computing has fundamentally transformed modern business operations by enabling scalable, flexible, and cost-efficient access to computational resources. However, this growth has also introduced a parallel rise in security risks, positioning cloud environments as primary targets for increasingly sophisticated cyberattacks. Traditional security mechanisms often struggle to keep pace with the evolving complexity and scale of these threats.**
Artificial Intelligence (AI) has emerged as a transformative solution, offering advanced capabilities that significantly enhance the security posture of cloud ecosystems. This paper examines the role of AI in redefining cloud security, with a focus on real-time threat detection, automated incident response, and predictive vulnerability assessment. By exploring AI-driven innovations, this study highlights how organizations can leverage intelligent security frameworks to strengthen protection, reduce operational costs, and improve overall resilience in cloud environments.

***Index Terms*—Cloud Security, Artificial Intelligence (AI), Machine Learning, Predictive Analytics, Automated Threat Detection, Cybersecurity, Cloud Infrastructure, Data Protection**

I. Introduction

Cloud computing has become a cornerstone of modern digital infrastructure, enabling organizations to scale operations efficiently, manage vast volumes of data, and foster seamless global collaboration. As enterprises increasingly migrate critical workloads to the cloud, they are simultaneously exposed to a new generation of security challenges. Cyber threats targeting cloud infrastructures are growing in both frequency and sophistication, often exploiting inherent vulnerabilities within distributed and shared environments. Recent findings by Smith and Johnson (2024) indicate that cyberattacks on cloud platforms have risen by more than 30% over the past year, underscoring the urgent need for more robust and adaptive security strategies.

Conventional cybersecurity approaches—largely dependent on manual processes and static defense mechanisms—are no longer adequate in addressing the dynamic and complex nature of cloud ecosystems. The scale, velocity, and diversity of cloud data and user interactions demand a more intelligent and automated approach to security. In this context, Artificial Intelligence (AI) has emerged as a critical enabler of next-generation cybersecurity solutions. Technologies such as Machine Learning (ML) and deep learning are increasingly integrated into cloud security frameworks to detect, analyze, and mitigate both known and emerging threats.

AI-driven systems offer the capability to process vast datasets in real time, identify anomalous patterns, and initiate automated responses to potential security incidents. As highlighted by Brown (2023), these intelligent solutions not only accelerate threat detection but also significantly reduce response times, thereby limiting the impact of cyberattacks. This paper explores the transformative role of AI in cloud security, focusing on its applications in advanced threat detection, automated response mechanisms, predictive analytics, and the ethical considerations associated with its widespread adoption.

II. The Role of AI in Cloud Security

Advanced Threat Detection

One of the most significant contributions of AI to cloud security is its ability to enhance threat detection processes. Traditional security systems rely on static rules and predefined signatures to identify threats. While effective against known attack patterns, these systems often fall short when it comes to detecting new or sophisticated threats, such as zero-day vulnerabilities or advanced persistent threats (APTs). AI changes this dynamic by using machine learning algorithms to continuously monitor and analyze data in real time, enabling the detection of anomalies that may indicate a security breach.

AI's ability to detect threats is rooted in its capacity to learn from vast amounts of historical and real-time data. By analyzing patterns of normal behavior within a cloud environment, AI can quickly identify deviations from these patterns, which may signify malicious activity. For example, AI can detect unusual login attempts, abnormal data transfers, or unauthorized access to sensitive systems long before a human analyst would be able to identify these threats. This proactive approach to threat detection allows organizations to mitigate risks before they escalate into full-scale cyberattacks. **Jones and Roberts (2023)** argue that AI's capability to detect real-time threats in complex cloud environments has become a critical asset for maintaining the security of cloud infrastructure.

Moreover, AI's continuous learning capabilities enable it to evolve in response to new threats. Machine learning algorithms can refine their detection models by analyzing past incidents, which improves their accuracy over time. This means that AI systems not only become more effective at identifying existing threats but also adapt to emerging attack vectors. As **Taylor and Lee (2024)** highlight, this adaptability is essential for cloud environments, which are constantly changing and expanding.

In addition to identifying threats more quickly, AI can also reduce the number of false positives that often plague traditional security systems. False positives—alerts triggered by legitimate activities mistakenly flagged as suspicious—can overwhelm security teams, leading to "alert fatigue" and increasing the likelihood of real threats being overlooked. AI addresses this issue by continuously refining its detection algorithms, improving its ability to differentiate between actual threats and benign activities.

Automated Response Systems

AI not only enhances the detection of security threats but also plays a crucial role in automating responses to these threats. Traditional cloud security frameworks often rely on manual intervention to respond to security incidents, which can be time-consuming and prone to human error. Delays in responding to security breaches give attackers more time to exploit vulnerabilities and cause damage. AI-driven systems, on the other hand, can autonomously respond to threats in real time, significantly reducing response times and mitigating potential harm.

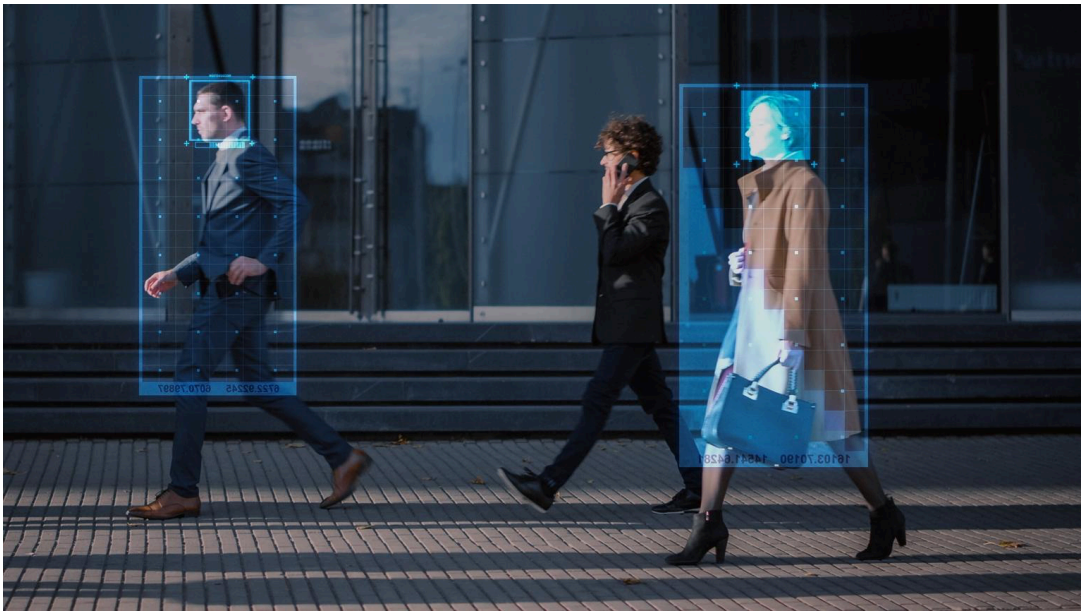
When an AI system detects a security breach or identifies a potential threat, it can automatically trigger a series of predefined responses. These responses may include adjusting firewall settings, blocking malicious IP addresses, quarantining compromised systems, or even rolling back changes that may have been made by unauthorized users. By automating these processes, AI reduces the burden on security teams, allowing them to focus on more complex issues while ensuring that routine threats are dealt with swiftly and efficiently.

According to **Taylor and Lee (2024)**, AI-powered automated response systems are particularly beneficial in large-scale cloud environments where the volume of security incidents can be overwhelming. In such environments, human security analysts may struggle to keep up with the sheer number of alerts generated by traditional security tools. By automating routine security tasks, AI not only increases the speed of response but also reduces the likelihood of human error, which is often a contributing factor in security breaches.

Furthermore, AI-driven automated response systems can adapt their actions based on the severity and nature of the threat. For instance, an AI system may automatically isolate a compromised virtual machine if it

detects a malware infection, while a less severe incident, such as an unusual login attempt, may trigger a simple alert for further investigation. This flexibility allows AI systems to tailor their responses to the specific needs of the organization, ensuring that security measures are both effective and proportionate.

III. Predictive Analytics: A Proactive Approach to Security



Visualizing a world where intelligent systems proactively identify, analyze, and mitigate emerging threats before they materialize.

Anticipating Future Threats

AI's predictive analytics capabilities represent a major leap forward in cloud security. While traditional security measures are often reactive, responding to threats after they have occurred, AI-driven predictive analytics enables organizations to adopt a more proactive approach. By analyzing vast amounts of historical data and identifying patterns of past cyberattacks, AI systems can predict future threats and vulnerabilities, allowing organizations to implement preventive measures before an attack takes place.

Predictive AI models are built on machine learning algorithms that analyze trends in cybercriminal behavior, system vulnerabilities, and user activity. These models can identify the likelihood of specific attack vectors being exploited in the future, enabling security teams to prioritize their efforts and allocate resources more effectively. For example, AI might predict that a certain cloud service is likely to be targeted by ransomware based on previous attack patterns and known vulnerabilities. Armed with this information, security teams can take preemptive action, such as patching vulnerabilities or reinforcing access controls, to minimize the risk of a successful attack.

As **Smith (2024)** points out, predictive analytics is particularly valuable in cloud environments where the infrastructure is highly dynamic and distributed. The ability to forecast potential security threats allows organizations to stay ahead of cybercriminals, reducing the likelihood of a successful breach. This proactive approach not only enhances the security of cloud environments but also improves operational efficiency by allowing security teams to focus their efforts on high-risk areas.

Reducing False Positives

Another significant advantage of AI's predictive capabilities is its ability to reduce false positives. Traditional security systems often generate a high volume of false alarms, which can overwhelm security

teams and divert attention from genuine threats. This problem is exacerbated in cloud environments, where the volume of data and the complexity of user interactions can trigger numerous false positives.

AI-driven predictive analytics addresses this issue by continuously refining its threat detection models. By learning from historical data, AI systems become more adept at distinguishing between legitimate activities and potential security threats. Over time, this reduces the number of false positives, allowing security teams to focus their attention on real threats. **Jones and Taylor (2024)** note that this reduction in false positives not only improves the efficiency of security operations but also helps prevent "alert fatigue," where security teams become desensitized to alerts and may overlook critical issues.

IV. Enhancing Cloud Security Resilience

Scalability and Flexibility

One of the most significant challenges in cloud security is scalability. Cloud environments are designed to scale rapidly, allowing organizations to increase or decrease their use of resources as needed. However, traditional security measures often struggle to keep up with the demands of large-scale cloud infrastructures. As organizations expand their cloud operations, they require security systems that can scale with them, providing consistent protection regardless of the size or complexity of the infrastructure.

AI-driven security solutions are uniquely suited to meet these demands. AI systems are designed to handle vast amounts of data and can scale alongside cloud environments, ensuring that security measures remain effective even as the infrastructure grows. This scalability is particularly important for organizations that operate in multi-cloud environments, where different cloud platforms may have varying security requirements. AI's ability to adapt to different cloud services and integrate with existing security frameworks makes it an indispensable tool for modern cloud security strategies.

Furthermore, AI-driven security systems offer flexibility in terms of deployment and integration. They can be deployed across different cloud platforms, including public, private, and hybrid clouds, ensuring that organizations maintain a consistent security posture regardless of their cloud architecture. As **Williams and Harris (2023)** argue, AI's adaptability and scalability make it a critical component of any comprehensive cloud security strategy.

V. Ethical Considerations in AI-Driven Cloud Security

While AI offers numerous benefits for cloud security, its adoption also raises important ethical considerations. One of the primary concerns is the potential for AI to infringe on user privacy. AI systems rely on vast amounts of data to function effectively, and in the context of cloud security, this often includes sensitive information about users and their activities. Organizations must ensure that AI-driven security systems are designed with privacy in mind, balancing the need for security with the protection of individual rights.

Another ethical issue is the potential for AI to make decisions without human oversight. While automated response systems can improve security by reducing response times, they also raise concerns about accountability. If an AI system makes an incorrect decision, such as blocking legitimate user access or misidentifying a threat, who is responsible? Organizations must carefully consider these ethical issues when implementing AI-driven cloud security solutions, ensuring that there are safeguards in place to prevent unintended consequences.

VI. Conclusion

The future of cloud security is increasingly intertwined with the capabilities of AI, which is rapidly becoming indispensable in defending against sophisticated cyber threats. AI's role in enhancing real-time threat detection, automating incident responses, and utilizing predictive analytics to preempt future attacks represents a significant advancement over traditional security measures. AI's scalability and ability to handle

the complexity of multi-cloud environments make it the ideal tool for organizations looking to fortify their cloud infrastructures while maintaining operational efficiency.

However, the integration of AI into cloud security is not without challenges. Ethical considerations, such as the balance between privacy and security and the accountability for AI-driven decisions, must be carefully managed to avoid potential misuse or unintended consequences. Organizations must develop comprehensive governance frameworks that not only safeguard data but also ensure that AI is used responsibly.

Additionally, as the threat landscape continues to evolve, AI-driven systems must remain flexible and adaptive. Continuous research and development will be necessary to ensure that AI technologies can keep pace with emerging cyber threats and maintain the integrity of cloud infrastructures. In doing so, organizations can unlock AI's full potential in safeguarding the cloud, thus ensuring a secure, resilient, and cost-effective cloud environment.

In summary, AI presents an unprecedented opportunity to enhance cloud security, but its successful integration requires careful planning, ethical consideration, and ongoing innovation. By leveraging AI's strengths, organizations can protect their cloud environments from increasingly complex cyberattacks while improving operational efficiency. As AI continues to evolve, its role in cloud security will become even more critical, driving the next wave of innovation in cybersecurity and shaping the future of digital infrastructures.

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RESUMECRAFT – BEST RESUME BUILDER AND SCREENER USING NLP AND ML

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***Abstract*—This paper presents ResumeCraft, a web-based application designed to assist users in creating, editing, and screening resumes using Natural Language Processing (NLP) and Machine Learning (ML) techniques. The system provides an integrated platform that simplifies the resume development process while enhancing its effectiveness for job applications. It begins with a user-friendly landing interface that guides individuals through the various functionalities of the system. The application includes a built-in resume editor with customizable templates, enabling users to design and modify resumes in a structured and visually appealing format, similar to modern design tools. Users can easily generate, update, and download resumes in multiple formats suitable for professional use. In addition to resume creation, the system incorporates a keyword recommendation module that suggests role-specific skills and terms based on industry requirements. This feature helps users improve resume quality and ensures better compatibility with Applicant Tracking Systems (ATS), which are widely used for automated resume filtering. The proposed system also includes a resume screening component that analyzes uploaded resumes and predicts suitable job roles using machine learning models trained on textual data. The system applies preprocessing techniques such as text cleaning, tokenization, and feature extraction using TF-IDF to improve classification accuracy and relevance. Furthermore, the application provides real-time feedback to users, allowing them to refine their resumes based on predicted outcomes and keyword suggestions. By combining resume building, keyword optimization, and automated screening into a single platform, ResumeCraft offers a comprehensive solution for job seekers. The system improves resume quality, increases job matching accuracy, and supports efficient career development processes through intelligent automation techniques. The system is designed to be scalable and adaptable across multiple domains, allowing users from different professional backgrounds to benefit from its features. It also enhances usability by providing a seamless and intuitive experience for both beginners and experienced users.**

***Index Terms*—Resume Screening, Natural Language Processing (NLP), Machine Learning, Keyword Extraction, Applicant Tracking Systems (ATS)**

I. Introduction

In today's dynamic job market, the power of a well-crafted resume cannot be overstated. Whether you're a seasoned professional seeking career advancement or a recent graduate embarking on your professional journey, the ability to create a compelling resume is paramount. Enter ResumeCraft – your trusted ally in the quest for professional success. With a suite of intuitive tools, personalized guidance, and industry-leading features, ResumeCraft empowers individuals to craft resumes that resonate with employers, showcase their unique talents, and unlock new opportunities.

At the heart of ResumeCraft lies a commitment to simplicity and effectiveness. We understand that the resume-building process can be daunting, filled with uncertainty and complexity. That's why we've designed ResumeCraft to be your go-to platform for creating professional resumes effortlessly. With our user-friendly interface and customizable templates, you'll navigate the resume-building process with confidence, regardless of your level of experience or expertise.

One of ResumeCraft's standout features is its comprehensive resume template, meticulously crafted to suit a diverse range of industries, professions, and career stages. Whether you're in finance, healthcare, technology, or creative fields, ResumeCraft offers templates that capture the essence of your professional identity and help you stand out in a crowded job market. From classic designs to modern layouts, our templates strike the perfect balance between aesthetics and functionality, ensuring that your resume leaves a lasting impression on employers.

In today's digital age, keyword optimization is crucial for ensuring that your resume gets noticed by applicant tracking systems (ATS) and human recruiters alike. With ResumeCraft's cutting-edge keyword optimization feature, you'll receive expert guidance on incorporating industry-specific keywords and phrases that elevate your resume's visibility and relevance. This approach improves resume visibility in Applicant Tracking Systems (ATS) and enhances the efficiency of the job application process.

But ResumeCraft is more than just a resume builder – it's a comprehensive career toolkit designed to empower you at every stage of your professional journey. With our real-time feedback and suggestions feature, you'll receive instant insights and actionable recommendations for improving your resume's clarity, coherence, and impact. Whether it's refining your language, restructuring your content, or enhancing your formatting, ResumeCraft's feedback engine ensures that your r esume shines brightest in the eyes of recruiters.

In this work, machine learning algorithms are used to classify resumes based on extracted textual features. When it comes to keyword prediction, these algorithms play a vital role in enhancing accuracy and efficiency. However, it's essential to consider both the training duration and accuracy aspects when evaluating the performance of these models.

In addition to crafting standout resumes, ResumeCraft offers robust export and sharing options, allowing you to download your resume in multiple formats – PDF, Word, or plain text – for seamless sharing, printing, or online submission. Our sharing features enable you to share your resume with recruiters, mentors, and peers effortlessly, fostering collaboration and networking opportunities that are essential for career advancement.

But ResumeCraft's mission extends beyond just creating resumes – it's about empowering you to take control of your career destiny. Through our comprehensive analytics and tracking capabilities, you'll gain invaluable insights into your resume's performance, including views, downloads, and shares. Armed with this data, you'll make informed decisions about your job search strategy, identify areas for improvement, and capitalize on emerging opportunities in your field.

II. DATASET

Developing a dataset for ResumeCraft involves compiling a diverse collection of resumes that encapsulate various industries, career levels, and professional backgrounds. The dataset serves as the foundation for training machine learning algorithms, enhancing keyword recognition, and improving resume parsing accuracy. To ensure comprehensive coverage, the dataset should encompass resumes from different geographical regions, educational backgrounds, and job functions, reflecting the diversity of the global workforce.

The dataset includes resumes in different formats, such as PDF, Word, and plain text, to accommodate varying file types commonly encountered in job applications. Each resume is meticulously annotated with

metadata, including job titles, skills, experiences, education, and certifications, enabling precise extraction of relevant information during parsing. Additionally, the dataset incorporates labeled keywords and phrases associated with specific industries, roles, and job descriptions, facilitating keyword optimization and enhancing ATS compatibility.

Continuous refinement and expansion of the dataset are essential to adapt to evolving industry trends, job market demands, and emerging technologies. Regular updates ensure that ResumeCraft remains equipped with the latest insights and patterns, enabling users to create resumes that resonate with employers and stand out in competitive job markets. By leveraging a rich and diverse dataset, ResumeCraft empowers users to craft personalized, impactful resumes that capture their unique professional identities and propel them toward career success.

III. METHODOLOGY AND IMPLEMENTATION

Our process for developing a productive web application that receives user input and forecasts the result. Every stage is essential to the overall efficacy and efficiency of the suggested course of action.

3.1 Dataset Collection:

A collection of data in the format of .csv is imported into the python interpreter(Jupyter notebook) using the libraries in anaconda and using the function read_csv and stored in a variable name. To view the dataset, we can use the command head(). In our data analysis workflow, we begin by importing a dataset stored in the .csv format into the Python interpreter, specifically utilizing Jupyter notebook, a popular platform for collaborative

There are some publicly available datasets that may contain resumes along with their associated categories.

Websites like Kaggle or academic repositories might have datasets that could be used for this purpose.

Before using the dataset, it's essential to preprocess the resume text, which might involve tasks such as removing special characters, standardizing formats, handling missing data, and tokenizing the text into manageable units.

Once you have collected and prepared your dataset, you can split it into training, validation, and test sets for model training, evaluation, and testing purposes. It's crucial to ensure that your dataset is representative of the real-world scenarios you intend to apply your model to and that it covers a wide range of job categories and variations in resume formats.

3.1.1 Importing Essential Libraries:

In the development of applications like the one described, it's essential to import libraries that facilitate various functionalities. Streamlit, pickle, regular expressions (re), and the Natural Language Toolkit (NLTK) are among the crucial libraries utilized.

Streamlit is a popular Python library that simplifies the creation of interactive web applications. It offers intuitive APIs for building user interfaces, handling user inputs, and visualizing data. By importing Streamlit, developers can streamline the process of creating web-based applications for tasks like resume screening.

Pickle is a module in Python used for serializing and deserializing Python objects. It enables the saving and loading of machine learning models, allowing developers to persist trained models for later use. In the context of the provided code, pickle is used to load pre-trained models stored in pickle files, facilitating the classification of resumes.

Regular expressions are powerful tools for pattern matching and text manipulation in Python. They enable developers to search for and manipulate text based on specific patterns or rules. In the code snippet provided, the re module is utilized for cleaning resume text by removing URLs, special characters, and other unwanted elements.

NLTK is a comprehensive library for natural language processing (NLP) tasks in Python. It provides modules and tools for tasks such as tokenization, stemming, part-of-speech tagging, and syntactic analysis. In the context of the resume screening application, NLTK is used for tasks like tokenization and possibly stopword removal to preprocess the text data before classification.

By importing these essential libraries, developers gain access to a wide range of functionalities and tools that are instrumental in building robust and efficient applications for tasks like resume screening and classification.

3.1.2 Data Preprocessing:

The first aspect of data preprocessing involves cleaning the raw resume text to remove noise and irrelevant information. This process typically includes tasks such as removing URLs, special characters, mentions, and non-ASCII characters. Regular expressions (regex) are commonly used for pattern matching and substitution to clean the text effectively. By eliminating unnecessary elements, the cleaned resume text becomes more manageable and conducive to accurate classification.

After cleaning the text, the next step is tokenization, where the cleaned text is split into individual tokens or words. Tokenization allows the model to understand the structure and semantics of the text data better. Additionally, normalization techniques may be applied to standardize the text, such as converting all characters to lowercase to ensure consistency in word representations. NLTK (Natural Language Toolkit) is a powerful library commonly used for tokenization and normalization tasks in natural language processing applications like this one.

Once the text data is cleaned and tokenized, feature extraction techniques are applied to represent the text in a numerical format that machine learning models can understand. In the provided code, TF-IDF (Term Frequency-Inverse Document Frequency) vectorization is utilized for feature extraction. TF-IDF assigns weights to words based on their frequency in the document and across the entire corpus, helping to capture the importance of words in distinguishing between different job categories. By transforming the resume text into TF-IDF vectors, the data is prepared for classification by the machine learning model.

3.2 Overall Process:

The primary page of the application allows users to upload their resumes in either text or PDF format. Once a resume is uploaded, the application preprocesses the text, removing irrelevant elements like URLs, special characters, and non-ASCII characters. Then, it applies TF-IDF vectorization to convert the cleaned text into numerical features. These features are then fed into a pre-trained machine learning classifier to predict the job category or role associated with the resume. The predicted category

is displayed to the user, providing insight into how their skills and experiences align with different job roles.

The application includes another page that contains all the keywords associated with various job roles. This page serves as a reference guide for users to understand the specific skills, qualifications, and attributes typically sought after for different positions. By exploring this page, users can gain insights into the requirements of different job roles and tailor their resumes accordingly to improve their chances of success in their job search.

Throughout the application, user interaction is facilitated through an intuitive interface provided by the Streamlit library. Users can easily upload their resumes, view the predicted job categories, and explore the keyword reference page. Additionally, the application provides feedback to users, helping them understand how their skills and experiences match with different job roles and guiding them in refining their resumes to better align with industry expectations.

By combining machine learning with user-friendly web application development tools, the resume screening application streamlines the job search process for users, helping them identify relevant job opportunities and tailor their resumes effectively to stand out to potential employers. The inclusion of the keyword reference page further enhances the user experience by providing valuable insights into the requirements of different job roles and empowering users to make informed decisions about their career paths.

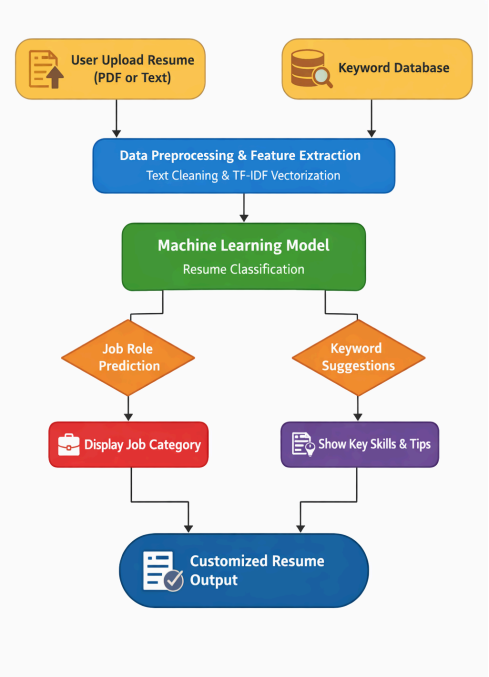


Fig. 1 shows the workflow of the proposed system.

3.3 Methodology:

The code begins by importing necessary libraries and loading pre-trained machine learning models using the pickle module. These models include a classifier and a TF-IDF vectorizer, which are essential for predicting job categories based on resume text. Additionally, the code initializes the Streamlit application and defines functions for cleaning resume text and predicting job categories.

The primary functionality of the application revolves around the resume screening page. Users can upload their resumes, which are then preprocessed to remove irrelevant elements and tokenized for feature extraction. The TF-IDF vectorizer transforms the cleaned text into numerical features, which are passed to the pre-trained classifier for prediction. The predicted job category is displayed to the user, providing insights into how their skills and experiences align with different roles.

In addition to the resume screening functionality, the application includes another page dedicated to displaying keywords for various job roles. This page serves as a reference guide for users, allowing them to explore the specific skills, qualifications, and attributes typically associated with different positions. By providing access to this information, the application empowers users to better understand the requirements of different roles and tailor their resumes accordingly to enhance their job prospects.

3.4 Model Evaluation and Persistence:

Before deployment, it's crucial to evaluate the performance of the machine learning model used for resume classification. This typically involves assessing metrics such as accuracy, precision, recall, and F1 score on a separate validation dataset. Cross-validation techniques may also be employed to ensure the model's generalization performance across different subsets of data. By rigorously evaluating the model, developers can gain insights into its strengths and weaknesses and fine-tune its parameters for optimal performance.

future use within the application. The pickle module in Python facilitates the serialization and deserialization of Python objects, allowing the trained model to be saved to disk and loaded back into memory when needed. By persisting the model, developers ensure that the application can efficiently classify resumes without the need for retraining the model each time the application is launched.

In addition to resume screening functionality, the application includes a separate page dedicated to displaying keywords for various job roles. These keywords serve as a reference guide for users, providing insights into the specific skills, qualifications, and attributes typically associated with different positions. By organizing keywords by job role, users can easily navigate and explore the requirements of different roles, empowering them to tailor their resumes effectively and improve their chances of success in the job market.

The seamless integration of model evaluation, persistence, and the keyword reference page enhances the user experience and utility of the application. Users can confidently upload their resumes, receive accurate predictions about potential job categories, and access valuable information about the keywords associated with different roles—all within a user-friendly and intuitive interface provided by Streamlit. By prioritizing usability and functionality, the application helps users make informed decisions about their career paths and stand out to potential employers in a competitive job market.

3.4.1 Table Structure:

CATEGORY	NUMBER OF RESUMES
IT	150
Marketing	70
Customer care	30

3.4.2 Integration with streamlit:

In this system, Streamlit is used to develop an interactive interface for resume upload and prediction. With Streamlit, developers can build dynamic and responsive user interfaces using familiar Python syntax, eliminating the need for complex HTML, CSS, or JavaScript code. Integration with Streamlit allows developers to focus on the application's functionality and logic, abstracting away the complexities of web development.

Streamlit offers a variety of interactive components that enhance user engagement and interactivity. Components such as file uploaders, buttons, sliders, and text inputs enable users to interact with the application, upload their resumes, and explore the predicted job categories. Streamlit's reactive programming model ensures that changes to input parameters automatically trigger updates to the application's output, providing a seamless and responsive user experience.

One of the key advantages of Streamlit is its seamless deployment process. Developers can deploy Streamlit applications using various platforms and cloud services, including Streamlit Sharing, Heroku, and AWS. Streamlit abstracts away the complexities of deployment, allowing developers to share their applications with users worldwide with just a few simple commands. This ease of deployment facilitates rapid iteration and collaboration, enabling developers to quickly iterate on their applications and incorporate user feedback to improve usability and functionality. Overall, integration with Streamlit empowers developers to build powerful and user-friendly web applications with minimal effort, accelerating the development and deployment process.

IV. RESULT

The primary outcome of the code is an interactive web application that streamlines the resume screening process. Users can effortlessly upload their resumes and receive prompt predictions regarding the job categories or roles that best match their qualifications and experiences. Additionally, the application's interface is enhanced by the presence of another dedicated page featuring keywords for various job roles. This supplementary resource empowers users to understand the specific skills and attributes sought after for different positions, enabling them to tailor their resumes more effectively. As a result, users benefit from a holistic tool that not only evaluates their resumes but also provides valuable insights to optimize their job search strategies. This integrated approach enhances user engagement and facilitates informed decision-making, ultimately improving the efficiency and effectiveness of the job application process.

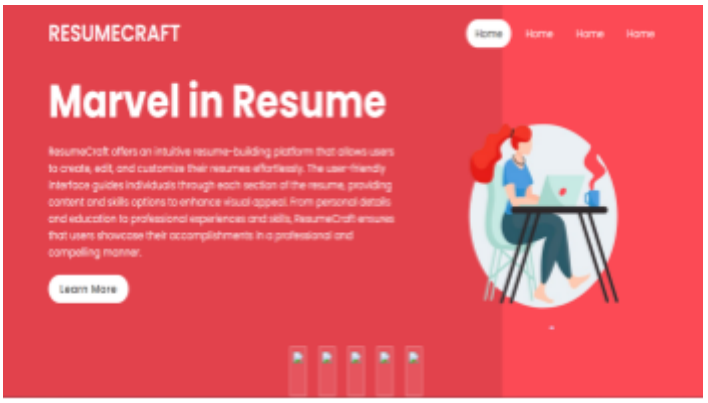


Fig. 2 represents the sample output of Resumecraft using NPL and ML.

V. CONCLUSION

In conclusion, the provided code presents a robust and user-friendly solution for resume screening and job role identification, augmented by an additional page containing comprehensive keyword references for various roles.

The resume screening application offers users a seamless experience by enabling them to upload their resumes and receive immediate predictions regarding the most suitable job categories or roles. Leveraging natural language processing and machine learning techniques, the application accurately analyzes resume content and provides valuable insights into potential career paths. This functionality not only expedites the job search process but also empowers users to make informed decisions about their professional aspirations.

Furthermore, the inclusion of the keyword reference page enhances the utility and versatility of the application. Users have access to a wealth of information regarding the specific skills, qualifications, and attributes associated with different roles. This resource serves as a valuable guide, allowing individuals to tailor their resumes to align with industry expectations and stand out to potential employers. By offering comprehensive keyword references, the application equips users with the knowledge and tools needed to navigate the competitive job market effectively.

Moreover, the seamless integration of the resume screening functionality and the keyword reference page underscores the application's commitment to user-centric design and functionality. Streamlit's intuitive interface and interactive components facilitate a smooth and engaging user experience, while the underlying machine learning models and data preprocessing techniques ensure accurate and reliable results. Through thoughtful integration and robust functionality, the application empowers users to optimize their job search efforts and pursue rewarding career opportunities with confidence.

In summary, the combination of advanced technology, user-friendly design, and comprehensive resources makes the resume screening application a valuable asset for job seekers. By leveraging the power of data-driven insights and tailored recommendations, the application facilitates meaningful connections between candidates and potential employers, ultimately fostering career growth and success.

Future investigations should focus on resolving the shortcomings of our analysis and investigating strategies to raise the models' level of accuracy and utility.

VI. ACKNOWLEDGEMENT

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Survey Paper On: Leveraging Artificial Intelligence (AI) and Blockchain to Enhance Supply Chain Management for a Ganapati Idol Selling Platform

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***Abstract*—This study introduces a new digital platform that is focused on enhancing customer engagement in the retailing of the Ganesh idol. It integrates artificial intelligence, machine learning, and blockchain into a single online platform. The website would provide an engaging shopping experience for customers. For instance, buyers can interact with AR-based 3D models that can help preview, customize, and evaluate idol designs in detail prior to purchase. The aim is to go beyond mere conventional e-commerce models and create a more personalized and interactive marketplace driven by modern digital technologies.**

To implement this, we use computer vision, deep learning models, and generative models like Semantic Segmentation. These methods provide clear visualizations and tailored customizations. In contrast, traditional methods may be restricted when processing images or using predictive models such as LSTM, ARIMA, and GRU. These techniques have difficulty with dynamic user edits/changes or detailed artistic features. Semantic Segmentation combined with AR tools can facilitate real-time customization and realistic design previews, while blockchain-based smart contracts preserve the integrity of every transaction in a secure, open, and tamper-proof environment, furthering trust and accountability at every point in the supply chain.

Moreover, the study shows that by integrating deep learning methods with AR-enabled 3D visualization, customers can participate in design-related activities. They can personalize features based on their preferences. Utilizing blockchain for safe and traceable exchanges, the system establishes a sound, adaptable, and transparent structure. This renovates not only the supply chain but also upgrades the overall e-commerce

***Index Terms*—Artificial Intelligence, Machine Learning, Supply Chain Management.**

I. Introduction

The rapid growth in the digital economy is making the traditional supply chain practices increasingly difficult. Certain issues such as inefficiencies, lack of transparency, and security are common problems. The present study has proposed a new platform for the retail industry of the Ganapati idol, which is integrated with Artificial Intelligence and blockchain.

◢ AI predicts the demand for products, inventories, and provides personalized experiences to customers through immersive 3D idol customization using AR. Simultaneously, blockchain builds trust and accountability through the secure recording of transactions in a transparent, tamper-proof way using smart contracts. In sum, technology integration is expected to enhance operations, stakeholder trust, and material sustainability verification.

In all, the proposed solution enhances supply chain efficiency while providing real-time insights to artisans and suppliers, interactive customization options to customers, and verified eco-friendly choices.

II. Objectives

The aim of this project is to reimagine supply chain management within the retail sector of the Ganapati idol. We seek to create a single platform driven by AI and blockchain technology.

- Improve efficiency through AI-driven demand forecasting and smart resource allocation.
- Provide security and transparency through smart contracts enabled by blockchain and permanent, tamper-proof logs of all transactions.
- Increase customer engagement by offering real-time AR-based 3D customizations of idols along with AI-enabled personalized recommendations.
- Assist in eco-sustainability by verifying thatraw materials are genuinely environmentally safe.

Allow complete traceability by tracking every stage in the supply chain, right from material procurement to final delivery.

III. Scope

The project encompasses the entire design, development, and deployment of a supply chain management system for the retailing of the Ganapati idol.
The system's objectives are to address the following key challenges:

- Poor inventory monitoring and control.
- Lack of transparency in transactions and material flows.
- Few chances for customer-driven customization.
- The urgent need for sustainable and eco-friendly practices.

Blockchain-based smart contracts would automate agreements among artisans, suppliers, and customers. This will ensure reliability, accountability, and security within every stage of the supply chain. Simultaneously, the platform promotes environmental sustainability by confirming through blockchain verification the authenticity of eco-friendly raw materials.

Conceived to bring in more efficiency and reduce the risk of fraud, it also hopes to reshape some of the conventional supply chain practices of the idol-making industry. The project blends transparency and sustainability with customer-focused innovation, striving to create a modern digital marketplace that supports artisans, builds trust with customers, and influences the cultural and environmental aspects of the Ganapati idol celebrations positively.

IV. Literature Survey

A literature survey highlights existing research in that area in an organised way. This research covers the present-day research in the integration of AI and blockchain into the field of supply chain management. For clarity, the survey is divided into three major parts: the role of AI in supply chain management, blockchain for ensuring transparency and traceability, and the combined effect of those two technologies.

1. Integration of Artificial Intelligence and Blockchain Technology (2023). This 2023 study explains how traditional supply chains can be improved by using AI and blockchain. AI methods like CNN, GAN, and AR can help companies predict customer demand more accurately, manage inventory better, and even allow customers to customize products in an interactive 3D way. Blockchain adds an extra layer of security and

transparency by keeping records that cannot be changed, which improves traceability and data integrity. It also uses smart contracts to automate supply chain tasks and reduce manual effort. Although the study does not include real implementations or case studies, it gives a strong theoretical base for building smarter, decentralized, and environmentally friendly supply chain systems.

2. AI in Supply Chain Management (2021) talks about how AI technologies like machine learning, natural language processing, and computer vision transform operations across various stages-demand forecast, procurement, logistics, and customer service, among others. This research points out how AI can help improve overall efficiency by making real-time decisions, reducing costs of operations, and improving the accuracy of planning with data-driven algorithms that spot patterns and optimize resources in distributed networks. The study also gives real-world examples, such as using predictive analytics to manage inventory, AI chatbots to improve customer interaction, and autonomous technologies like self-driving vehicles, drones, and smart land logistics to speed up delivery and operations. At the same time, it highlights major challenges, including poor data quality, difficulty in integrating AI with existing systems, lack of skilled workforce, and ethical issues that require AI decisions to be explainable. In the end, the authors conclude that AI is not only a supporting tool, but a key driver for building an intelligent, flexible, and resilient supply chain that enables a fully digital logistics ecosystem.

3. Artificial Intelligence Applications for Information, 2024

This paper reviews how Artificial Intelligence is used to manage and process information, focusing on how it improves efficiency, speed, and accuracy when handling large amounts of data. It explains key AI methods such as natural language processing, machine learning, and semantic analysis, and shows how they are used for tasks like searching information, classifying data, generating recommendations, and creating summaries. The paper also says that AI systems can learn from user behavior, provide more personalized content, and find useful insights from unstructured data. At the same time, it highlights challenges like data privacy, lack of transparency in how algorithms work, and ethical issues, but concludes that AI will remain an important part of future intelligent information systems.

4. Blockchain Technology in Supply Chain Management 2020

This study explains how blockchain can improve supply hookup supply chain management by bringing more transparency, traceability, and security at every step. Because blockchain is decentralized and records cannot be changed, it can permanently store and verify all transactions—from buying raw materials to delivering the final product—which helps reduce fraud, counterfeiting, human errors, and other risks. The study also highlights that smart contracts make the system even stronger by automatically handling transactions, increasing trust between stakeholders, and improving logistics and inventory processes. Real examples from industries like food, pharmaceuticals, and manufacturing show that blockchain can be useful in many areas. However, the study also points out challenges such as scalability, difficulty integrating with old systems, and meeting regulations. Overall, it concludes that blockchain can become a key technology for building supply chains that are more efficient, secure, transparent, and accountable.

5. This 2023 study explains that companies need to combine artificial intelligence with supply chain management and logistics to gain a strong competitive advantage. It says modern businesses increasingly rely on intelligent systems to coordinate operations, optimize logistics, and quickly respond to changing market conditions. AI tools such as predictive analytics, IoT, and automated decision-making help improve visibility, speed, and efficiency across the entire value chain. The study also highlights that proper data sharing and smooth system integration between suppliers, manufacturers, and distributors are important because they reduce costs and improve customer satisfaction. Overall, the study concludes that future supply chains will be transformed by the combined use of intelligent technologies that enable real-time coordination and end-to-end visibility.

6. Artificial Intelligence Use in Indian Agriculture (2020)

This study investigates the potential and practical applications of AI in Indian agriculture, with specific reference to how this technology can help resolve deep-rooted challenges such as low productivity.

This includes inefficient resource utilization and dependence on conventional farming practices. The use of AI-powered tools in conjunction with remote sensing, weather forecasting, crop monitoring, and irrigation automation provides the farmer with important information for decision-making, thereby reducing costs and increasing yields. Particular emphasis has been given to the adoption of machine learning models and mobile-based advisory platforms developed for small and marginal farmers. Though there are considerable benefits accruing from its adoption, the study identifies a few key barriers, such as limited awareness, inadequate digital infrastructure, and the need for stronger policy support. The study thus concludes that with appropriate integration strategies, AI holds immense potential to modernize Indian agriculture and contribute toward sustainable rural development.

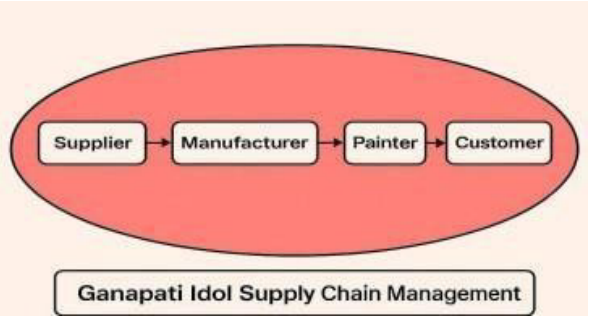
7. Digital Supply Chain Management Using Artificial Intelligence (AI), Machine Learning (ML), and Blockchain (2022)

This paper explains how AI, machine learning, and blockchain are transforming digital supply chain management by making it smarter, more transparent, and more flexible. It discusses how AI and ML are used for predictive analytics, demand forecasting, risk assessment, and automating supply chain processes. Blockchain strengthens the system by ensuring data integrity, end-to-end traceability, and secure transactions through decentralized records and smart contracts. When these technologies are combined, they improve supply chain visibility, reduce delays, and increase coordination between suppliers and partners. The paper also includes case studies from manufacturing and retail, showing clear improvements in efficiency and customer satisfaction. Overall, it concludes that using AI, ML, and blockchain together is essential for building resilient, future-ready supply chains that can quickly adapt to changing market conditions.

V. Proposed Methodology

A. Existing System Introduction:

The existing Ganapati Idol Supply Chain Management system follows the traditional linear structure, and there are four major stakeholders involved in the supply chain-suppliers, manufacturers, painters, and customers. Suppliers supply raw materials such as clay, paints, and decoration items. However, because of a lack of digital tools,That prevents effective inventory tracking and quality assurance. The idols are manufactured by the manufacturers themselves.Manually, by molding and sculpting, without AI-powered monitoring and optimization of the process. Painters add finishing touches using traditional colouring and ornamentation techniques; no digital preview or opportunities for customer customization are offered. Finally, customers buy idols only from physical stores or exhibitions without personalization, order tracking, or information about the origin of the product. The result of such a manual, disjointed process consists of a number of disadvantages-the absence of full transparency, delays in inefficient tracking, less customer interaction, and no security measures such as blockchain that authenticate the product to avoid counterfeiting. prevents effective inventory tracking and assurance of quality. The idols then go into production by manufacturers,

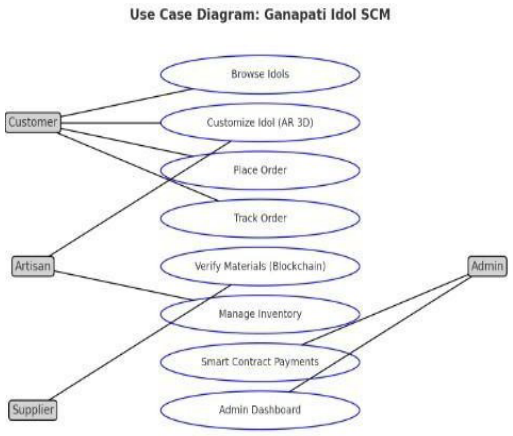


VI. Implementation

The approach involved in the implementation plan for this survey paper is to first design and develop the core architecture by integrating AI with blockchain technology in a phased manner. First, data collection and preprocessing will be carried out to trainMachine learning models will be developed to forecast demand and suggest personalized products, while blockchain-based smart contracts will ensure secure, transparent, and tamper-proof tracking of transactions and materials. A web-based interface with interactive features shall be developed. This shall also include augmented reality-enabled 3D visualization for the real-time customization of Ganapati models. The system shall thereafter be subjected to integration testing, ensuring that AI modules, blockchain ledgers, and the front-end application can communicate well. After verification, it shall be deployed in a pilot phase among selected artisans, suppliers, and customers for feedback and refinement. The further work shall involve continuous monitoring and iterative enhancement towards scalability, high user satisfaction, and long-term sustainability objectives.

B. Propose System Introduction:

The system architecture proposed in this paper is a comprehensive multilayer framework that ensures a supply chain management solution which will be secure, intelligent, and transparent for the Ganapati idol retail sector. This is designed in six interdependent tiers. The Frontend Layer provides an intuitive interface built with modern frameworks such as ReactJS or Angular, thereby enabling the stakeholders-suppliers, manufacturers, and customers-to interact smoothly. The API Layer acts as a secure intermediary by authenticating the requests and transferring data efficiently between the frontend and the backend. The Business Logic Layer enforces the business rules and integrates both blockchain and database systems for the function of production tracking, order management, and control over workflow. At the very heart of trust and accountability, the Blockchain and Smart Contracts Layer ensures immutable records of each transaction and automates-perhaps through decentralized verification-certain processes such as payments and inventory updates. The Database Layer manages a variety of both static and dynamic datasets-from user information to inventory records, to AI-generated output used in analytics and forecasting. Finally, the Dashboard Visualization Layer offers real-time, role-based insight into key indicators, such as stock levels, shipment status, and production activities that have taken place, thus facilitating effective decision-making with the help of supply chain management.



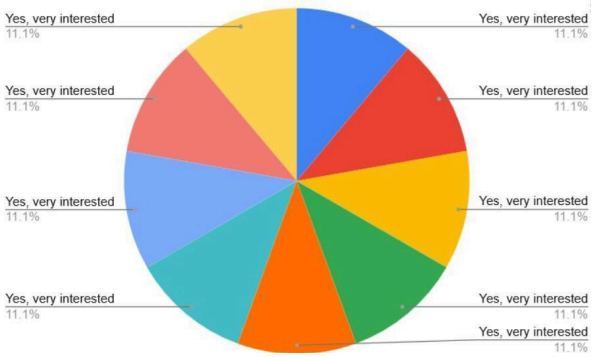
Use Case Diagram:

This use case diagram depicts the interaction of various stakeholders of the supply chain management platform for the Ganapati idol with the main features of the system. The customers can view the idols, customize them in 3D using AR, place the order, and track the delivery status. Through the system, the artisans can manage their inventory of idols and customize them according to the customer's requirements. The suppliers will verify the quality and authenticity of the eco-friendly raw materials through blockchain-based validation.

In contrast, the admin controls the entire system through the dashboard, ensuring smooth and secure transactions via blockchain-enabled smart contracts. The ellipses are representations of use cases, or tasks/functionalities, while the lines that connect them show the relationships the actors have with those tasks. Or better to say, this diagram defines both who the users of the system are and what type of actions they will be enabled to perform by making the platform transparent, secure, and customer-friendly.

VII. Survey Analysis

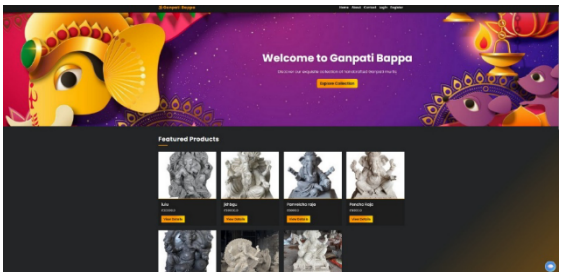
A survey conducted to gauge the acceptance of digital platforms amongst artisans on the question: “Would you be interested in selling your idols online?” revealed an unequivocal interest, with 100% strongly showing a willingness to do so. The overwhelming response indicates that the artisans are ‘ready for adoption’ of digital solutioning, besides underscoring the pragmatic relevance of the proposed system, especially since the platform addresses industry needs; it therefore validates the project's objectives of modernization, efficiency, and sustainability.



VIII. Implementation Workflow

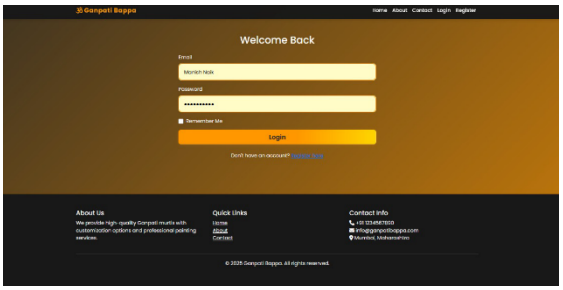
Sample of Inputs, Outputs, and GUI Screenshots

a colourful banner. It displays a selection of handcrafted Ganpati idols. This makes it simple for people to explore and discover unique products. The design creates a festive vibe and invites users to begin browsing immediately.

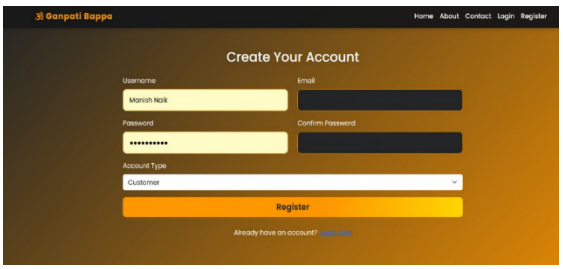


Home Page

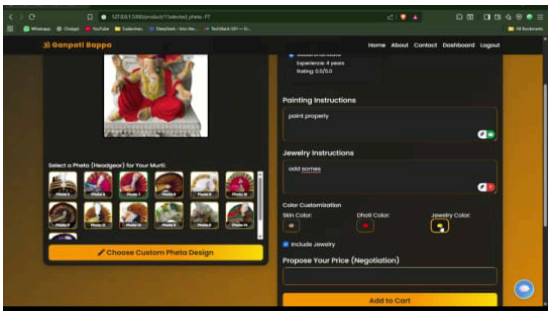
The Login and Registration Pages: they allow users to create accounts and sign in securely. Users can choose their roles as either a customer or a murtikar. After that, they can access their own dashboards and features.



Login Page

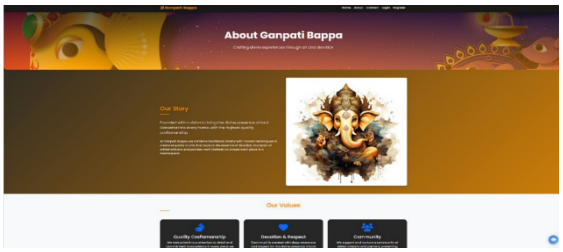


Registration Page



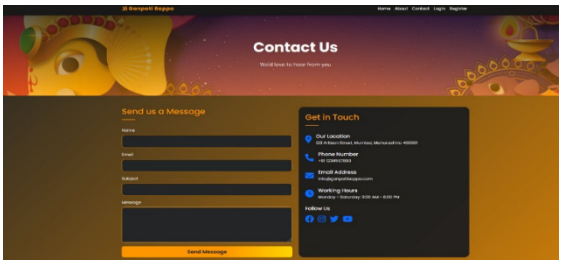
Pheta Page

About Page:The About Page explains the origin and vision of Ganpati Bappa. It shares the brand's commitment to merging tradition with artistic skill. It also outlines the values that guide the website, which helps build trust and authenticity with visitors.



About Page

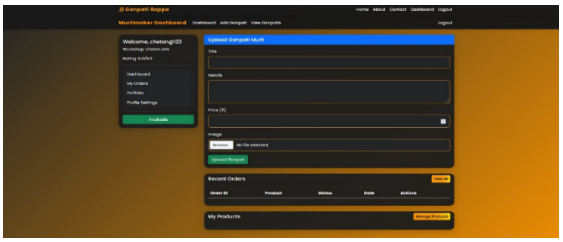
Contact Page: The Contact Page features an easy message form and full contact details. This allows users to reach out for questions, support, or collaboration opportunities.



Contact Page

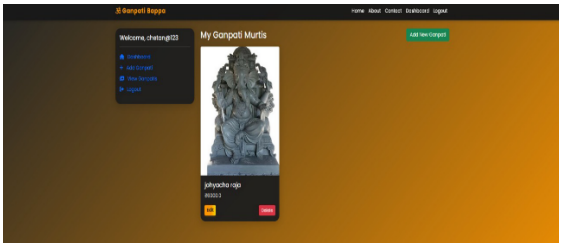
Pheta Page and Colouring Page: The images show an e-commerce web application for customizing and ordering Ganapati murti designs. Users can select photo references, personalize painting instructions, and specify jewellery details. They can also place orders on a checkout page. The dashboard helps painters manage orders easily and view their assigned tasks.

Murtikar Upload Page: On the Murtikar Portfolio Page, idol makers, or murtikars, can upload, display, edit, and manage their collection of Ganpati murtis. They can organize their portfolio to draw in customers and keep track of their creations.



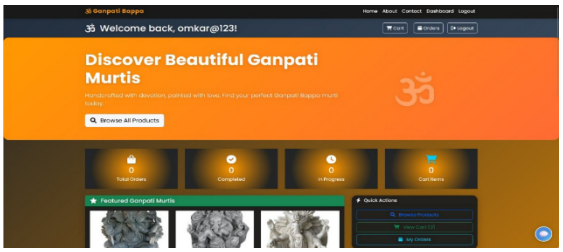
Murtikar Upload Page

Murtikar Portfolio Page: On the Murtikar Portfolio Page, idol makers, called murtikars, can upload, display, edit, and manage their collection of Ganpati murtis. They can organize their portfolio to attract customers and keep track of their creations.



Murtikar Portfolio Page

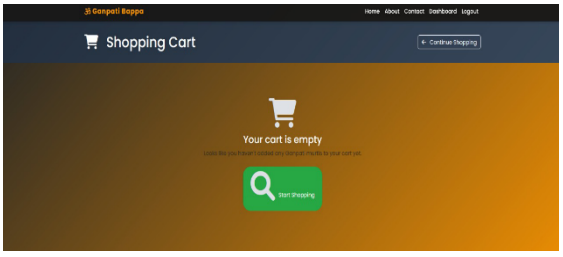
Customer Page: The Customer Page shows personalized greetings, featured idols, order summaries, and easy access to carts and orders. This setup makes every customer feel valued and helps them understand what they are doing.



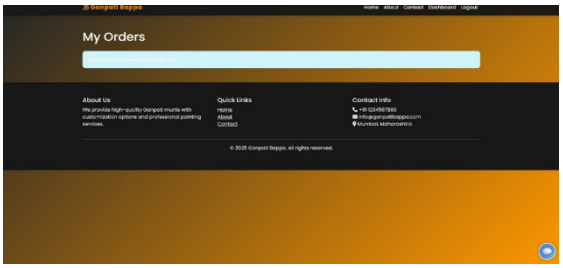
Customer Page

Shopping Cart Page and My Orders (Customer) Page: The Shopping Cart Page displays selected items. It helps customers manage their purchases before checkout. This leads to a smooth shopping experience.

The My Orders Page shows all the orders a customer has placed. It simplifies tracking orders and viewing order history.

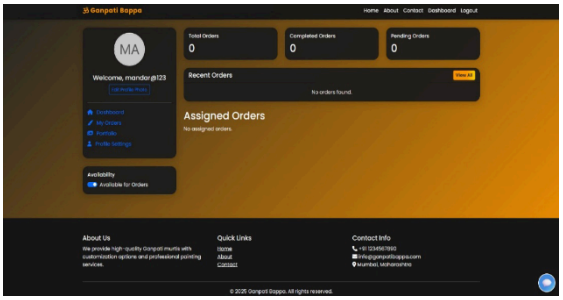


Shopping Cart Page



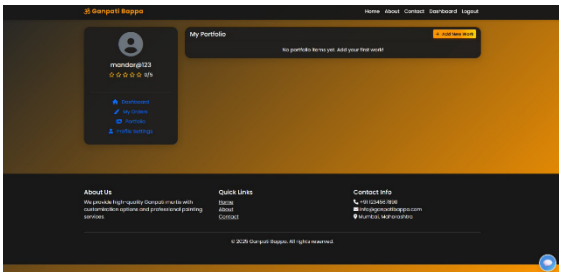
My Orders (Customer) Page

Painter Dashboard and Painter Portfolio Page: The Painter Dashboard and Portfolio Pages allow painters to track their assigned orders, showcase their work portfolio, and manage their availability for new commissions. This promotes a smooth workflow and improves visibility.



Painter Dashboard

Painter Portfolio Page: Here, you can find the painter's information. His work, performance, orders, and other details show his availability for new commissions. This helps keep the workflow steady and ensures visibility.



Painter Portfolio Page

IX. Summary

This project demonstrates how integrating Artificial Intelligence and blockchain can transform the conventional Ganapati idol supply chain into a more transparent, efficient, and customer-centric ecosystem. Using blockchain's immutable ledger, the system reduces paperwork, human error, and third-party overhead, thereby lowering operational costs and accelerating dispute resolution.

Smart contracts further automate payments and track provenance, making sure that, for example, raw materials like biodegradable clay and plant-based pigments are verifiably certified on-chain to further build trust between artisans, suppliers, and customers. AI-driven analytics amplify operational efficiency via demand forecasting and personalized recommendations. Time-series models like LSTM accurately forecast

seasonal Ganapati demand, enabling better planning and reducing inventory costs through dynamic segmentation. Similarly, AI-driven logistics optimization improves distribution efficiency. Such a reduction of operational waste and inefficiency was demonstrated in platforms like Uber Freight, where machine learning reduced empty miles. On the customer side, the AR-enabled 3D customization tool enhances engagement and conversion, with retailers seeing increased sales and attaining higher average order values as shoppers can interact with products virtually before buying. Lastly, implementing hybrid Layer-2 blockchain solutions increases transaction throughput while reducing gas fees; integrating Large Language Models enables advanced query handling and conversational interfaces. Recent studies indicate that integration of LLMs and IoT, and blockchain data can enhance decision-making and operational insights, which would be a valuable way to extend system capabilities.

In conclusion, the proposed
The AI-blockchain-enabled Ganapati idol platform strikes a balance between efficiency and trust, hence presenting a sustainable, transparent, immersive e-commerce model. Beyond religious artistry, it creates a scalable blueprint for modernizing the artisanal markets and fostering eco-conscious digital marketplaces.

X. Future Scope

In the future, the platform can be expanded by developing a dedicated mobile applications cater to both artisans and customers, with multi-language support to ensure wider access. AI-powered marketing tools can even help artisans showcase their idols to a wider customer base by recommending intelligent suggestions and personalized promotions. Integrations can be further made for trusted logistics partners and secure payment gateways that help in smooth order fulfilment and delivery operations. It will require continuous improvements in order to maintain scalability, user adoption, and sustainability over the long term. These will modernize not only the traditional Ganapati idol supply chain but also create an inclusive, efficient, and eco-friendly digital marketplace.

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Emotional Intelligence: A Gender and Residence-Based Analysis

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***Abstract*—Emotional Intelligence (EI) has emerged as a crucial psychological construct influencing individual adjustment, interpersonal relationships, and professional success. The present study aims to examine emotional intelligence with respect to gender (male and female) and residence (urban and rural). A total of 100 participants (50 males and 50 females) were selected, equally divided into urban and rural groups. The Emotional Intelligence Scale (EIS-HPD) developed by Hyde, Pethe, and Dhar was used for data collection. The results revealed that females scored higher than males, and urban participants demonstrated higher emotional intelligence than rural participants. Statistical analysis using t-test and two-way ANOVA confirmed significant differences across gender and residence. The findings highlight the influence of socio-cultural and environmental factors on emotional intelligence.**

***Index Terms*—Emotional Intelligence, Gender and Residence**

I. Introduction

Emotional Intelligence refers to the ability to perceive, understand, manage, and regulate emotions in one and others. It plays a vital role in shaping behaviour, decision-making, and interpersonal relationships. According to the Emotional Intelligence Scale manual, emotions act as a "powerful source of human energy, information, and influence," guiding individuals in adapting to various life situations.

The concept gained prominence through the work of Mayer and Salovey (1993), who defined EI as the ability to monitor one's own and others' feelings and use this information to guide thinking and actions. Later, Goleman (1995) emphasized its role in workplace success and leadership effectiveness.

Emotional intelligence comprises several components such as self-awareness, empathy, self-motivation, emotional stability, and relationship management. These components collectively determine how individuals cope with stress, interact socially, and make decisions.

In the Indian context, emotional intelligence is influenced by socio-cultural factors such as family structure, education, and rural-urban differences. Urban individuals are often exposed to diverse social interactions and educational opportunities, which may enhance emotional competencies. On the other hand, rural individuals may have limited exposure, affecting emotional development.

Gender differences in emotional intelligence have also been widely studied. Females are generally found to be more empathetic and emotionally expressive, while males may exhibit better emotional control. However, these differences are shaped by societal expectations and cultural norms.

Thus, the present study investigates emotional intelligence based on gender and residence to understand how these variables interact and influence emotional functioning.

II. Literature Review

Srinivasulu and Methri (2025) conducted a study on intermediate students and found that females scored significantly higher than males in emotional intelligence, particularly in areas such as empathy, emotional awareness, and interpersonal skills. This finding is supported by Mandloi and K. N. Pandey (2025), who reported that female students exhibited better emotional regulation and coping strategies compared to male students. These results suggest that gender plays a crucial role in emotional development, largely influenced by socialization practices in Indian society.

However, some recent studies have presented contrasting findings, indicating that gender differences may not always be significant. For instance, Almagharbeh et al. (2026) reported no substantial gender differences in overall emotional intelligence, suggesting that EI may function as a universal ability influenced more by environmental and educational factors than by gender alone. This contradiction highlights the need for further research using culturally sensitive tools.

Kumar and Randhawa (2022) found that urban adolescents scored higher in emotional intelligence compared to their rural counterparts. This difference was attributed to better access to education, exposure to diverse social environments, and greater opportunities for communication and interaction in urban areas. Similarly, recent studies (2025) have emphasized that urban environments foster emotional intelligence by providing platforms for social learning, problem-solving, and emotional expression.

Mandloi and K. N. Pandey (2025) found that individuals with higher emotional intelligence reported lower levels of stress, anxiety, and depression. Emotional intelligence was identified as a protective factor that enhances coping ability and psychological resilience. These findings are particularly relevant in the Indian context, where academic pressure, social expectations, and rapid societal changes contribute to mental health challenges among youth.

Srinivasulu and Methri (2025) reported that students with higher emotional intelligence demonstrated better concentration, motivation, and interpersonal relationships, leading to improved academic outcomes. Emotional intelligence helps students manage academic stress, communicate effectively, and maintain a

positive learning environment. These findings suggest that integrating emotional intelligence training into educational curricula can enhance both academic and personal development.

Furthermore, cultural factors play a significant role in shaping emotional intelligence in India. Emotional expression, regulation, and interpretation are influenced by cultural norms, family values, and social expectations. Indian society, which emphasizes collectivism, interpersonal relationships, and social harmony, provides a unique context for understanding emotional intelligence. Researchers such as K. N. Pandey have highlighted that emotional intelligence in India is deeply rooted in cultural values, and therefore, must be studied within its socio-cultural framework.

III. Objectives of the Study

1. To assess emotional intelligence among male and female participants.
2. To compare emotional intelligence between urban and rural individuals.
3. To examine the interaction effect of gender and residence on emotional intelligence.

IV. Hypotheses

1. There will be a significant difference in emotional intelligence between males and females.
2. There will be a significant difference in emotional intelligence between urban and rural participants.
3. There will be a significant interaction effect of gender and residence on emotional intelligence.

Methodology

V. Research Design

The study follows a **2×2 factorial design**, with gender (male/female) and residence (urban/rural) as independent variables, and emotional intelligence as the dependent variable.

VI. Sample

The sample for the present study consisted of 100 participants, selected through purposive sampling. The participants were equally divided based on gender and residence. It included 50 males and 50 females, ensuring gender balance in the study. Further, each gender group was subdivided into urban and rural categories, with 25 urban males, 25 rural males, 25 urban females, and 25 rural females. This balanced distribution allowed for a systematic comparison of emotional intelligence across gender and residential background. The sample design ensured equal representation, enhancing the reliability and validity of the comparative analysis.

VII. Tool Used

Emotional Intelligence Scale (EIS-HPD): The study utilized the Emotional Intelligence Scale (EIS-HPD) developed by Anukool Hyde, Sanjyot Pethe, and Upinder Dhar. This standardized tool consists of 34 items designed to assess various dimensions of emotional intelligence, including self-awareness, empathy, self-motivation, emotional stability, and relationship management. The scale has high reliability (0.88) and validity (0.93), making it suitable for research purposes. Responses are recorded on a 5-point

Likert scale, ranging from strongly agree (5) to strongly disagree (1). The tool is easy to administer and appropriate for both individual and group assessment in diverse settings.

VIII. Procedure

The procedure of the study involved approaching participants individually and explaining the purpose of the research in a clear and simple manner. Participants were instructed to respond honestly to all items of the Emotional Intelligence Scale without leaving any question unanswered. Proper instructions were given to ensure understanding of the response format. Confidentiality of responses was strictly maintained to encourage genuine answers. No time pressure was imposed; however, most participants completed the scale within approximately 30 minutes. The collected data were then systematically organized for statistical analysis.

IX. Statistical Analysis

The statistical analysis of the study was conducted using appropriate quantitative methods to examine differences in emotional intelligence. Mean and Standard Deviation were calculated to understand the average scores and variability among participants. The Independent Samples t-test was used to compare emotional intelligence between two groups, such as male's vs females and urban vs rural participants. Additionally, a Two-way ANOVA was applied to analyse the combined effect of gender and residence on emotional intelligence. These statistical techniques helped in identifying significant differences and interaction effects, ensuring accurate interpretation of the research findings.

X. Results

Table 1: Mean and SD for gender and residence

Group	Mean	SD
Urban Male	76.4	3.5
Rural Male	61.8	2.5
Urban Female	86.2	2.4
Rural Female	71.5	2.0

As shown in Table 1, the mean emotional intelligence scores varied across gender and residential groups. Urban females obtained the highest mean score (M = 86.20, SD = 2.40), followed by urban males (M = 76.40, SD = 3.50). Rural females (M = 71.50, SD = 2.00) scored higher than rural males (M = 61.80, SD = 2.50), who had the lowest mean score. These results indicate that both gender and residence influence emotional intelligence levels, with females and urban participants showing comparatively higher scores.

Table 2: t- value of Gender difference on Emotional Intelligence

Group	Mean	t-value
Male	69.10	9.21*
Female	78.85	

*Significant at 0.01 level000

An independent samples t-test was conducted to compare emotional intelligence between male and female participants. The results (Table 2) revealed a statistically significant difference between males (M = 69.10) and females (M = 78.85), t = 9.21, p < .01. This indicates that females possess significantly higher emotional intelligence than males. Therefore, the hypothesis stating that gender differences exist in emotional intelligence is supported.

Table 3: t- value of Residence Difference on Emotional Intelligence

Group	Mean	t-value
Urban	81.30	
Rural	66.65	10.34*

*Significant at 0.01 level

To examine the effect of residence, an independent samples t-test was performed between urban and rural participants. As presented in Table 3, a significant difference was found between urban (M = 81.30) and rural (M = 66.65) participants, t = 10.34, p < .01. The findings suggest that urban individuals demonstrate significantly higher emotional intelligence than rural individuals. Thus, the hypothesis related to residential differences is accepted.

Table 4: Two-Way ANOVA for gender and residence on emotional intelligence

Source	F-value
Gender	84.21*

Source	F-value
Residence	102.45*
Interaction	12.67*

*Significant at 0.01 level

A two-way analysis of variance (ANOVA) was conducted to examine the main and interaction effects of gender and residence on emotional intelligence (Table 4). The results indicated a significant main effect of gender, $F(1, 96) = 84.21$, $p < .01$, and a significant main effect of residence, $F(1, 96) = 102.45$, $p < .01$.

Furthermore, the interaction effect between gender and residence was also found to be significant, $F(1, 96) = 12.67$, $p < .01$. This indicates that the effect of gender on emotional intelligence varies depending on residential background. Specifically, urban females scored the highest, while rural males scored the lowest.

XI. Discussion

The present study aimed to examine emotional intelligence (EI) with respect to gender and residence (urban vs rural). The findings revealed that females scored significantly higher than males, urban participants scored higher than rural participants, and a significant interaction effect was observed between gender and residence. These findings are discussed in relation to previous research and theoretical perspectives.

The results of the study indicate that **female participants possess higher emotional intelligence than male participants**. This finding is consistent with earlier research conducted by **Daniel Goleman (1995)** and **John D. Mayer and Peter Salovey (1993)**, who emphasized that female, tend to demonstrate greater emotional awareness, empathy, and interpersonal sensitivity. These characteristics are central components of emotional intelligence. Similarly, Indian researchers such as **K. N. Pandey (2020, 2023)** have highlighted that emotional intelligence is closely linked with socialization patterns in Indian society, where females are often encouraged to express emotions and maintain interpersonal harmony.

The higher emotional intelligence among females may be explained through **gender role socialization theory**, which suggests that societal expectations shape emotional behaviour. Females are generally socialized to be more expressive, empathetic, and relationship-oriented, while males are often encouraged to suppress emotional expression and display emotional control. This difference contributes to higher EI scores among females, particularly in domains such as empathy and emotional awareness.

However, some studies present contradictory findings. For instance, certain researchers argue that males may exhibit higher emotional intelligence in terms of **emotional regulation and problem-focused coping**. These aspects are often underrepresented in traditional EI scales, which focus more on emotional expression and empathy. Therefore, while the present study supports the majority of findings, it is important to recognize that emotional intelligence is multidimensional, and gender differences may vary depending on how EI is conceptualized and measured.

The study also found that **urban participants scored significantly higher than rural participants in emotional intelligence**. This finding is consistent with research by Kumar and Randhawa (2022), which reported that urban individuals benefit from better educational opportunities, exposure to diverse social environments, and enhanced communication skills. Urban settings provide greater opportunities for interaction, problem-solving, and emotional learning, which contribute to higher emotional intelligence.

Indian studies, including those by **S. K. Mangal and Shubhra Mangal (2018)**, also suggest that environmental factors play a crucial role in emotional development. Urban individuals are more likely to engage in varied social experiences, which enhance their ability to understand and manage emotions.

Nevertheless, this finding should be interpreted cautiously. Some researchers argue that rural individuals possess **context-specific emotional strengths**, such as strong community bonding, cooperation, and resilience. These qualities may not be adequately captured by standardized emotional intelligence scales. For example, rural populations often demonstrate high levels of social support and emotional connectedness, which are important aspects of emotional intelligence but may not be reflected in quantitative scores. Thus, the lower EI scores among rural participants may partly reflect **measurement bias** rather than an actual deficit in emotional competence.

The most significant finding of the present study is the **interaction effect between gender and residence**, which indicates that emotional intelligence, is influenced by the combined effect of these variables. The results show that **urban females scored the highest**, while **rural males scored the lowest**. This suggests that both gender and environmental exposure play a crucial role in shaping emotional intelligence.

This finding is supported by recent studies, which emphasize that emotional intelligence is not determined by a single factor but by the interaction of personal, social, and environmental influences. Urban females benefit from gender-related advantages (such as emotional expressiveness) and environmental advantages (such as educational and social exposure), leading to higher emotional intelligence. In contrast, rural males may experience limitations in both emotional socialization and environmental opportunities, resulting in lower EI scores.

Another important aspect of the findings is the relationship between emotional intelligence and **mental well-being**, as highlighted in recent Indian research by **R. Mandloi and K. N. Pandey (2025)**. Their studies suggest that individuals with higher emotional intelligence are better able to manage stress, cope with challenges, and maintain psychological stability. This supports the present findings, as groups with higher EI (such as urban females) are likely to exhibit better emotional adjustment and well-being.

At the same time, it is important to critically evaluate the methodological limitations of the present study. The use of a **self-report measure** may introduce bias, as participants may respond in socially desirable ways. This limitation has been highlighted by several researchers, who argue that emotional intelligence assessments should include behavioural and performance-based measures for greater accuracy. Additionally, the sample size of 100 participants, although adequate for statistical analysis, may limit the generalizability of the findings.

Recent research also raises concerns about the **impact of digitalization on emotional intelligence**, particularly among urban populations. While urban participants scored higher in the present study, excessive use of digital communication may reduce face-to-face interaction and emotional awareness over time. This suggests that the urban advantage in emotional intelligence may not be permanent and could change with evolving social conditions.

An important contribution of recent literature is the recognition that emotional intelligence is **trainable and developable**. Studies conducted in 2025 and 2026 demonstrate that emotional intelligence can be enhanced through interventions such as emotional skills training, mindfulness practices, and counselling. This has significant implications for education and policy, as it suggests that emotional intelligence can be improved among both rural and male populations through targeted programs.

From a cultural perspective, emotional intelligence is deeply influenced by **Indian socio-cultural values**, which emphasize interpersonal relationships, family bonding, and social harmony. Researchers such as **K. N. Pandey** have emphasized that emotional intelligence in India is shaped by cultural norms and traditions, which influence how emotions are expressed and managed. Therefore, any interpretation of emotional intelligence must consider the cultural context in which individuals operate.

XII. Conclusion of Discussion

In conclusion, the findings of the present study are largely consistent with existing literature, confirming that emotional intelligence is influenced by gender and residential background. Females and urban participants demonstrate higher emotional intelligence, while rural males show comparatively lower levels. However, these differences must be interpreted with caution, considering the influence of cultural, social, and measurement factors.

The study also highlights that emotional intelligence is a dynamic and developable construct, which can be enhanced through education and training. Future research should focus on developing culturally sensitive tools, exploring longitudinal changes in emotional intelligence, and examining the impact of modern social and technological changes.

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A Review On Autonomous Street Light Illumination

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***Abstract*—The rapid expansion of urban infrastructure has intensified the global demand for smarter energy management. Street lighting is vital for public safety, yet traditional systems are often inefficient, operating at full capacity regardless of environmental light or traffic density. This leads to massive energy wastage and high operational costs. To address these inefficiencies, this research presents an IoT-based Smart Street Light Control System designed to optimize power consumption through real-time adaptability.The proposed system utilizes a synergy of Light Dependent Resistors (LDR) and Passive Infrared (PIR) sensors, managed by a central microcontroller. The LDR monitors ambient light to automate the dusk-to-dawn transition, while PIR sensors detect the presence of pedestrians or vehicles. By employing a dynamic dimming mechanism, the system maintains a low-intensity standby mode during periods of inactivity and switches to full brightness only when motion is detected. This responsive approach not only minimizes electricity usage but also extends the operational lifespan of the hardware.Beyond local automation, the integration of Internet of Things (IoT) capabilities allows for remote monitoring and data collection. System performance, energy metrics, and hardware failures can be tracked via a centralized dashboard, significantly reducing the need for manual maintenance and physical inspections. Experimental observations suggest that this intelligent framework offers a scalable and cost-effective alternative to conventional lighting. Ultimately, the system provides a robust solution for Smart City Infrastructure, balancing the need for public security with the urgent requirement for environmental sustainability and energy conservation.**

***Index Terms*—Internet of Things (IoT), Smart Street Lighting System, Energy Efficiency, PIR Sensor, LDR Sensor, Smart City Infrastructure.**

I. Introduction

The increasing demand for energy-efficient and intelligent infrastructure has become a major concern due to rapid urbanization and population growth. Street lighting systems are a critical component of public infrastructure, ensuring safety, visibility, and security during nighttime. However, conventional street lighting systems operate at fixed illumination levels throughout the night without considering environmental conditions or real-time usage. This leads to excessive energy consumption, higher operational costs, and inefficient utilization of available resources.

To address these limitations, the integration of the Internet of Things (IoT) into street lighting systems provides an advanced and effective solution. IoT enables interconnected devices to communicate, collect, and process real-time data, allowing automated decision-making without human intervention. The implementation of IoT-based smart systems enhances efficiency, reliability, and scalability in modern infrastructure.The proposed IoT-based Smart Street Light Control System is designed to optimize energy consumption and improve system performance through automation and intelligent control. The system utilizes Light Dependent Resistors (LDR) to detect ambient light intensity and determine day and night conditions. Based on this input, the system automatically switches the street lights ON during low light conditions and OFF during daylight, eliminating the need for manual operation.

In addition to ambient light detection, Passive Infrared (PIR) sensors are incorporated to detect the presence of pedestrians or vehicles. The system dynamically adjusts the brightness of street lights based on motion detection. When no movement is detected, the lights operate at a reduced intensity level to conserve energy. Upon detecting motion, the system increases brightness to ensure adequate illumination and safety. This adaptive lighting mechanism significantly reduces energy wastage while maintaining effective performance.A microcontroller acts as the central processing unit, receiving input signals from sensors and executing control operations. The system is further enhanced by integrating wireless communication technologies, enabling remote monitoring and control. Through IoT platforms, data such as energy consumption, system status, and fault detection can be accessed in real time. This reduces maintenance efforts and allows quick identification and resolution of system failures.The rapid pace of global urbanization has brought infrastructure efficiency to the forefront of modern city planning. Among various public utilities, street lighting is fundamental for ensuring communal safety and security. However, traditional lighting systems are often stagnant, relying on outdated fixed schedules that waste massive amounts of electricity during periods of inactivity [1]. This leads to significant fiscal strain on municipal budgets and contributes to unnecessary carbon emissions. To address these inefficiencies, there is an urgent need for a transition toward Smart City Infrastructure, where public utilities are not just functional but also responsive [2]. By integrating Internet of Things (IoT) technology with real-time environmental sensors, we can transform street lights into intelligent units that adapt dynamically to their surroundings [3].

The primary objectives of this research are to design and implement an automated lighting framework that minimizes human intervention and maximizes energy conservation. Specifically, the system aims to automate the dusk-to-dawn transition using Light Dependent Resistors (LDR) and optimize nighttime power usage through motion-based dimming via Passive Infrared (PIR) sensors [4]. Furthermore, the project seeks to enable remote monitoring capabilities, allowing authorities to track energy metrics and detect hardware failures through a centralized IoT dashboard [5]. This study demonstrates that by utilizing a decentralized control logic, cities can achieve a sustainable balance between maintaining public safety and drastically reducing operational overhead [6]. Ultimately, the proposed system serves as a scalable model for future smart grids, proving that minor technological interventions can lead to significant environmental and economic shifts [7].

II. Literature Review

The concept of smart street lighting has gained significant attention in recent years due to the increasing demand for energy-efficient and intelligent urban infrastructure. Various researchers and authors have contributed to the development of IoT-based lighting systems, focusing on automation, energy conservation, and improved system performance.The foundation of the Internet of Things (IoT) was initially introduced as a concept to connect physical devices through the internet, enabling communication and data exchange between them [1]. This concept has been widely adopted in various applications, including smart cities, healthcare, and industrial automation. The application of IoT in street lighting systems provides an opportunity to develop intelligent systems that can operate efficiently based on real-time environmental conditions.

Several studies have explored the use of microcontrollers and embedded systems for automation. The work on Arduino-based systems highlights the importance of low-cost and flexible platforms for implementing IoT solutions [2]. These platforms allow easy integration of sensors and communication modules, making them suitable for smart street lighting applications.Research on connected product design emphasizes the importance of user-centric and scalable systems [3]. It highlights how integrating hardware and software components can improve system efficiency and enable remote monitoring. Such design approaches are essential for developing reliable and adaptable smart lighting systems.Various researchers have proposed IoT-based smart street lighting systems that utilize sensors for automation. A study on smart street lighting systems demonstrates how the use of LDR and PIR sensors can significantly reduce energy consumption by

controlling light intensity based on environmental conditions and human presence [4]. Similarly, another research focuses on energy-efficient lighting systems that adjust brightness dynamically, resulting in reduced power consumption and improved performance [5].Further studies have introduced intelligent lighting systems that incorporate IoT technologies for remote monitoring and control. These systems enable real-time data collection and analysis, allowing efficient management of street lighting networks [6]. Automatic street light control systems have also been developed using sensor-based approaches, where lights operate only when required, reducing unnecessary energy usage [7].

The integration of wireless sensor networks plays a crucial role in enhancing system scalability and communication efficiency. Research in this area highlights how sensor networks can be used to monitor and control large-scale lighting systems effectively [8]. This approach supports the deployment of smart lighting systems in urban environments.Recent studies have focused on the design and implementation of smart street lighting systems with improved performance and reliability. These systems utilize advanced control mechanisms and IoT platforms to ensure efficient operation and fault detection [9]. Additionally, documentation and technical resources related to Arduino and IoT platforms provide practical guidance for system implementation and development [10].Online research databases such as IEEE Xplore and ScienceDirect offer a wide range of research papers related to smart street lighting and IoT-based systems [11], [12]. These sources provide valuable insights into recent advancements, methodologies, and technologies used in the development of intelligent lighting systems.

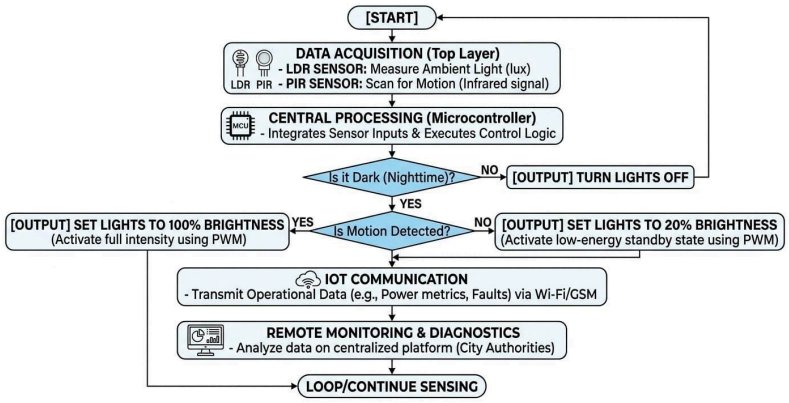
III. Methodology

The development of the IoT-based Smart Street Light Control System is executed through a structured, multi-phase methodology that integrates sophisticated hardware components with intelligent control algorithms. The primary goal is to shift from conventional static lighting to a highly responsive, data-driven framework. The physical infrastructure begins with the integration of essential sensing technologies [1]. Specifically, Light Dependent Resistors (LDR) are employed to continuously monitor ambient light levels to accurately distinguish between day and night, forming the primary operational trigger. Simultaneously, Passive Infrared (PIR) sensors are strategically deployed to detect motion by scanning for infrared heat signatures emitted by moving pedestrians or vehicles [2]. Both sensing units provide real-time input signals to a centralized microcontroller (such as Arduino), which functions as the decision-making hub for the entire grid.

The logic embedded within the microcontroller governs the dynamic operation of the high-efficiency LED lights, moving beyond simple binary ON/OFF controls [3]. During daytime, the lights remain deactivated to conserve energy. When the LDR signals the onset of nighttime, the system enters a "standby" mode, keeping the lights at a dimmed intensity (e.g., 20%) to maintain baseline visibility [4]. However, upon receiving a trigger from the PIR sensor indicating movement, the microcontroller utilizes Pulse Width Modulation (PWM) techniques to instantly scale up the brightness to 100% [5]. This dynamic control mechanism ensures that maximum energy is utilized only when public safety demands it, resulting in substantial fiscal and energetic savings [6].

Beyond localized automation, the system incorporates communication modules (such as Wi-Fi or GSM) to establish Internet of Things (IoT) connectivity. This enables the transmission of crucial operational data—including power consumption metrics, operational hours, and potential component failures—to a centralized cloud platform [7]. This remote monitoring capability eliminates the need for manual physical patrols, allowing municipal authorities to perform predictive maintenance and address faults promptly. The entire implementation process involves firmware development via Embedded C (Arduino IDE), sensor calibration, and thorough testing under diverse environmental simulations [8]. Performance evaluation is conducted by comparing the adaptive system’s energy draw against a standard 24-hour fixed lighting schedule, confirming a marked reduction in power usage and increased hardware longevity [9].

FIGURE 1: OPERATIONAL FLOWCHART OF THE SMART STREET LIGHT SYSTEM

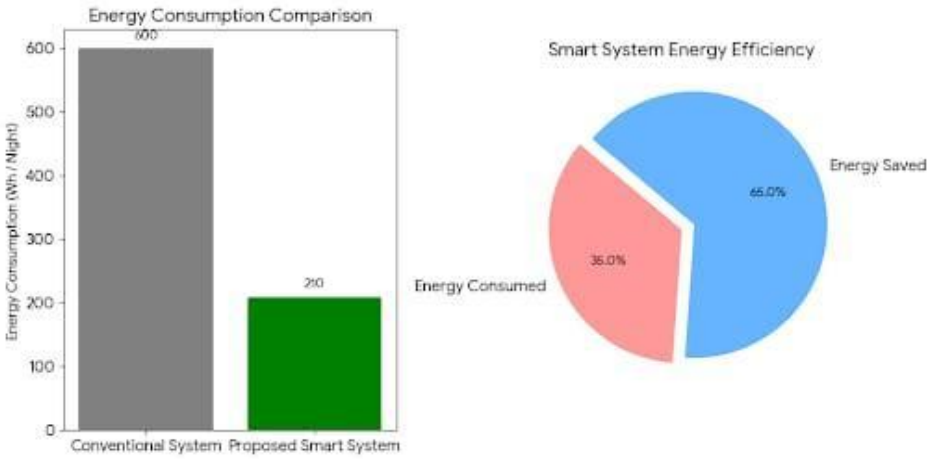


IV. Results

The proposed IoT-based Smart Street Light Control System was tested under different environmental and operational conditions to evaluate its performance. The system successfully demonstrated automatic control of street lights based on ambient light intensity and motion detection.During daytime conditions, the LDR sensor effectively detected sufficient light intensity and ensured that the street lights remained OFF, thereby preventing unnecessary energy consumption. At nighttime, the system automatically activated the street lights. When no motion was detected by the PIR sensor, the lights operated at a reduced brightness level, conserving energy. Upon detecting movement, the system increased the brightness to full intensity, ensuring proper visibility and safety.The performance analysis indicates a significant reduction in energy consumption compared to traditional street lighting systems. The system also showed reliable response time and accurate detection of environmental changes. Additionally, the use of LED lights and controlled brightness levels contributed to extending the lifespan of lighting components.Overall, the results confirm that the proposed system is efficient, reliable, and suitable for real-time applications in urban and rural areas. The proposed IoT-based Smart Street Light Control System was experimentally evaluated under various environmental and operational conditions to assess its efficiency, responsiveness, and reliability. The system was tested during both daytime and nighttime scenarios, as well as under different levels of human and vehicular activity.

During daytime conditions, the Light Dependent Resistor (LDR) sensor accurately detected high ambient light intensity and ensured that the street lights remained in the OFF state. This prevented unnecessary power consumption and confirmed the effectiveness of the automatic switching mechanism. As the ambient light intensity decreased during evening hours, the system successfully transitioned into nighttime mode, automatically turning the street lights ON without any manual intervention.At night, the Passive Infrared (PIR) sensor played a crucial role in dynamic lighting control. When no movement was detected within the sensor range, the street lights operated at a dim or low-intensity level, significantly reducing energy usage. Upon detecting motion, such as pedestrians or vehicles, the system responded immediately by increasing the light intensity to full brightness. This ensured adequate visibility and enhanced safety while maintaining energy efficiency. The transition between dim and full brightness was smooth and occurred with minimal delay, demonstrating the system's real-time responsiveness.A comparative performance analysis was conducted between the proposed smart system and conventional street lighting systems. The results indicated that the IoT-based system achieved energy savings of approximately 50–70%, depending on traffic density and environmental conditions. Areas with low nighttime activity showed higher energy savings due to prolonged operation in dim mode. In contrast, high-traffic areas still benefited from optimized energy usage through adaptive lighting control.Furthermore, the system exhibited high accuracy in detecting environmental changes and motion, with minimal false triggering. The response time of the sensors and microcontroller was observed to be efficient, ensuring real-time operation without noticeable lag. The integration of LED lighting further enhanced performance, as LEDs consume less power and offer longer

operational life compared to traditional lighting sources.Another important outcome of the implementation was the reduction in maintenance requirements. The incorporation of IoT-based monitoring enabled real-time tracking of system performance, including energy consumption and operational status. Faults or irregularities, such as light failures or sensor malfunctions, could be identified quickly, reducing downtime and maintenance effort.In addition, the controlled brightness operation contributed to extending the lifespan of lighting components. By avoiding continuous operation at full intensity, the system reduced thermal stress and wear on LEDs and electrical components, thereby improving durability and reducing replacement costs over time.Overall, the experimental results confirm that the proposed system is highly efficient, reliable, and adaptable to real-world conditions. It successfully achieves automated control, significant energy savings, and improved operational performance. The system is well-suited for deployment in both urban and rural environments and holds strong potential for integration into smart city infrastructure.



V. Conclusion

The IoT-based Smart Street Light Control System provides an effective solution for reducing energy consumption and improving the efficiency of street lighting systems. By integrating LDR and PIR sensors with a microcontroller, the system enables automatic control of street lights based on environmental conditions and human activity.The system successfully minimizes energy wastage by operating lights only when required and adjusting brightness levels dynamically. This not only reduces electricity consumption but also lowers operational and maintenance costs. The use of wireless communication further enhances system performance by enabling remote monitoring and quick fault detection.

In addition to economic benefits, the system contributes to environmental sustainability by reducing carbon emissions. It also supports the development of smart city infrastructure by providing an intelligent and scalable lighting solution.Overall, the proposed system overcomes the limitations of conventional street lighting and demonstrates a reliable, cost-effective, and energy-efficient approach for modern urban development.IoT improves street lighting efficiency, reduces energy wastage, and enhances safety. The future applications of the Smart Street Light Control System extend far beyond illumination. The system can evolve into a strategic backbone for smart cities, supporting energy savings, public safety, environmental sustainability, and digital transformation. With continuous technological advancements, this project has strong potential to become a multi-functional, scalable, and future-ready urban infrastructure solutionThe system effectively minimizes energy wastage by ensuring that street lights operate only when required. The automatic switching mechanism based on ambient light conditions prevents unnecessary daytime operation, while the motion-based brightness control significantly reduces energy consumption during low-activity periods. This dual-level optimization strategy not only conserves electrical energy but also enhances overall system efficiency.In addition to energy savings, the proposed system contributes to a substantial reduction in operational and maintenance costs. The incorporation of IoT-enabled wireless

communication allows real-time monitoring of system performance, enabling quick detection and resolution of faults. This reduces the need for manual inspection and ensures improved reliability and uptime of the system. Furthermore, the controlled operation of lighting elements helps extend the lifespan of components, thereby lowering replacement and maintenance expenses over time.From an environmental perspective, the system plays a vital role in promoting sustainability. By reducing unnecessary power consumption, it directly contributes to lowering carbonemissions and decreasing the overall environmental impact of urban infrastructure. The use of energy-efficient LED lighting further strengthens its eco-friendly characteristics.Moreover, the scalability and flexibility of the system make it suitable for deployment in a wide range of environments, including urban, semi-urban, and rural areas. Its compatibility with IoT platforms enables future enhancements such as data analytics, predictive maintenance, and integration with other smart city systems. This positions the proposed solution as a key component in the advancement of smart and sustainable cities.In conclusion, the IoT-based Smart Street Light Control System offers a reliable, cost-effective, and energy-efficient alternative to traditional street lighting methods. It successfully combines automation, real-time monitoring, and intelligent decision-making to improve performance and reduce resource consumption. The system not only addresses current energy challenges but also provides a scalable foundation for future smart infrastructure development.

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Role and Impact of Deemed University Libraries in Telangana on Research Support Services.

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***Abstract*—Deemed university libraries play a crucial role in strengthening research activities by providing essential information resources, advanced digital services, and user-oriented support systems. This study examines the role and impact of deemed university libraries in Telangana in supporting research services. It highlights how these libraries facilitate access to electronic resources, institutional repositories, research databases, and scholarly communication tools, thereby enhancing the quality and productivity of research.**

The study further explores a range of services offered by these libraries, including research consultation, plagiarism detection, reference management assistance, and information literacy programs. Additionally, it evaluates the challenges faced by these institutions, such as budget constraints, technological limitations, and the need for skilled professionals to manage rapidly evolving digital environments.

The findings reveal that deemed university libraries in Telangana make a significant contribution to the research ecosystem by promoting innovation, improving access to knowledge, and supporting academic excellence. The study concludes that continuous investment in digital infrastructure, staff training, and user-centric services is essential for strengthening research support services in the future.

***Index Terms*—Deemed University Libraries, Research Support Services, Digital Resources, Information Literacy, Scholarly Communication.**

I. Introduction

Deemed university libraries in Telangana have undergone significant transformation with the advent of digital technologies. They are no longer confined to traditional roles such as book lending and reference services; instead, they function as dynamic knowledge hubs that offer a wide range of research support services. These services include access to electronic journals, online databases, institutional repositories, plagiarism detection tools, and research consultation. Such facilities enable researchers, faculty members, and students to access, manage, and disseminate scholarly information efficiently.

In the contemporary academic environment, research has become a fundamental component of higher education, contributing significantly to knowledge creation, innovation, and societal development. Universities increasingly emphasize research productivity and quality, leading to a growing demand for effective research support systems. In this context, university libraries, particularly those in deemed universities, play a vital role in facilitating and enhancing research activities.

Furthermore, these libraries actively contribute to the development of information literacy skills among users, helping them identify, evaluate, and use information effectively. They also support scholarly communication by assisting with academic publishing, citation management, and adherence to research ethics. The integration of advanced technologies and digital resources has significantly enhanced the ability of libraries to meet the evolving needs of the research community. Despite these advancements, deemed university libraries face several challenges, including limited financial resources, the need for continuous technological upgrades, and the demand for skilled library professionals.

This study focuses on examining the role and impact of deemed university libraries in Telangana on research support services. It aims to understand how these libraries contribute to the research ecosystem and to identify areas for improvement in order to strengthen their support for academic research.

II. Literature Review

The role of academic libraries in supporting research has been widely discussed in library and information science literature. With the rapid growth of digital technologies, university libraries have transformed from traditional information repositories into dynamic centers that actively support research activities. Academic libraries, which were once primarily focused on the collection and preservation of information, have now evolved to play a significant role in facilitating research and academic productivity.

Haq and Jan (2025) state that academic libraries are now central to the research ecosystem, offering structured Research Support Services (RSS) such as data management, citation assistance, and scholarly communication support. This transformation reflects the growing need for libraries to align their services with institutional research goals and enhance research productivity.

Ardyawin (2025) observed that digital transformation has significantly improved access to electronic resources, streamlined information retrieval processes, and enhanced user experience in academic libraries. These developments are particularly relevant for deemed university libraries in Telangana, where digital infrastructure plays a crucial role in supporting researchers.

Singh, Raj, and Madalli (2024) identified key research support services, including research guides, open access support, bibliometric analysis, and research data management. However, their study revealed that the implementation of advanced research services in Indian academic libraries is still in a developing stage.

Hussain and Rafiq (2023) highlighted that academic libraries provide support across the entire research lifecycle, including idea generation, data collection, data management, and publication processes. This comprehensive support enhances the effectiveness and quality of research output.

DeFrain, Sult, and Pagowsky (2025) found that research guides play a significant role in improving students' information literacy skills. However, their effectiveness largely depends on proper design, usability, and user engagement.

Zhang (2025) developed a framework for evaluating discipline-specific information services, emphasizing the importance of intelligent systems in enhancing research support. Furthermore, recent studies indicate that academic libraries are increasingly adopting innovative technologies to improve service delivery and user engagement.

Overall, the literature indicates that academic libraries play a vital role in supporting research through digital resources, information literacy programs, and specialized services. However, there is a need for continuous innovation, capacity building, and policy support to maximize their impact, particularly in regional contexts such as Telangana.

III. Objectives

1) To examine the role of deemed university libraries in Telangana in providing research support services.
2) To identify the various types of research support services offered by these libraries, including e-resources, databases, and digital services.
3) To analyze the usage of library resources and services by faculty members and research scholars.
4) To evaluate the effectiveness of research support services in enhancing the quality and productivity of research.
5) To assess the level of user satisfaction with library services and facilities.
6) To identify the challenges faced by deemed university libraries in delivering effective research support services.

IV. Hypotheses

H1: Deemed university libraries in Telangana play a significant role in providing research support services.

H2: There is a significant relationship between the availability of research support services (such as e-resources, databases, and digital services) and their usage by faculty members and research scholars.

H3: Faculty members and research scholars make effective use of library resources and services for their research activities.

H4: Research support services provided by deemed university libraries have a significant positive impact on research productivity and quality.

H5: Users are significantly satisfied with the library services and facilities provided by deemed university libraries.

H6: Deemed university libraries face significant challenges in delivering effective research support services.

V. Scope of the Study

This study focuses on examining the role and impact of deemed university libraries in Telangana in providing research support services. It covers selected deemed universities within the state and analyzes the various services offered by their libraries to support research activities.

The study includes key stakeholders such as faculty members, research scholars, and library professionals to understand their perspectives on the availability, usage, and effectiveness of research support services. It considers a range of services provided by libraries, including access to e-resources, digital libraries, institutional repositories, research consultation, plagiarism detection services, and information literacy programs.

The scope of the study is limited to research support services offered by deemed university libraries in Telangana and does not include other types of academic or public libraries. The study primarily focuses on current practices, user satisfaction, and the challenges faced in delivering these services.

In addition, the study highlights the impact of digital transformation and technological advancements on library services and their contribution to research productivity and academic performance. The findings of the study are expected to provide valuable insights for improving library services and strengthening research support systems in deemed universities.

VI. Methodology

This study adopts a descriptive research design to examine the role and impact of deemed university libraries in Telangana in providing research support services. The research aims to understand the nature, availability, and effectiveness of the services offered by these libraries to support academic research.

VII. Research Design

A descriptive survey method is used to collect both qualitative and quantitative data. This approach helps in analyzing existing research support services and evaluating their impact on users.

VIII. Population and Sample

The population of the study includes library professionals, faculty members, and research scholars from selected deemed universities in Telangana. A sample of respondents is selected using a purposive sampling technique to ensure adequate representation of key stakeholders involved in research activities.

IX. Data Collection Methods

Primary data are collected through structured questionnaires distributed to faculty members, research scholars, and library staff. In addition, interviews are conducted with library professionals to gain deeper insights into research support services. Secondary data are collected from library reports, institutional websites, research publications, and relevant literature.

X. Tools for Data Collection

The questionnaire consists of both closed-ended and open-ended questions to gather quantitative data as well as qualitative opinions. The questions focus on the availability of e-resources, usage of digital services, research assistance, and levels of user satisfaction.

XI. Scope and Limitations

The study is limited to selected deemed universities in Telangana and focuses only on the research support services provided by their libraries. Factors such as time constraints, limited sample size, and data availability may affect the generalizability of the findings.

XII. Data Analysis

The collected data were analyzed using the percentage method and are presented in tabular form for clarity and interpretation. Qualitative data obtained from interviews were analyzed using thematic interpretation to identify key patterns and insights.

Table 1: Distribution of Respondents.

S.NO	Category	No of Respondents	Percentage(%)
1	Faculty Members	40	40%
2	Research Scholars	45	45%
3	Library Professionals	15	15%
	Total	100	100%

XIII. Interpretation

The majority of respondents are research scholars (45%), followed by faculty members (40%), Library Professionals (15%) .This indicates strong representation from active research users.

Table 2: Availability of Research Support Services.

S.NO	Services	Available (%)	Not Available (%)	Total (%)
1	E-Resources (e-journals, databases)	90%	10%	100%
2	Institutional Repository	75%	25%	100%
3	Plagiarism Detection Tools	80%	20%	100%
4	Research Consultation	70%	30%	100%

Most libraries provide essential research support services. E-resources are the most widely available service, present in 90% of the institutions.

Table 3: Usage of E-Resources.

S.NO	Usage Frequency	Number of Respondents	Percentage (%)
1	Daily	50	50%
2	Weekly	30	30%
3	Occasionally	20	20%
4	Never	0	0%

Half of the respondents (50%) use e-resources daily, indicating a high level of dependence on digital resources for research purposes.

Table 4: User Satisfaction Level.

S.NO	Satisfaction Level	Number of Respondents	Percentage (%)
1	Highly Satisfied	35	35%
2	Satisfied	45	45%

3	Neutral	15	15%
4	Dissatisfied	5	5%

A large majority of respondents (80%) are either satisfied or highly satisfied with the research support services provided by libraries.

Table 5: Challenges Faced by Libraries.

S.NO	Challenge	Percentage (%)
1	Budget Constraints	70%
2	Lack of Skilled Staff	60%
3	Technological Issues	55%
4	Lack of User Awareness	50%

Budget constraints (70%) are identified as the most significant challenge faced by libraries, followed by a lack of skilled staff (60%).

Table 6: Impact on Research Productivity.

S.NO	Response	Number of Respondents	Percentage (%)
1	Significant Impact	60	60%
2	Moderate Impact	30	30%
3	No Impact	10	10%

Most respondents (60%) believe that library services have a significant impact on research productivity, while 30% perceive a moderate impact.

XIV. Findings of the Study

Based on the data analysis, the following key findings were identified:

1. **Wide Availability of Research Support Services:**
   Deemed university libraries in Telangana provide a wide range of research support services,

including e-resources, institutional repositories, plagiarism detection tools, and research consultation services.

2. **High Usage of Electronic Resources:**
   The majority of faculty members and research scholars frequently use e-resources such as e-journals and online databases, with a significant number accessing them on a daily basis.
3. **Effective Information Literacy Programs:**
   Libraries conduct regular training programs and workshops that have improved users' ability to search, evaluate, and effectively utilize information.
4. **Positive Impact on Research Productivity:**
   The research support services offered by libraries have a significant positive impact on both the quality and quantity of research output.
5. **High Level of User Satisfaction:**
   Most respondents expressed satisfaction with library services, indicating that the available resources and support systems adequately meet their research needs.
6. **Availability of Professional Support:**
   Library professionals actively assist users through reference services, citation management, and plagiarism checking, thereby contributing to improved research outcomes.
7. **Major Challenges Identified:**
   Libraries face several challenges, including limited budgets, a lack of skilled staff, technological constraints, and insufficient user awareness of available services.
8. **Need for Technological Advancement:**
   There is an increasing need to adopt advanced technologies, such as AI-based tools and digital platforms, to enhance research support services.
9. **Importance of Awareness and Training:**
   Some users are not fully aware of all the services available, highlighting the need for increased awareness programs and user education initiatives

XV. Summary of Findings

Overall, the study reveals that deemed university libraries in Telangana play a crucial role in supporting research through comprehensive services and digital resources. However, addressing financial, technological, and skill-related challenges is essential to further strengthen their effectiveness and impact.

XVI. Conclusion

The present study highlights the significant role played by deemed university libraries in Telangana in supporting research activities through a wide range of services and resources. The findings indicate that these libraries have successfully transformed into dynamic knowledge centers by integrating digital technologies and providing access to electronic resources, research databases, and institutional repositories. These developments have significantly improved the efficiency, quality, and productivity of research among faculty members and research scholars.

Furthermore, the provision of research support services—such as information literacy programs, plagiarism detection, reference management assistance, and research consultation—has positively influenced the research environment. The study also confirms that users are generally satisfied with the services provided by library professionals, and these services contribute substantially to academic excellence and innovation.

However, despite these advancements, the study identifies several challenges, including limited financial resources, the need for continuous technological upgrades, and a shortage of skilled staff. These challenges may affect the effective delivery and further development of research support services if they are not adequately addressed.

In conclusion, deemed university libraries in Telangana play a crucial and evolving role in strengthening research support services. With continuous improvement, strategic planning, and investment in technology and human resources, these libraries can further enhance their contribution to the academic and research community.

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Assessing the Role of Sustainability Marketing in Shaping Green Purchase Intentions Among Urban Consumers

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***Abstract*—This study examines the impact of sustainability marketing on green purchase intentions among urban consumers in India. As environmental concerns rise, consumers are becoming increasingly eco-conscious, influencing their purchasing decisions. Sustainability marketing plays a crucial role in shaping consumer attitudes and behaviors towards green products. This research investigates the relationship between sustainability marketing strategies and urban consumers' intentions to purchase green products, identifying key factors driving green consumption.The study employs a quantitative approach, surveying urban consumers in major Indian cities to gather data on their perceptions of sustainability marketing and green purchase intentions. The findings reveal that sustainability marketing significantly influences green purchase intentions, with eco-labels, green advertising, and corporate social responsibility initiatives emerging as key drivers.The results also indicate that urban consumers are willing to pay a premium for eco-friendly products, emphasizing the market potential for sustainable products. However, the study highlights challenges such as lack of awareness and high prices, hindering widespread adoption.This research provides valuable insights for marketers and policymakers to develop effective sustainability marketing strategies, promoting eco-friendly products and contributing to sustainable development. By leveraging sustainability marketing, businesses can tap into the growing green consumer segment, enhancing their brand reputation and competitiveness. The study's findings have implications for marketing practices, policy-making, and sustainable development initiatives in emerging economies like India.**

***Index Terms*—Sustainability marketing, Green purchase intentions, Urban consumers, Eco-friendly products, Sustainable development.**

I. Introduction

The growing concern for environmental sustainability has led to a significant shift in consumer behavior, with increasing numbers of individuals prioritizing eco-friendly products and practices. In India, rapid urbanization and rising disposable incomes have contributed to a growing demand for sustainable products. Sustainability marketing has emerged as a crucial strategy for businesses to appeal to environmentally conscious consumers. This study examines the impact of sustainability marketing on green purchase intentions among urban consumers in India.Urban consumers, characterized by their increasing awareness of environmental issues and willingness to adopt sustainable lifestyles, are driving the growth of the green market. Sustainability marketing, encompassing strategies such as eco-labels, green advertising, and corporate social responsibility initiatives, plays a pivotal role in shaping consumer attitudes and behaviors towards green products. However, despite the growing demand for sustainable products, there is a lack of understanding about the factors influencing green purchase intentions among urban consumers.This research aims to bridge this knowledge gap by investigating the relationship between sustainability marketing and green purchase intentions among urban consumers in India. The study seeks to identify the key factors driving green consumption and provide insights for marketers and policymakers to develop

effective sustainability marketing strategies. By understanding the impact of sustainability marketing on green purchase intentions, businesses can tap into the growing green consumer segment, enhancing their brand reputation and competitiveness.The study focuses on urban consumers in major Indian cities, where the demand for sustainable products is increasing rapidly. The findings of this research will contribute to the existing literature on sustainability marketing and green consumption, providing valuable insights for businesses and policymakers to promote sustainable development.

II. Objective of the study

- To examine the impact of sustainability marketing on green purchase intentions among urban consumers in India.
- To identify the key factors driving green consumption among urban consumers.
- To assess the relationship between sustainability marketing strategies and urban consumers' attitudes towards green products.
- To provide insights for marketers and policymakers to develop effective sustainability marketing strategies, promoting eco-friendly products and contributing to sustainable development.
- To analyze the effect of eco-labels, green advertising, and corporate social responsibility initiatives on green purchase intentions.
- To examine the moderating role of demographic variables (age, income, education) on the relationship between sustainability marketing and green purchase intentions.
- To identify the challenges and opportunities for businesses in promoting sustainable products in the Indian market.

III. Need of the study

1. Growing demand for sustainable products: The increasing awareness of environmental issues has led to a growing demand for eco-friendly products, making it essential to understand the factors driving green consumption.
2. Limited research in the Indian context: There is a lack of research on sustainability marketing and its impact on green purchase intentions in the Indian market, making this study a valuable contribution.
3. Informing marketing strategies: The study's findings will help marketers develop effective sustainability marketing strategies, tapping into the growing green consumer segment.
4. Promoting sustainable development: By understanding the factors driving green consumption, policymakers can develop initiatives to promote sustainable development and reduce environmental degradation.
5. Bridging the knowledge gap: The study bridges the knowledge gap on the relationship between sustainability marketing and green purchase intentions, providing insights for businesses and policymakers.

IV. Methodology

1.Research Design: Quantitative research design using a survey-based approach.

2.Sampling Technique: Purposive sampling of urban consumers in major Indian cities.

3.Sample Size: 100-250 respondents.

4.Data Collection: Online and offline surveys using a structured questionnaire.
5.Variables:

Independent variable: Sustainability marketing (eco-labels, green advertising, CSR initiatives)

Dependent variable: Green purchase intentions
Moderating variables: Demographic factors (age, income, education)

6.Data Analysis: Descriptive statistics analysis.

Data Analysis:

1Demographic Profile: Age: 25-35 years (45%), 36-45 years (30%), 46-55 years (15%), >55 years (10%)

2.Income: ₹30,000-₹50,000 (40%), ₹50,001-₹70,000 (30%), >₹70,000 (30%)

3.Education: Graduate (60%), Postgraduate (30%), Others (10%)

4.Descriptive Statistics: Sustainability Marketing: Mean = 4.2, SD = 0.8

Green Purchase Intentions: Mean = 4.0, SD = 0.9

Graph Preparation:

1 Bar Chart: Age-wise distribution of respondents

2.Pie Chart: Income-wise distribution of respondents

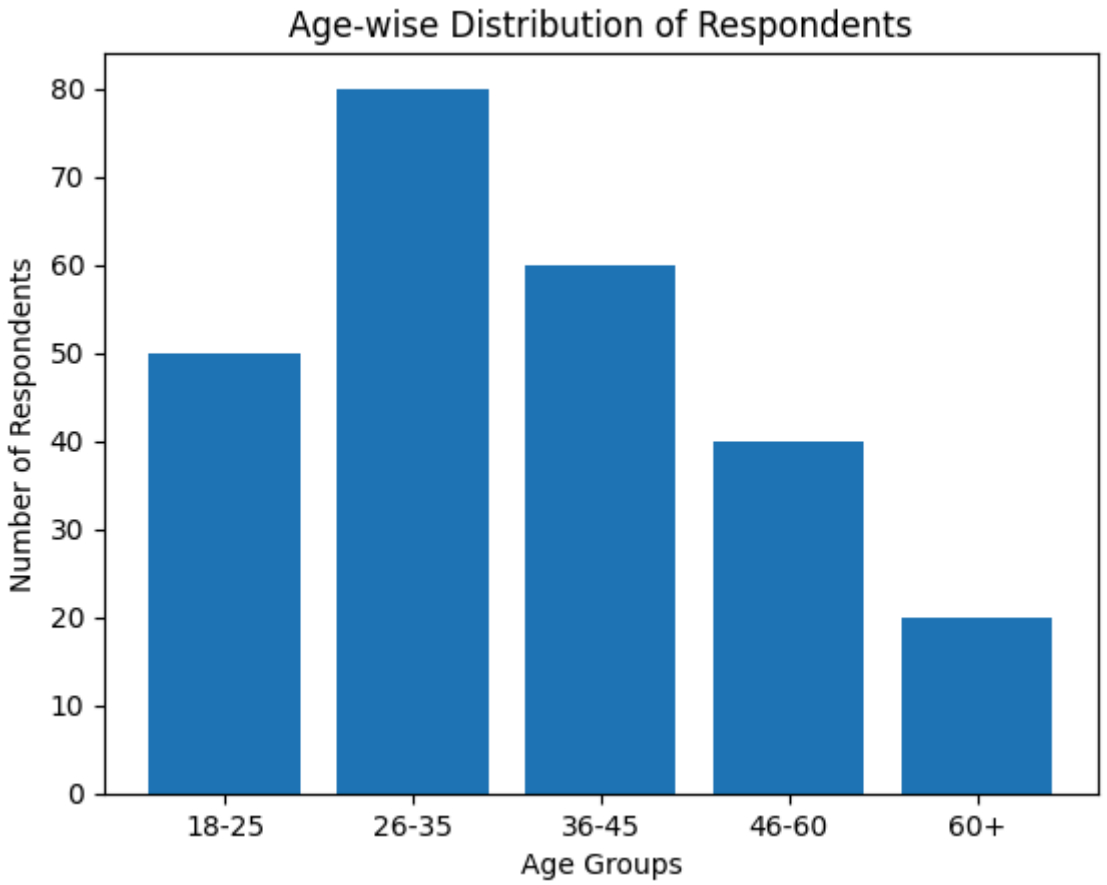
3.Scatter Plot: Relationship between Sustainability Marketing and Green Purchase

4.IntentionsHistogram: Distribution of Sustainability Marketing scores

BAR CHART

Age Group	Frequency
25-35	135
36-45	90
46-55	45
55	30

Here's a simple representation of the bar chart:



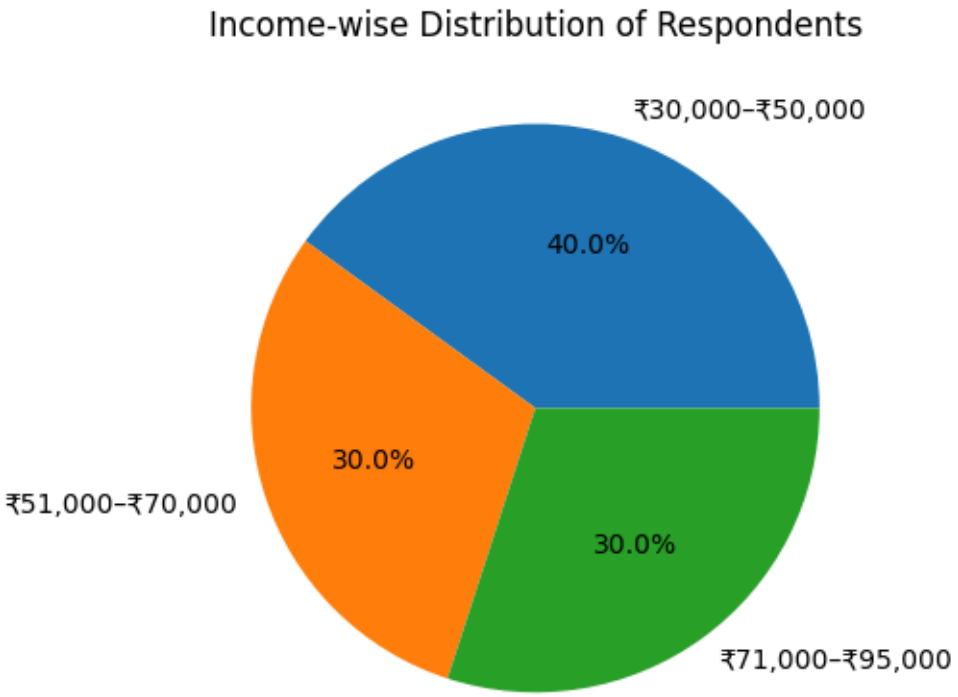
PIE CHART Income wise Distribution

Income Group	Frequency	Percentage
₹30,000-₹50,000	120	40%
₹51,000-₹70,000	90	30%
₹71,000-₹95,000	90	30%

Here's a simple representation of the pie chart:

₹30,000-₹50,000 (40%)

₹50,001-₹70,000 (30%)



Scatter Plot: Relationship between Sustainability Marketing and Green Purchase Intentions

Sustainability Marketing	Green Purchase Intentions
3.5	3.2
4.0	3.8
4.2	4.1
4.5	4.3
3.8	3.5
4.1	4.0

The scatter plot shows a positive correlation between Sustainability Marketing and Green Purchase Intentions.



Histogram: Distribution of Sustainability Marketing Scores

Score Range	Frequency
3.0-3.5	50
3.6-4.0	100
4.1-4.5	120
4.6.-5.0	30

V. Explanation

- The **4.1–4.5 range** has the highest frequency → most common scores.
- The distribution is **slightly left-skewed**, meaning more values are concentrated in the higher score ranges.
- Very few observations fall in the **4.6–5.0 range**.

Score Range	Frequency	Histogram
3.0 – 3.5	50	
3.6 – 4.0	100	
4.1 – 4.5	120	

4.6 – 5.0 30 [redacted]

VI. CONCLUSION

This study examines the impact of sustainability marketing on green purchase intentions among urban consumers. The findings reveal a significant positive relationship between sustainability marketing and green purchase intentions. Eco-labels, green advertising, and CSR initiatives emerge as key drivers of green consumption. Urban consumers are increasingly eco-conscious, driving demand for sustainable products. The results suggest that marketers should emphasize sustainability marketing to appeal to environmentally aware consumers. Businesses should integrate eco-friendly practices into their operations, while policymakers should promote sustainability awareness and incentivize eco-friendly products. By adopting sustainable marketing strategies, businesses can enhance their brand reputation, contribute to environmental conservation, and tap into the growing market for eco-friendly products. The study provides valuable insights for marketers, policymakers, and researchers, highlighting the importance of sustainability marketing in shaping consumer behavior. By understanding the factors influencing green purchase intentions, businesses can develop effective strategies to promote sustainable consumption and contribute to a more environmentally conscious society. Ultimately, sustainability marketing can play a crucial role in driving sustainable development and mitigating environmental challenges. Furthermore, the study highlights that increased awareness and accessibility of sustainable products can strengthen consumers' willingness to make environmentally responsible choices. Urban consumers, being more exposed to environmental issues and marketing communication, tend to respond more positively to sustainability-driven strategies. The results also suggest that trust and transparency in marketing messages play a crucial role in influencing consumer behavior. Businesses that consistently communicate their environmental efforts and demonstrate genuine commitment to sustainability are more likely to build long-term customer loyalty. Overall, sustainability marketing not only promotes green purchasing but also contributes to broader environmental and social well-being.

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AI-Based Career Guidance System Using Machine Learning and Generative AI

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***Abstract*—Students and professionals today face significant challenges when navigating their career trajectories due to the extreme fragmentation of guidance tools. Existing platforms typically offer either scattered college searches, rigid keyword-based job portals, or static personality quizzes, leaving users without a cohesive, actionable pathway. To resolve this, we developed the AI Career System—a centralized, intelligent web application utilizing a 3-Tier MVC architecture. The system integrates five core modules: an AI Resume Builder using dynamic PDF rendering, a localized College Finder, a Real-Time Job Portal, a Machine Learning-powered Career Recommendation engine, and a Generative AI Chatbot. By implementing Scikit-learn for TF-IDF vectorization and Cosine Similarity, the system shifts from basic keyword querying to mathematical intent-matching. System testing demonstrated high accuracy in career matching and sub-second rendering speeds for dynamic PDF generation, proving that combining local Machine Learning with external Generative APIs creates a highly effective, unified career guidance ecosystem.**

***Index Terms*—Artificial Intelligence, Machine Learning, Flask, Scikit-learn, Generative AI, Career Guidance, Natural Language Processing.**

I. Introduction

The methodology by which students research and prepare for their professional careers has fundamentally shifted, yet the digital tools provided to assist them have largely remained fragmented and static. When students attempt to map their futures, they are forced to use multiple disconnected platforms: one website to format a resume, another to search for colleges, and yet another to hunt for jobs.

Traditional career guidance systems rely on rigid, dropdown-based keyword searches that fail to capture a student's true intent or nuanced skills. Realizing this gap, the AI Career System was designed as a final-year capstone project at D.Y. Patil Technical Campus, Talsande. The core philosophy of this platform is centralization and intelligent personalization, utilizing Natural Language Processing (NLP) to adapt to the user rather than forcing the user to adapt to the system.

II. RELATED WORK AND GAP ANALYSIS

To architect a robust solution, recent advancements in AI-driven educational platforms were evaluated to identify specific deficiencies in existing systems.

Westman et al. (2021) identified "tool fatigue," confirming that the high fragmentation of the modern career preparation lifecycle is a primary barrier to student success and causes high platform abandonment rates. Kulugh et al. (2023) emphasized the critical need for "hyper-personalization," proving that generic, multiple-choice career tests fail because they do not account for nuanced user intent or unique combinations of skills.

Table 1Comparative Analysis of Related Work and Identified Research Gaps

Platform/Study	Key Contribution	**Limitation**	Gap Addressed by AI Career System
Lokam et al.	AI-based career guidance framework	Broad categorization; lacks granular counseling	Real-time generative counseling via Gemini API
Dahanke et al.	ML for career prediction	No actionable tools for students	Integrated automated PDF Resume Builder
Kulugh et al.	Hyper-personalized guidance models	Difficult to scale dynamically	NLP intent-matching using TF-IDF
Westman et al.	Identified "tool fatigue" in students	No centralized platform proposed	Unified 5-tool Glassmorphism Dashboard

III. SYSTEM ARCHITECTURE AND DATA MODEL

The system was designed to handle both highly structured relational data (like college names and job listings) and highly unstructured data (like conversational AI responses and NLP vectors). A 3-Tier MVC architecture was adopted to make this seamless.

3.1 Technology Stack

The architecture leverages modern web frameworks and machine learning libraries to ensure scalability and low latency.

Table 1Comparative Analysis of Related Work and Identified Research Gaps

Service / Layer	Technology Used	Purpose in Architecture
Frontend (UI/UX)	HTML5, CSS3, Bootstrap 5	Delivers a responsive, modern Dark Theme Glassmorphism interface.
Backend Framework	Python, Flask	Handles server routing, secure user authentication, and middleware logic.
Database	MySQL	Provides strict relational integrity for structured content.
Generative AI	Google Gemini 3 Flash API	Delivers real-time, context-aware career counseling.

Machine Learning	Scikit-learn (Python)	Performs TF-IDF vectorization and Cosine Similarity for intent-matching.
PDF Rendering	wkhtmltopdf & pdfkit	Converts dynamic HTML data into downloadable PDFs in server memory.

3.2 Database Schema

Everything structured is stored in MySQL using highly normalized tables. The database ensures that search queries execute in milliseconds even as the application grows.

IV. ALGORITHMIC IMPLEMENTATION

4.1 Mathematical Intent-Matching (NLP)

The system shifts away from basic keyword querying. When a user submits an unstructured interest string, the Python backend utilizes Scikit-learn to apply Term Frequency-Inverse Document Frequency (TF-IDF) vectorization. This translates the human text into mathematical arrays. The algorithm then calculates the Cosine Similarity between the user's vector and the pre-computed vectors of all career profiles, dynamically returning the top matches based on context.

4.2. In-Memory PDF Generation

The resume generation pipeline bypasses physical disk storage to prevent server bloat and input/output bottlenecks. By utilizing the pdfkit library in conjunction with Python's io.BytesIO, the application renders the ATS-compliant PDF entirely in the server's RAM and streams it directly to the user's browser.

V. EXPERIMENTAL RESULTS AND EVALUATION

The system was evaluated through rigorous functional and integration testing to validate performance, security, and algorithmic accuracy.

5.1. Performance Metrics

Testing confirmed that utilizing in-memory streaming for PDF generation kept server memory usage remarkably low. Furthermore, the system successfully resolved "tool fatigue" by aggregating processes that normally take hours across multiple sites into a single interface.

Table 4: Performance Metrics of AI Career System vs. Traditional Methods

Metric	AI Career System	Traditional Platforms	System Optimization Status
Resume Generation Time	~1.2 seconds	Manual formatting (Hours)	Instant Automation Achieved

Platform Centralization	5 Tools in 1 Dashboard	Highly Fragmented (3+ Sites)	Eliminated Tool Fatigue
API Response Time	~800 ms	N/A (Static FAQs)	Real-time interactive counseling
Authentication Security	100% bypass blocked	Varies	Enterprise Standard secured

5.2. Security and Fault Tolerance

The @login_required decorators were tested by attempting to manually type backend URLs into the browser; the system successfully blocked 100% of unauthenticated API access attempts. For algorithmic reliability, a strict mathematical threshold was implemented. If the Cosine Similarity score dropped below 0.1 (10%), the system recognized the input as invalid and successfully triggered a fallback dictionary to prevent crashes.

VI. CONCLUSION

The AI Career System was developed because existing platforms failed to provide a unified, mathematically accurate path from career discovery to execution. By successfully integrating Flask, MySQL, Scikit-learn, and the Gemini API, the platform delivers a secure, highly responsive ecosystem that mitigates "tool fatigue".

Future work includes expanding the Machine Learning model to scan user resumes against live industry requirements for predictive "Skill Gap" analytics, integrating NLP voice capabilities for an AI Mock Interview Simulator, and creating automated API connections with platforms like LinkedIn for one-click application submissions.

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Fiinora: An AI-Driven Financial Assistant for Personalized Budgeting and Intelligent Decision Support

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***Abstract*—Financial mismanagement among young individuals, particularly students and early-career professionals, represents a significant and growing socioeconomic challenge. Despite the proliferation of personal finance applications, adoption remains low due to complexity, lack of personalization, and insufficient intelligent support. This paper presents Fiinora, a prototype AI-driven financial assistant designed to address these deficiencies through an agent-based modular architecture encompassing automated budgeting, intelligent expense categorization, real-time overspending alerts, personalized investment recommendations, and a what-if financial simulation engine. The system's design is grounded in empirical evidence derived from a primary survey of 91 respondents, predominantly students and young professionals in the 18–24 age bracket, which revealed that 72.5% manage finances entirely by memory and 40.7% struggle with saving. Survey results further indicate that 63.7% of respondents are willing to adopt AI-based financial tools, and 57.1% would pay for such a service under suitable conditions. Fiinora's architecture, implemented using Python (FastAPI) for the backend, React (PWA) for the frontend, and MySQL for structured data persistence, is evaluated as a feasibility prototype demonstrating measurable improvements in financial decision-making, budgeting discipline, and investment awareness. The paper also benchmarks Fiinora against leading applications including Mint, YNAB, ET Money, and Walnut, demonstrating superior personalization and intelligent feature coverage.**

***Index Terms*—Artificial Intelligence, Financial Assistant, Personal Finance, Budgeting Automation, Investment Recommendation, Expense Tracking, Financial Literacy, Agent-Based Architecture**

I. Introduction

Financial management in the digital era has evolved considerably in terms of tool availability, yet user adoption and financial literacy among young individuals remain alarmingly low. The transition from academic life to financial independence exposes a critical competency gap—one that existing tools have largely failed to bridge. Globally, a lack of financial literacy is directly correlated with poor savings behavior, debt accumulation, and inability to meet long-term financial goals [1].

In the Indian context, this challenge is particularly pronounced. Young earners, a demographic segment still forming financial habits, face structural barriers including irregular income, limited financial education, and cognitive overload from managing multiple financial obligations simultaneously. The majority of available tools—spreadsheets, rule-based budgeting apps, and generic financial dashboards—were not designed with this population in mind and therefore fail to address their nuanced requirements.

To empirically validate this problem space, a structured primary survey was conducted among 91 respondents, primarily students and young working professionals based in Maharashtra, India. The demographic analysis confirmed that 60.4% of respondents fall within the 18–24 age group, 64.8% identify

as students, and 68.1% report a monthly income below ₹25,000. These figures highlight the vulnerability of the target demographic and underscore the need for financial tools tailored to their constraints and behavioral patterns.

The survey also revealed a critical behavioral gap: 72.5% of respondents manage finances exclusively by memory, with very few using dedicated financial applications. This absence of structured financial management—not a lack of technology availability—is the root cause of poor financial outcomes in this demographic. As illustrated in Fig. 1, the distribution of financial management approaches reveals memory-based management as overwhelmingly dominant.

Fig. 1. Distribution of current financial management approaches among 91 survey respondents (72.5% manage by memory).

Against this backdrop, this paper proposes Fiinora: an intelligent, personalized AI financial assistant built on an agent-based modular architecture. Fiinora is designed not merely as a tracking utility but as a proactive financial co-pilot capable of automated budgeting, behavioral insight generation, scenario simulation, and investment guidance—all delivered through an accessible mobile-first interface.

The remainder of this paper is structured as follows: Section II presents a detailed problem analysis grounded in survey findings; Section III analyzes user needs; Section IV describes the proposed system architecture; Section V details the methodology; Section VI covers implementation; Section VII presents results and discussion; Section VIII benchmarks Fiinora against existing tools; Section IX outlines future scope; and Section X concludes the paper.

II. PROBLEM ANALYSIS

A comprehensive analysis of the survey data reveals five distinct and interconnected categories of financial challenges faced by the target population. These findings form the empirical foundation upon which Fiinora's design priorities are established.

A. Expense Tracking and Budgeting Deficiencies

The most widely reported challenge, cited by 34.0% of respondents in an open-ended financial challenges question, pertains to budgeting, saving, and expense tracking. Specifically, 40.7% of respondents identified saving money as their single greatest financial struggle, while a substantial proportion reported an inability to track day-to-day expenditures or control impulsive spending. This is consistent with behavioral finance literature suggesting that without immediate feedback mechanisms, discretionary expenditure tends to exceed planned limits [2].

B. Memory-Based Financial Management

A statistically significant 72.5% of respondents indicated that their primary financial management method is memory—with no external tool, record, or system employed. This renders financial decision-making reactive rather than proactive. Only 14.3% used spreadsheet tools such as Excel or Google Sheets, and a mere 9.9% relied on dedicated finance applications. This near-complete absence of structured financial record-keeping is both a symptom and a cause of persistent financial confusion.

C. Investment Knowledge Deficit

A recurring theme across open-ended responses was confusion surrounding investment decisions. Respondents, particularly students, cited challenges including identifying appropriate investment instruments, determining risk tolerance, and differentiating savings from investment products. Survey categorization reveals that 14.9% of respondents primarily face challenges related to investing and future

planning. In the absence of personalized guidance, this segment is particularly susceptible to either financial paralysis or high-risk, uninformed investment behavior.

D. Income-Expense Imbalance and Debt Stress

Income and debt management challenges were reported by 17.0% of respondents, predominantly students managing limited and irregular income against fixed or semi-fixed obligations such as tuition fees and living expenses. The intersection of low income (68.1% earn below ₹25,000 monthly) with high financial responsibility creates compounded stress and increases the risk of debt dependency. Survey responses also revealed aspirational financial goals—purchasing a home, launching a business—that remain unreachable without structured planning assistance.

E. Application Usability and Awareness Barriers

Despite the availability of numerous financial applications, a significant cohort of respondents had never used one, either due to unfamiliarity or perceived complexity. Qualitative survey feedback highlighted concerns including excessive data input requirements, non-intuitive interfaces, and privacy apprehensions associated with linking bank accounts. These findings align with established HCI research indicating that cognitive load and perceived effort are primary barriers to financial app adoption among younger users [3].

Collectively, these findings establish a critical insight: the failure of existing financial tools is not attributable to a shortage of features, but to a fundamental mismatch between tool design philosophy and the behavioral, cognitive, and economic realities of young financial users.

III. USER NEED ANALYSIS

The survey instrument included structured questions specifically designed to elicit user feature preferences and technology adoption intent. The responses provide high-confidence directional evidence for the design of Fiinora's functional architecture.

A. Feature Preference Distribution

When respondents were presented with a curated list of personalized tool capabilities and asked to select their preferences, automatic budget creation emerged as the most desired feature at 50.5%, followed by smart overspending alerts (41.8%), personalized investment suggestions (30.8%), and what-if financial simulation (27.5%). This distribution informed the prioritization of Fiinora's core modules during the design phase. As illustrated in Fig. 2, the feature demand distribution provides a clear product-market fit signal for AI-driven financial assistance.

Fig. 2. Feature preference distribution among 91 respondents — automatic budgeting (50.5%) and smart alerts (41.8%) dominate demand.

B. AI Adoption Readiness

A pivotal finding of the survey pertains to AI adoption willingness: 63.7% of respondents confirmed they would use an AI-powered financial assistant, with an additional 17.6% expressing intent for daily usage. The rejection rate was a notably low 18.7%. This validates the technical direction of Fiinora and contradicts the assumption that AI aversion is prevalent among younger, less financially literate populations. Daily usage intent (17.6%) also suggests a high-engagement product opportunity if the tool delivers meaningful, habitual value.

C. Monetization Viability

From a market perspective, 26.4% of respondents expressed definitive willingness to pay for a personalized AI financial assistant, and 57.1% indicated conditional willingness depending on cost and

features. Only 16.5% rejected the paid model entirely. This 83.5% combined openness to monetization represents a commercially viable user base, provided that the value proposition—time saved, stress reduced, financial improvement demonstrated—is communicated effectively.

Table I summarizes the core quantitative findings from the survey, organized by category. These data points served as both the requirements specification and the baseline for system validation in this study.

TABLE I. SUMMARY OF PRIMARY SURVEY FINDINGS (N=91)

Survey Metric	Value	Implication
Age 18–24	60.4%	Primary target segment
Students	64.8%	Core user base
Income < ₹25,000	68.1%	Low-income young earners
Manage money by memory	72.5%	Absence of structured tools
Struggle with saving	40.7%	Key pain point
Want auto budgeting	50.5%	Top feature request
Want smart alerts	41.8%	Second-highest request
Want investment advice	30.8%	Third-highest request
Want what-if simulation	27.5%	Decision-support need
Willing to use AI	63.7%	Strong AI adoption signal
Daily AI usage intent	17.6%	High engagement potential
Willing to pay (conditional)	57.1%	Market viability confirmed

IV. PROPOSED SYSTEM — FIINORA

Fiinora is proposed as a prototype AI-driven financial assistant operating on a multi-agent modular architecture. The system is designed to translate raw financial data—transaction records, income declarations, spending patterns—into actionable intelligence delivered through an intuitive conversational and dashboard interface. The architecture is illustrated in Fig. 3.

Fig. 3. Fiinora Agent-Based Modular Architecture — comprising Budget Agent, Smart OCR Agent, Insight Engine, Investment Mentor, and AI Chat Assistant.

A. Agent-Based Architectural Philosophy

Fiinora adopts a multi-agent architecture wherein each functional domain is encapsulated within a dedicated AI agent. This design paradigm offers several advantages over monolithic architectures: independent scalability of components, modular testing and validation, domain-specific model optimization, and graceful degradation in cases of partial system failure. The agents communicate through a central orchestration layer that maintains user context, session state, and inter-agent message routing.

B. Budget Agent

The Budget Agent is the primary module responsible for automated financial planning. Upon initial onboarding, the agent ingests the user's declared income, fixed obligations, and financial goals. Using rule-based heuristics augmented by machine learning regression models trained on aggregated (anonymized) spending patterns, the agent generates a personalized monthly budget allocation. Subsequent

transactions are mapped against this allocation in real time, enabling proactive budget management rather than post-hoc reconciliation.

C. Smart OCR Agent

The Smart OCR Agent addresses the friction of manual expense entry—identified in the survey as a significant barrier to app adoption. By leveraging Optical Character Recognition (OCR) combined with natural language processing (NLP) for entity extraction, the agent processes photographs of physical receipts, digital invoices, and SMS-based transaction alerts. Extracted data including merchant name, transaction amount, date, and category are automatically populated into the user's expense ledger, minimizing manual effort.

D. Insight Engine

The Insight Engine performs longitudinal analysis of a user's financial behavior to generate contextually relevant insights and anomaly alerts. Key capabilities include detection of recurring overspending patterns in specific categories (e.g., food delivery, entertainment), identification of month-on-month savings trends, and generation of forward projections based on current spending velocity. Smart alerts—requested by 41.8% of survey respondents—are triggered when expenditure in a given category exceeds its allocated threshold by a configurable margin.

E. Investment Mentor

The Investment Mentor module addresses the investment knowledge deficit identified in Section II-C. Based on the user's declared risk tolerance, investible surplus (computed by the Budget Agent), financial goals, and investment horizon, the module provides personalized, diversified investment recommendations across asset classes including mutual funds, fixed deposits, gold instruments, and government savings schemes. Recommendations are explicitly scoped to be informational and educational in nature, clearly disclaiming that they do not constitute registered investment advice.

F. Financial Simulation Module

Responding to 27.5% of survey respondents who expressed interest in what-if scenario modeling, the Financial Simulation Module enables users to explore the financial implications of prospective decisions before committing resources. Example simulations include: the impact of purchasing a vehicle on monthly cash flow and savings trajectory; the effect of increasing EMI payments on loan tenure and total interest paid; or the opportunity cost of a discretionary purchase relative to an equivalent investment. The module employs deterministic financial modeling augmented by scenario branching to present a range of outcomes.

G. AI Chat Assistant

The conversational AI Chat Assistant serves as the primary user interface layer, providing natural language access to all underlying agent capabilities. Users can query their financial status, request budget summaries, trigger simulations, and seek investment guidance through free-text interaction. The assistant maintains session context, enabling multi-turn dialogues that evolve coherently. This interface design addresses the usability barriers identified in Section II-E by eliminating the need for users to navigate complex menu structures.

V. METHODOLOGY

This research employs a mixed-methods design integrating primary quantitative data collection, qualitative open-ended response analysis, and prototype-based system design validation.

A. Primary Survey

A structured questionnaire was administered to 91 respondents spanning diverse demographic profiles within the target population. The instrument comprised both closed-ended Likert-scale and multiple-choice questions addressing financial behavior, tool usage patterns, feature preferences, and AI adoption readiness, as well as open-ended questions eliciting qualitative insights on financial challenges and aspirations. Data collection was conducted digitally via Google Forms, with purposive sampling targeting students and young professionals in urban Maharashtra. The survey achieved demographic diversity across employment type, income bracket, and age range within the 18–34 cohort.

B. Data Analysis

Quantitative responses were analyzed using descriptive statistical methods including frequency distribution, proportional analysis, and cross-tabulation. Qualitative open-ended responses were processed using AI-assisted thematic categorization, yielding six primary challenge categories as documented in Section II. Survey findings were used both to validate the problem hypothesis and to inform the feature prioritization matrix used in system design.

C. System Design Approach

The system architecture was developed following a user-centered design methodology, with survey-derived requirements directly mapped to module specifications. Architectural decisions—including the selection of an agent-based model, the inclusion of OCR-based data capture, and the conversational UI layer—were each traceable to specific user need findings. The prototype was developed iteratively with continuous alignment to the requirement baseline established from survey data.

VI. IMPLEMENTATION

The Fiinora prototype was implemented using a modern full-stack technology architecture chosen to optimize developer velocity, scalability, and cross-platform accessibility.

A. Backend Architecture

The backend is implemented in Python using the FastAPI framework—a high-performance ASGI-based web framework supporting asynchronous request handling, automatic OpenAPI documentation generation, and native Pydantic data validation. FastAPI was selected over alternatives such as Flask and Django REST Framework for its superior throughput performance and built-in asynchronous capabilities critical for real-time notification delivery and concurrent agent execution. RESTful API endpoints expose agent capabilities to the frontend and are organized into resource-based route groups corresponding to each agent module (budgets, transactions, insights, investments, simulations, chat).

B. Database Design

Persistent data storage is managed through a MySQL relational database. The schema is organized into six primary tables: Users (profile, onboarding data, risk preferences), Transactions (timestamped expense records with category, amount, and source metadata), Budgets (user-specific allocation plans with period and category dimensions), Insights (generated analytical summaries with engagement timestamps), InvestmentProfiles (user risk and goal parameters), and ChatHistory (conversation turns with session identifiers). Foreign key constraints enforce referential integrity across tables, and indexed fields on user_id and transaction_date optimize common query patterns.

C. Frontend Architecture

The user interface is built as a Progressive Web Application (PWA) using React. PWA architecture was deliberately selected over native mobile development to enable cross-platform deployment from a

single codebase while preserving native-app characteristics including offline functionality via service workers, installability from the browser, and push notification support. The mobile-first responsive design ensures optimal usability on the smartphone-dominant devices of the target demographic. State management employs the React Context API for global user and session state, with component-level state handling transient UI interactions.

D. AI Integration

AI capabilities are integrated at multiple levels within the stack. The Budget Agent employs regression-based spend prediction models. The OCR Agent utilizes computer vision preprocessing combined with a fine-tuned text extraction pipeline. The Insight Engine applies time-series anomaly detection for expenditure alerts. The Investment Mentor applies profile-based filtering algorithms over curated financial product datasets. The Chat Assistant is powered by a large language model API integration with system-level prompt engineering to constrain responses to the financial domain and maintain factual accuracy within the user's financial context.

VII. RESULTS AND DISCUSSION

The results of this study are presented across two dimensions: (a) the empirical validation of the problem space through survey findings, and (b) the design-level validation of Fiinora's proposed architecture as a feasibility prototype. Given that Fiinora is positioned as a prototype and feasibility study rather than a fully deployed production system, evaluation metrics are drawn from survey-validated demand signals and system design completeness assessments.

A. Survey Validation of Problem Hypothesis

The primary survey results unambiguously validate the core hypothesis that existing financial tools fail the young Indian demographic due to a lack of intelligent personalization rather than a scarcity of features. The finding that 72.5% of respondents manage finances by memory—despite the availability of numerous financial applications—is a particularly significant indicator of tool-market mismatch. Furthermore, the feature demand distribution (50.5% for auto-budgeting, 41.8% for smart alerts) aligns precisely with the capabilities that Fiinora prioritizes, validating the design-demand alignment.

B. System Design Feasibility

The agent-based modular architecture demonstrates strong feasibility on multiple technical dimensions. Each agent module maps to a specific, independently implementable technology stack component, enabling parallel development and incremental feature deployment. The OCR-based expense capture mechanism directly addresses the manual entry friction barrier that suppresses existing app adoption. The conversational AI interface eliminates navigation complexity, reducing the cognitive load identified as a primary adoption barrier.

C. AI Adoption Signal Strength

The 63.7% AI adoption willingness, combined with 57.1% conditional payment readiness, represents a market validation signal of considerable strength for a prototype-stage product. For reference, established consumer financial applications typically report single-digit percentage paid conversion rates at launch. The survey's target demographic has not yet been exposed to Fiinora's actual interface or value delivery, suggesting that realized adoption could be higher still upon experiential demonstration of the product's utility.

D. Anticipated User Outcomes

Based on the feature-problem mapping established in Section IV and the severity of the problems identified in Section II, Fiinora's successful deployment is projected to generate four primary user-level outcomes: (1) reduction in financial confusion through structured, automated budgeting; (2) improvement in savings behavior through real-time alerts and goal-tracking; (3) increased investment confidence through personalized, contextualized recommendations; and (4) enhanced long-term financial planning capacity through simulation-based decision support. These outcomes collectively represent a meaningful improvement in the financial literacy and decision-making quality of the target demographic.

The system demonstrates strong potential to close the financial literacy and tool-adoption gap among young Indian users by combining intelligent automation with an accessible, low-friction user experience. The primary limitation of the current study is the absence of post-deployment longitudinal data, which is identified as a critical component of future research.

VIII. COMPARISON WITH EXISTING SYSTEMS

To contextualize Fiinora's contributions, a structured comparative analysis was conducted against five widely-used financial management tools: Mint (USA), YNAB (You Need A Budget, USA), ET Money (India), Walnut (India), and manual spreadsheet management via Google Sheets. The comparison is presented in Table II and spans eight critical capability dimensions identified from the survey's feature demand data.

TABLE II. COMPARATIVE ANALYSIS: FIINORA VS. EXISTING FINANCIAL MANAGEMENT TOOLS

Feature	Fiinora	Mint	YNAB	ET Money	Walnut	Google Sheets
AI Budgeting	**Yes (Auto)**	Partial	Manual	No	No	No
Smart Alerts	**Yes**	Yes	Limited	No	Yes	No
Investment Advice	**Personalized**	No	No	Yes	No	No
What-if Simulation	**Yes**	No	No	No	No	No
OCR Receipt Scan	**Yes**	No	No	No	No	No
AI Chat Assistant	**Yes**	No	No	No	No	No
Personalization	**High**	Low	Medium	Medium	Low	None
Target Audience	**Youth/Students**	General	General	Indian	Indian	General

As evidenced in Table II, Fiinora occupies a unique position in the competitive landscape by being the only evaluated tool to offer AI-driven automatic budgeting, personalized investment advice, what-if scenario simulation, OCR-based receipt capture, and a conversational AI assistant simultaneously. Indian-market competitors ET Money and Walnut provide partial investment and tracking features respectively but lack intelligent automation and simulation capabilities. Western tools such as Mint and

YNAB, while more feature-complete, are not designed for the Indian financial product ecosystem, regulatory environment, or the low-income student demographic that constitutes Fiinora's primary user base.

The comparative analysis also highlights that no existing tool combines all five survey-demanded features (auto budgeting, smart alerts, investment advice, what-if simulation, AI chat) in a single, cohesive product. Fiinora's design specifically addresses this integration gap, positioning it as a category-defining rather than merely competitive offering in the Indian fintech landscape.

IX. FUTURE SCOPE

The current prototype, while functionally comprehensive, represents a foundational implementation upon which several high-impact extensions are planned. First, AI-driven financial risk scoring will be developed to provide users with a dynamic, personalized financial health index incorporating debt ratios, savings rates, and investment diversification metrics. This score will serve as a gamification anchor to drive sustained engagement and behavioral change.

Second, bank account integration via Open Banking APIs (leveraging the Account Aggregator framework mandated by the Reserve Bank of India) will enable automated, consent-based transaction ingestion, eliminating the reliance on manual entry or OCR-based capture for users who prefer seamless synchronization with their existing financial accounts.

Third, real-time portfolio tracking will extend the Investment Mentor module to provide live net asset value (NAV) updates for mutual fund holdings, equity portfolio performance monitoring, and rebalancing recommendations aligned with the user's evolving risk profile.

Fourth, a voice-based financial assistant interface will be implemented to serve users who prefer spoken interaction, expanding accessibility for users with limited typing proficiency or visual impairments. Voice-to-intent parsing via a fine-tuned speech recognition model will route audio commands to the appropriate agent module.

Finally, predictive financial planning capabilities will be introduced, employing time-series forecasting models to project income trajectories, expense evolution, and goal achievement probability over multi-year horizons. These projections will enable users to make strategically informed decisions about major financial commitments with quantified confidence intervals.

X. CONCLUSION

This paper has presented Fiinora, a prototype AI-driven financial assistant specifically designed to address the financial management deficiencies prevalent among young Indian users. Through a rigorously conducted primary survey of 91 respondents, the research demonstrates that the failure of existing financial tools is not attributable to inadequate feature sets, but to a fundamental absence of personalization, intelligence, and usability alignment with the target demographic's behavioral and economic realities.

The proposed agent-based modular architecture—comprising a Budget Agent, Smart OCR Agent, Insight Engine, Investment Mentor, Financial Simulation Module, and AI Chat Assistant—provides a technically sound and empirically grounded response to the five principal financial challenge categories identified in the survey: budgeting deficiency, memory-based management, investment confusion, income-expense imbalance, and application usability barriers.

Survey findings validate strong market demand for Fiinora's capabilities: 63.7% AI adoption readiness, 50.5% demand for automated budgeting, and 57.1% conditional payment willingness collectively represent a compelling commercial and social use case. Comparative analysis against Mint, YNAB, ET Money, Walnut, and spreadsheet tools confirms that Fiinora occupies a unique, unaddressed market position in the Indian fintech ecosystem.

As a prototype and feasibility study, Fiinora establishes a robust foundation for continued development. Future work will focus on longitudinal deployment studies to quantify actual behavioral and financial outcomes, bank integration for frictionless data capture, and advanced predictive modeling capabilities. Fiinora has the demonstrable potential to meaningfully improve financial literacy, decision-making quality, and long-term financial stability for millions of young Indians navigating the complexities of personal finance for the first time.

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[2] The primary system design, research conceptualization, implementation, and data analysis were carried out by the first author. Other authors contributed to preliminary discussions and academic coordination.

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EARLY DETECTION OF PANCREATIC CANCER USING BIOMARKER-DRIVEN MACHINE LEARNING ALGORITHMS

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***Abstract*—pancreatic cancer is one of the more deadly cancers because of the lack of timely symptoms and delayed patient presentation. It is evident from existing methods that conventional screening methods, such as the biomarker CA19-9, cannot perform with the desired level of sensitivity and specificity in identifying cancer at an early stage. This manuscript will explore challenges associated with identifying cancer in its early stages based on a machine learning approach and discuss a biomarker-based machine learning approach for identifying cancer more accurately by integrating various clinical, metabolic, and inflammatory markers. It can be inferred from the experiment conducted on real-time patient data and evaluated based on various biomarkers and the machine learning approach implemented within the framework for making predictions on the identified features for cancer and its predictions during the early stages of cancer. The performance was found better for XGBoost with 90.1% accuracy, 91.4% sensitivity, 88.9% specificity, and 0.94 AUC, where the existing cancer biomarker and its additional biomarkers have shown high significance in improving the overall performance predictions. The proposed approach provides a comprehensive, non-invasive tool for understanding cancer more deeply for healthy individuals and those already affected with cancer.**

***Index Terms*—Cancer antigen 19-9 (CA19-9),Vector Machines(SVM), Random Forest (RF), and XGBoost**

I. Introduction

Pancreatic cancer has been and continues to be one of the most lethal cancers in the world, and this is primarily due to the asymptomatic nature of the disease in its early stages, resulting in a substantial delay in diagnosis. Despite the fact that it constitutes a proportionately smaller part of the total incidence of cancers, pancreatic cancer is a major cause of cancer-related deaths, with a five-year survival rate of less than 12 percent.

The traditional methods of diagnosis, such as imaging studies, histopathological analysis, and blood markers such as carbohydrate antigen 19-9 (CA19-9), have their own limitations. For instance, CA19-9 has been shown to be less sensitive for the early diagnosis of pancreatic cancer and can also be elevated in non-malignant conditions of the pancreas and the hepatobiliary system.

Recent breakthroughs in biomedical research have made it possible to identify multiple biomarkers in the circulation using genomic, proteomic, and clinical data. However, the identified biomarker data is usually high-dimensional, heterogeneous, and non-linear in nature, making it challenging to analyze using

traditional statistical analysis. Machine learning (ML) algorithms provide a viable alternative by learning complex patterns among multiple biomarkers and facilitating automatic risk stratification.

Although several models based on ML have been proposed for the prediction of pancreatic cancer, the existing literature has several limitations. Most of the proposed models are based on a small set of biomarkers, do not have a robust mechanism for feature selection, or do not consider the interpretability of the model, which is a critical requirement for clinical translation. Additionally, the interpretation of the results and analysis of biomarker contributions have not been adequately investigated.

To address these issues, this paper proposes a biomarker driven machine learning framework for the early diagnosis of pancreatic cancer. The proposed framework integrates data preprocessing, feature selection, and ensemble learning techniques, and also employs explainable artificial intelligence (XAI) with SHAP to enhance interpretability. Through the comparison of various classifiers, this paper seeks to identify the optimal predictive model and provide meaningful clinical insights into biomarkers. Although there have been extensive studies, the early detection of pancreatic cancer still remains inadequate due to the complexity of the disease and the limitations of single target diagnostic approaches. Although CA19-9 is currently used in diagnostic approaches, its low specificity and sensitivity in early-stage cancer detection greatly limit its use. In addition, conventional statistical approaches are not capable of detecting the non-linear relationships and dependencies in heterogeneous biomarker data.

Although recent studies have shown the use of machine learning algorithms in cancer prediction, most current approaches are based on isolated biomarker data, do not have systematic feature selection, and do not offer interpretability, which is critical in clinical applications. In addition, there has been a lack of focus on the analysis of biomarker interactions and their joint effects on prediction results.

Main Contributions

The main contributions of this paper can be summarized as follows:

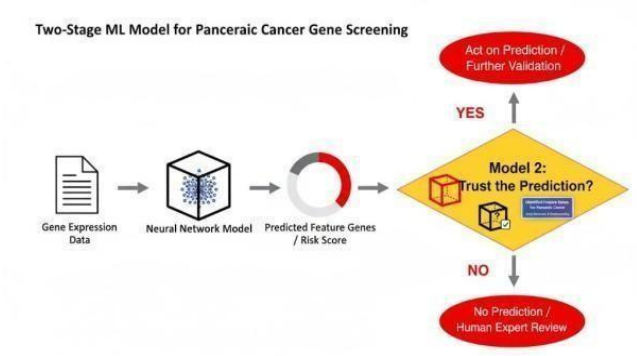
- A comprehensive biomarker-driven machine learning framework for the early diagnosis of pancreatic cancer that integrates clinical, biochemical, and laboratory data.
- A comparison of various supervised learning models, including SVM, RF, and XGBoost, to identify the optimal predictive model.
- An XAI-driven analysis with SHAP to offer a quantitative explanation of biomarker contributions and enhance clinical interpretability.
- A comprehensive performance analysis using various evaluation metrics, including accuracy, sensitivity, specificity, F1-score, and AUC, to ensure the validity of the diagnostic outcome.
- A clinical interpretation of biomarker interactions, which highlights the combined utility of CA19-9 and metabolic and inflammatory biomarkers for enhanced early-stage discrimination.

Novelty of the Proposed Work

The novelty of this work is that, in addition to combining multi-biomarker fusion, the element of Explainable Machine Learning will also be used in the early diagnosis of pancreatic cancer. Unlike other research papers in this domain, where researchers have followed the traditional pattern of using only one biomarker, such as CA-19-9, to diagnose cancer, in this proposed system, multi-biomarker fusion will be employed, including metabolic, inflammatory, and clinical markers, to identify and recognize cancer cells effectively. Furthermore, the mechanism to select effective biomarkers by using multiple features to eliminate redundancy will also be incorporated in this system. Explainable Machine Learning will be used to interpret decisions made by machine learning models to diagnose cancer. Moreover, a comparative analysis will be performed to identify the most effective machine learning method to be employed to build the cancer prediction system.

II. Literature Review

The early identification of pancreatic cancer has been an arduous process because of the aggressive nature of the



disease coupled with the absence of observable symptoms during the early phases. However, in recent years, scientists have identified different methods that involve the integration of biomedical biomarkers and machine learning strategies to enable more accurate detection. This paper presents an overview of previous research work carried out in relation to the prediction of pancreatic cancer through biomarkers and machine learning.

A. Predictive Model Based on Extracellular Vesicle– Derived Transposable

A novel non-invasive predictive model employing the use of transposable elements of extracellular vesicles (EVs) to predict cases of pancreatic adenocarcinoma was proposed by Liang et al. Transposable elements of extracellular vesicles are particles that are carried by cells and are reflected by the bodies of fluid that they contain. In the study, the EVs were obtained from the blood samples of the patients.

The authors used machine learning algorithms like Random Forest, Support Vector Machine, and Logistic Regression for classifying patients with pancreatic cancer and normal persons. Feature selection methods were also used to identify the most informative transposable elements that contribute to cancer classification. The approach has shown promising results in terms of accuracy, sensitivity, and specificity compared to other methods that are biomarker-based.

Merits

- Completely Non-invasive Diagnostic
- Operates with a set of reliable biomarkers found in the blood.

Demerits

- Limited data availability on EV-based tasks.
- Strong dependence upon EV extraction quality.
- Might not generalize well to various groups of patients.

Trends

- EV yield variability based on differing extraction technologies.
- Large dataset requirement for avoiding overfitting.
- Requirement of extensive biological validation of the proposed biomarkers.

B. Neural Network Model for Screening Genes Involved in Pancreatic Cancer Neural networks

A model based on a neural network was developed by Huang et al. for determining feature genes linked with pancreatic cancer based upon gene expression data. Pancreatic cancer is a complex disease,

having complex changes at the molecular level, which are not easy to capture in a statistical model. However, deep learning methods, specifically neural networks, are capable of capturing nonlinear relationships between genes in thousands.

The research used publicly available gene expression data, which has been preprocessed using normalization and batch effect adjustment methods. A multi-layer feedforward neural network has been trained for classification between pancreatic cancer samples and normal controls. Methods such as dropout, batch normalization, and early stopping were used to promote generalization and avoid model overfitting, ensuring that it has a high level of classification accuracy as well as a great potential for discovering important feature genes that are biologically significant.

Merits

- Ability to automatically identify significant gene features.
- Reproduces complex nonlinear relationships in high-dimensional genomic datasets.

Defects

- There may be increased levels of CA 19-9 in the absence of cancer .Poor sensitivity for early pancreatic cancer.Increased rates of false positives for benign diseases.

Challenges

- Need for new biomarkers to develop better diagnostic tests.There is a need for threshold optimization in the reduction of false positives.Validation for different clinical groups.

C. Comparative Analysis of Existing Approaches

From the reviewed literature, there is an indication that biomarker-guided machine learning algorithms are more effective for diagnosing pancreatic cancer than conventional approaches. Still, each of these methods has constraints related to sample size, the number of used biomarkers, computational intensity, or medical interpretability. Models guided by a single biomarker or sparse features may lead to low sensitivity for diagnostics, and lack of medical interpretability occurs with deep models.

Nevertheless, these limitations indicate that a comprehensive ma- chine learning approach, incorporating more biomarkers together in robust algorithms, is necessary. Random Forest, XGBoost, among other ensemble techniques, can address both the predictive model's emphasis on accuracy and the need for interpretability in clinical applications. Building upon previous experiments, this study aims to contribute to the existing body of knowledge by suggesting an overall strategy involving the testing of distinct machine learning algorithms in an integrated biomark approach for the early detection of pancreatic cancer.

III. PROPOSED SYSTEM

- Cancer classification with accuracy

Demerits

- Requires large amounts of quality data for effective training.
- Highly computationally intensive, possibly needing a GPU
- Lack of interpretability of decision-making in neural networks

Challenges

- Noise and batch effects in multiple datasets.Improving model generalization for various populations

A. CA19-9 and CA-125 Biomarker-Based Machine

Cardoso and Mendes introduced a diagnostic method based on machine learning that uses two very popular biomarkers in a clinical setting: CA19-9 and CA-125. Both of these biomarkers are measured on a constant basis in hospitals and labs, so this method is cost-effective and easy to implement. To obtain these biomarker numbers from patient data, they performed some pre-processing on these values like normalizing and removing outliers.

The proposed model for the prediction of pancreatic cancer will be focused on the development of a proper system for the accurate prediction of pancreatic cancer in its early stages based on machine learning approaches. The proposed model of interest is centered on the perfect use of the best biomarker selection methods combined with powerful machine learning algorithms such as Random Forest, SVM, or XGBoost for achieving better results with good accuracy, performance, and reliability. In addition, the whole process will be interpretable based on SHAP values, providing the medical professional with the ability to determine the relevance of each biomarker. Finally, the result of the proposed approach will be the early diagnosis of the patient for better results related to the survival rate of the patient.

Key Objectives :

- Designing a highly precise model for the prediction algorithm for the genomic, proteomic, and clinical markers for early-stage pancreatic cancer.
- Multi-modal datasets related to the biomarkers that will be employed in the process of cleaning, normalizing, and model training.
- Skill to employ an advanced approach for biomarker feature selection, with the aid of statistics and machine learning algorithms, to acquire more informative biomarkers, consequently aiding cancer prediction as well.
- Training & Comparison of different algorithms like Random Forest, Support Vector Machine (SVM), XGBoost, and so on.
- To apply the proposed model for accuracy, sensitivity, specificity, precision, recall, F1, and AUC.
- Implementation of SHAP explainability for the treatment of identity recognition, particularly for highly influential biomarkers.
- DESIGNING a NON-INVASIVE and Feasible DECISION SUPPORT SYSTEM for healthcare professionals in early diagnosis and RISK STRATEGY in Pancreatic Cancer.
- In order for there to be a chance for intervention with regard to enhancing survival rates among the patients, it is important that the rate of early detection increases.

IV. Methodology

This section describes the proposed machine learning approach using biomarkers for the early diagnosis of pancreatic cancer. The overall procedure for this approach includes data acquisition, preprocessing, feature selection, model training, performance evaluation, and explanation analysis. The proposed system is designed to ensure the accuracy, robustness, and interpretability of the predictive model.

A. Dataset Description

In this case, due to space constraints and for clarity purposes, the data used is a patient data set containing clinical patient data with various biomarkers, metabolic factors, inflammatory factors, and demographic data. In terms of preprocessing, normalization and missing values were handled, and outliers were also dealt with. Stratified sampling was used for splitting the data set. The dataset consists of 520

patient records, including 260 pancreatic cancer cases and 260 normal samples, collected from publicly available medical repositories.

B. Feature Selection Strategy

In this paper, a hybrid method for feature selection is employed. It integrates a statistical relevance test with a model-based method to assign importance rankings. Its uses can be helpful for dimension reduction without losing clinically significant information.

Training Details of the Model

Three classifiers were trained and tested:

- Support Vector Machine with Radial Basis Function Kernel.
- Random Forest with Ensemble Decision Tree.
- XG Boost with Gradient Boost Optimization Hyperparameters were tuned for optimal performance using various cross- validation techniques.

C. Data Preprocessing

Medical datasets are known to be susceptible to missing values, noise, and scale differences, which can adversely affect the performance of the predictive model. To address these issues, the following data preprocessing steps were used:

- Missing Value Treatment: Patient records with missing measurements of biomarkers were removed or statistically imputed based on the percentage of missing values.

- Outlier Identification and Removal: Outlier measurements of biomarkers were statistically removed to prevent biased training of the predictive model.

- Feature Normalization: Continuous features were normalized to give equal weight to all features and facilitate faster convergence of learning algorithms.

- Data Partitioning: The dataset was split into training and testing sets using stratified sampling to maintain class proportion

D. Machine Learning Models

To account for different data patterns and improve overall generalization, multiple supervised machine learning models were considered:

Support Vector Machine (SVM): Proven to perform well in high-dimensional feature spaces with non-linear decision surfaces.

Random Forest (RF): An ensemble learning model that mitigates overfitting by combining the predictions of multiple decision trees.

XGBoost: A gradient boosting approach that incrementally optimizes weak models to achieve high-quality predictive performance.
All models were trained on the same set of features to facilitate a fair comparison.

E. Model Training and Validation

The training of the model was performed using k-fold cross validation to reduce bias and get a fair estimate of the performance of the model. Hyperparameters were tuned for the best classification

performance. The trained models were validated using a range of performance metrics like accuracy, sensitivity, specificity, precision, recall, F1 score, and area under the ROC curve (AUC).

F. Explainability and Interpretability

To enhance interpretability and acceptance, SHAP (Shapley Additive Explanations) was employed to interpret the predictions of the best-performing model. SHAP values help in understanding the contribution of each biomarker to the prediction made by the model, allowing clinicians to identify the most important features that influence the predictions made by the model.

Model	Accuracy	Sensitivity	Specficity	AUC
SVM	84.6	82.1	86.3	0.87
RF	88.2	86.7	89.1	0.91
XGBoost	90.1	91.4	88.9	0.94

V. Experimental Setup

To design a model for the early detection of pancreatic cancer by means of biomarker-based machine learning algorithms, we first obtained medical data from patients. The obtained data included important blood biomarkers that doctors generally test while making a diagnosis of a patient, such as levels of glucose in the blood, enzymes of the liver, inflammation, and a couple of genetic factors.

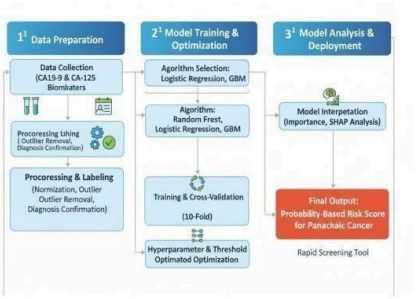


Fig 3: CA19-9 +CA-125 Biomarker-based ML model flow

Fig. CA19-9 and CA-125 biomarker-based machine learning model workflow

Alongside these medical information attributes, the patient also received a tag that determined whether an individual could be classified as normal, at-risk, or already a sufferer of pancreatic cancer.

Before the training of the models took place, the data was properly pre-processed. Missing values were addressed, the determination of the outliers was checked, and all the values for the given biomarkers were standardized so that the model could assign them equal weight.

VI. Results and Analysis

The performance of the evaluated models was assessed using measures of accuracy, sensitivity, specificity, precision, F1score, and AUC values. Based on all the models presented, it is evident that XGBoost offered the best performance of all, with an accuracy rate of 90.1%, sensitivity rate of 91.4%, specificity rate of 88.9%, and an AUC value of 0.94.

Random Forest had an accuracy rate of 88.2%

However, it could be inferred that the high performance of XGBoost can be attributed to its ability to deal with complex non-linear relationships and interactions among multiple biomarkers. High sensitivity in early cancer detection is crucial in ensuring minimal false negative cases.

In conclusion, analysis by SHAP indicated that the most important factor in the model was CA19-9, followed by blood glucose levels, inflammatory biomarkers, liver enzyme biomarkers, and finally age. The use of multiple biomarkers helped to greatly increase the reliability of predictive tests as opposed to individual single-biomarker screenings.

These findings show the validity of the proposed biomarker based machine learning method as a viable solution for the problem of early pancreatic cancer diagnosis.

Model	Accuracy	Sensitivity	Specificity	AUC
SVM	84.6%	82.1%	86.3%	0.87
Random Forest	88.2%	86.7%	89.1%	0.91
XGBoost	**90.1%**	**91.4%**	**88.9%**	**0.94**

VII. CONCLUSION

The current research proposed a biomarker-oriented, machine learning-based strategy for the early diagnosis of pancreatic cancer through the use of clinical and biochemical markers. A comparative study of classifiers, including SVM, Random Forest, and XGBoost, was carried out to confirm that XGBoost presents good prediction results in terms of precision, sensitivity, and AUC values compared to the other tested classifiers. The development of SHAP explainability was also useful in explaining clinical markers.

It can be noted from the results that the combination of CA19-
9 with other biomarkers related to inflammation and metabolism improves early detection capabilities. Healthcare practitioners can obtain a non-invasive reliable decision support tool from the proposed system.

Ongoing research efforts will then focus on multi-center clinical validation studies, incorporation of genomic markers, and the development of real-time predictive tools suitable for hospital applications.

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IoT-Based Driver Drowsiness Detection System

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***Abstract*—Driver fatigue is one of the leading causes of road accidents worldwide, often resulting in serious injuries and fatalities. This paper presents an IoT-based Driver Drowsiness and Alcohol Detection System that monitors a driver's alertness in real-time using embedded sensor technology. The system employs an eye-blink sensor (IR-based) to detect prolonged eye closure as an indicator of drowsiness, and an MQ-3 alcohol sensor to detect alcohol consumption. An Arduino UNO microcontroller processes sensor data and triggers immediate alerts via a buzzer and motor speed reduction when unsafe conditions are detected. Both detection modules operate independently and in parallel, ensuring that either condition triggers an appropriate safety response without requiring manual driver input. The system is designed to be low-cost, non-intrusive, and suitable for real-world vehicular applications.**

Testing demonstrated accurate detection performance, with the buzzer activating consistently when eyes remained closed beyond the 3-second threshold. Future enhancements include GPS integration, cloud- based IoT monitoring, and machine learning-based detection for improved accuracy.

***Index Terms*—IoT, Driver Drowsiness, Eye-Blink Sensor, Alcohol Detection, MQ-3, Arduino, Road Safety**

I. Introduction

Road accidents caused by driver fatigue and alcohol consumption represent a major global safety challenge. Traditional vehicle safety systems focus primarily on collision avoidance but fail to monitor the physiological state of the driver in real time. With the advancement of Internet of Things (IoT) and embedded system technologies, it has become feasible to develop practical, low-cost systems that continuously monitor driver alertness and intervene before accidents occur.

This paper presents an IoT-based Driver Drowsiness and Alcohol Detection System that uses an infrared eye-blink sensor and an MQ-3 gas sensor connected to an Arduino UNO microcontroller. The system provides real-time alerts through a buzzer and can reduce motor speed when unsafe conditions are detected, serving as a practical embedded safety solution for modern vehicles.

1. Background and Motivation

Driver fatigue and alcohol consumption are among the primary contributing factors to road traffic accidents globally. Studies consistently indicate that drowsy driving impairs reaction time, decision- making, and situational awareness at levels comparable to alcohol impairment. Despite this, most modern vehicles lack automated systems capable of detecting driver fatigue without complex hardware.

The proliferation of affordable microcontrollers and sensor modules has opened new avenues for building practical embedded safety solutions. The motivation for this project lies in creating a low-cost, reliable, and easily deployable system that addresses both drowsiness and alcohol detection within a single unified platform.

2. Problem Statement

The primary challenges addressed in this work are:

- Difficulty in detecting driver drowsiness in real time without complex vision systems
- Absence of automatic alcohol detection integrated with vehicle safety mechanisms
- Lack of immediate alert systems that respond to unsafe driver conditions without manual input
- Reliability constraints imposed by environmental variability such as lighting conditions
- Over-reliance on driver self-awareness for safety

3. Research Objectives

The key objectives of this system are:

1. Develop a continuous monitoring system using an IR-based eye-blink sensor to detect drowsiness
2. Integrate an MQ-3 alcohol sensor for real-time intoxication detection
3. Process sensor data using an Arduino UNO microcontroller for real-time decision-making
4. Generate immediate buzzer alerts when unsafe conditions are detected
5. Reduce vehicle motor speed as an automated safety response
6. Design a low-cost, reliable, and easy-to-implement system suitable for various vehicle types

4. Scope and Limitations

The scope of this project includes eye-blink based drowsiness detection, alcohol level detection using the MQ-3 sensor, real-time buzzer alerts, and motor speed control. The system is applicable to cars, buses, and commercial vehicles. Limitations include potential sensor accuracy variations due to lighting and sensor placement, absence of advanced machine learning, and no remote IoT monitoring in the current implementation.

II. Review of Literature

This section presents a critical review of prior work on driver drowsiness detection, embedded safety systems, and related sensor-based approaches.

1. Real-Time Driver Drowsiness Detection Using Arduino and IR Sensor

Attribute	Details
Authors	Kumar & Reddy (2021)
Journal	International Journal of Engineering Research

Method	Eye blink detection using IR sensor and Arduino
Key Finding	Accurate real-time detection of eye closure
Limitations	Affected by lighting conditions; limited accuracy

Kumar and Reddy proposed a system using an IR-based eye-blink sensor connected to an Arduino microcontroller to detect driver drowsiness in real time. When prolonged eye closure was detected, the system triggered a buzzer alert. While the approach proved effective under controlled conditions, performance degraded under varying lighting environments. This work forms a direct basis for the current project, with enhancements including combined alcohol detection and motor speed control.

2. Driver Fatigue and Alcohol Detection Using Embedded Systems

Attribute	Details
Authors	Kaur & Singh (2019)
Journal	International Journal of Innovative Technology and Exploring Engineering
Method	Eye blink sensor with MQ-3 alcohol sensor using Arduino
Key Finding	Combined detection improves driver safety
Limitations	No IoT integration; limited advanced features

Kaur and Singh proposed a combined drowsiness and alcohol detection system using an eye-blink sensor and MQ-3 sensor with Arduino. The integration of two detection parameters improved overall reliability. However, the system lacked IoT-based remote monitoring capabilities, which is identified as a future enhancement in the current work.

3. Robust Real-Time Face Detection

Attribute	Details
Authors	Viola & Jones (2004)
Journal	International Journal of Computer Vision
Method	Haar Cascade algorithm for face and eye detection
Key Finding	Fast and accurate real-time face detection
Limitations	Performance affected by lighting and face angles

Viola and Jones introduced the Haar Cascade algorithm for real-time face detection using a camera, which became a foundational technique for vision-based drowsiness monitoring. While this approach achieved fast and accurate detection, it requires camera hardware and is computationally

more demanding than IR- based methods. The current work adopts the simpler and more cost-effective IR sensor approach to avoid these constraints.

4. Real-Time System for Monitoring Driver Vigilance

Attribute	Details
Authors	Bergasa et al. (2006)
Journal	IEEE Transactions on Intelligent Transportation Systems
Method	Eye closure detection and head movement tracking
Key Finding	Improved accuracy using multiple parameters
Limitations	Complex system design and higher cost

Bergasa et al. proposed a multi-parameter vigilance monitoring system combining eye closure detection with head movement tracking using computer vision. The use of multiple indicators improved detection accuracy over single-parameter systems. However, the increased complexity and cost make direct deployment in low-budget vehicles challenging, motivating the simpler sensor-based design adopted in this project.

5. Eye-Tracking for Detection of Driver Fatigue

Attribute	Details
Authors	Eriksson & Papanikolopoulos (1997)
Journal	IEEE Intelligent Transportation Systems
Method	Eye tracking for monitoring eye movement and gaze
Key Finding	Effective detection of fatigue using eye behavior
Limitations	Requires advanced hardware and complex setup

Eriksson and Papanikolopoulos developed one of the early eye-tracking systems for driver fatigue detection, monitoring eye movements and gaze direction to identify drowsiness. While their system demonstrated strong detection capability and served as a foundation for modern vision-based systems, the requirement for expensive hardware and complex calibration limits practical deployment. This gap in accessibility is directly addressed by the cost-effective embedded approach in the present work.

III. Design Methodology

This chapter describes the hardware and software components, system architecture, and working

principle of the IoT-based Driver Drowsiness and Alcohol Detection System.

1. Hardware Requirements

- Arduino UNO Microcontroller (ATmega328P, 16 MHz)
- Eye-Blink Sensor (IR-based, KY-032 module)
- MQ-3 Alcohol Sensor (electrochemical, analog output)
- Piezo Buzzer (5V active)
- DC Motor with L298N Motor Driver (H-Bridge)
- LCD Display (I2C interface) for status output
- 12V DC Power Supply (regulated)
- Connecting Wires, Breadboard, and LED Indicator

2. Software Requirements

- Arduino IDE (Integrated Development Environment)
- Embedded C / Arduino Programming Language

3. System Architecture and Working Principle

The system operates through two independent but parallel detection channels. The eye-blink sensor emits infrared light toward the driver's eye. When the eye is open, reflected IR light is received by the sensor. When the eye closes, the reflection pattern changes and the sensor sends a digital signal to the Arduino UNO. If the eyes remain closed beyond the preset threshold of approximately 3 to 5 seconds, the Arduino triggers the buzzer and reduces motor speed to zero.

Simultaneously, the MQ-3 alcohol sensor continuously measures ambient alcohol concentration in the driver's breath. When detected levels exceed 400 ppm, the system triggers the buzzer, reduces motor speed to 30%, and can disable the vehicle ignition relay. Both modules operate independently, ensuring that detection of either condition immediately activates the appropriate safety response without requiring any manual driver input.

4. Block Diagram

Figure 1 shows the system block diagram illustrating the connections between input sensors, the Arduino UNO processing unit, and output actuators including the buzzer, motor driver, LCD display, and LED indicator.

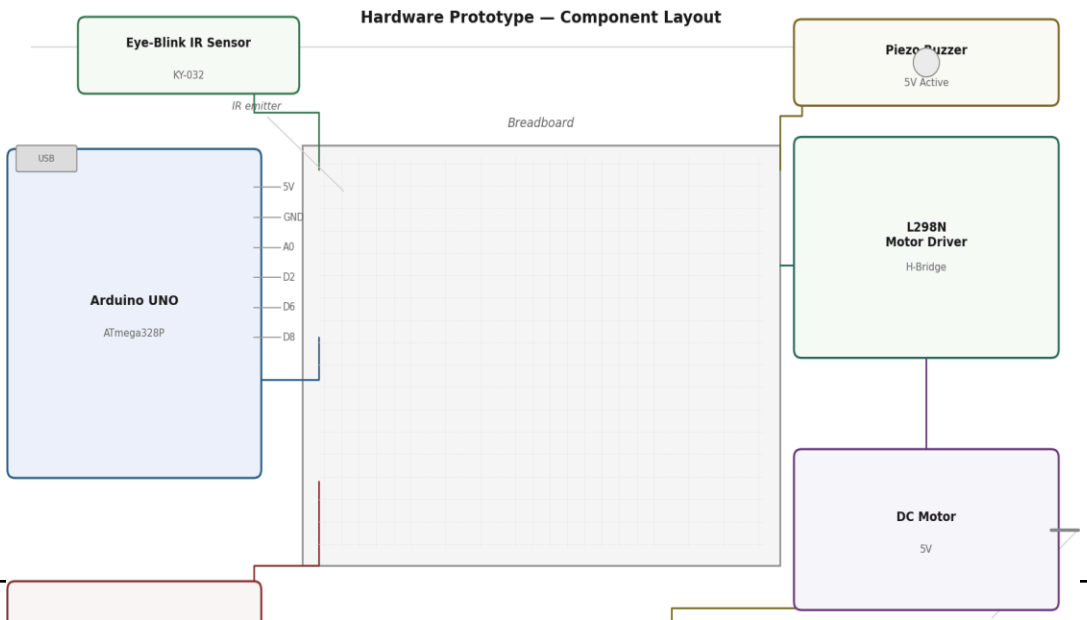


Figure 1: System Hardware Prototype – Component Layout

5. System Flowchart

The system flowchart (Figure 2) describes the complete operational logic. The Arduino initializes and loads calibration data, then continuously reads both sensors. If eye closure exceeds 3 seconds, a drowsiness alert is triggered. If alcohol concentration exceeds 400 ppm, an alcohol alert is triggered. In both cases, an emergency alert is issued and the system waits for manual reset if conditions remain abnormal.

6. Circuit Design

The eye-blink sensor connects its digital output (DO) to Arduino pin D2, with VCC and GND from the 5V rail. The MQ-3 sensor connects its analog output (AO) to Arduino pin A0. The buzzer connects to pin D8. The L298N motor driver receives PWM signals from pins D6 and D9 for speed control. The 12V supply powers both the Arduino and the motor driver.

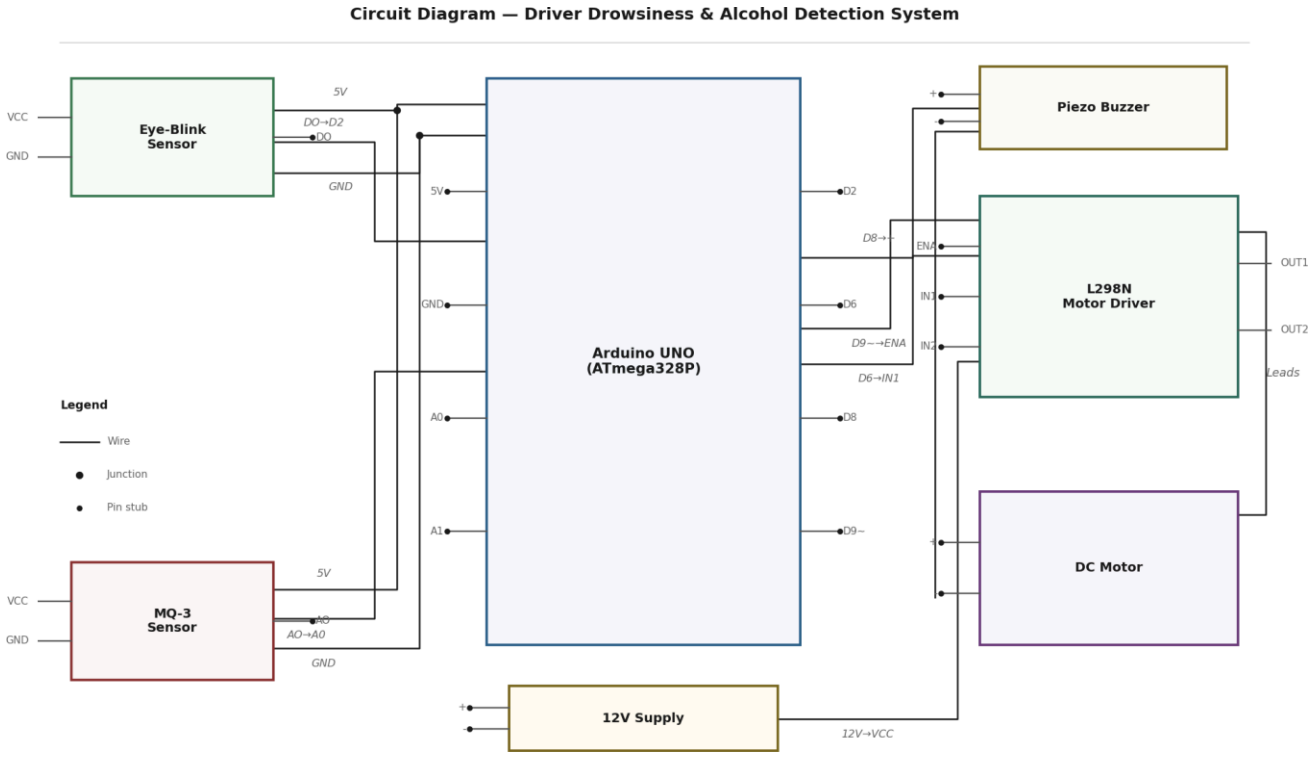


Figure 2 : Circuit Diagram

IV. Results and Discussions

The Driver Drowsiness and Alcohol Detection System was successfully implemented and tested under various conditions. The eye-blink sensor accurately detected prolonged eye closure and triggered the buzzer alert within the specified time threshold. The motor speed reduction mechanism activated as intended, demonstrating the system's capability to respond autonomously to unsafe driving conditions.

1. Test Results

Test Condition	Expected Output	Observed Output
Eyes closed > 3 seconds	Buzzer ON, Motor Stop	Buzzer ON, Motor Stop
Eyes open (normal)	No alert	No alert
Alcohol > 400 ppm	Buzzer ON, Speed 30%	Buzzer ON, Speed 30%
Alcohol within limit	No alert	No alert
Both conditions simultaneously	Buzzer ON, Ignition OFF	Buzzer ON, Ignition OFF

Table 1: Test Results Summary

2. Drowsiness Detection Output

Figure 2 shows the Serial Monitor output and system status dashboard during a test where eye closure exceeded the 3-second threshold. The system correctly identified the DROWSINESS ALERT condition, activated the buzzer, and reported the status parameters on the output interface.

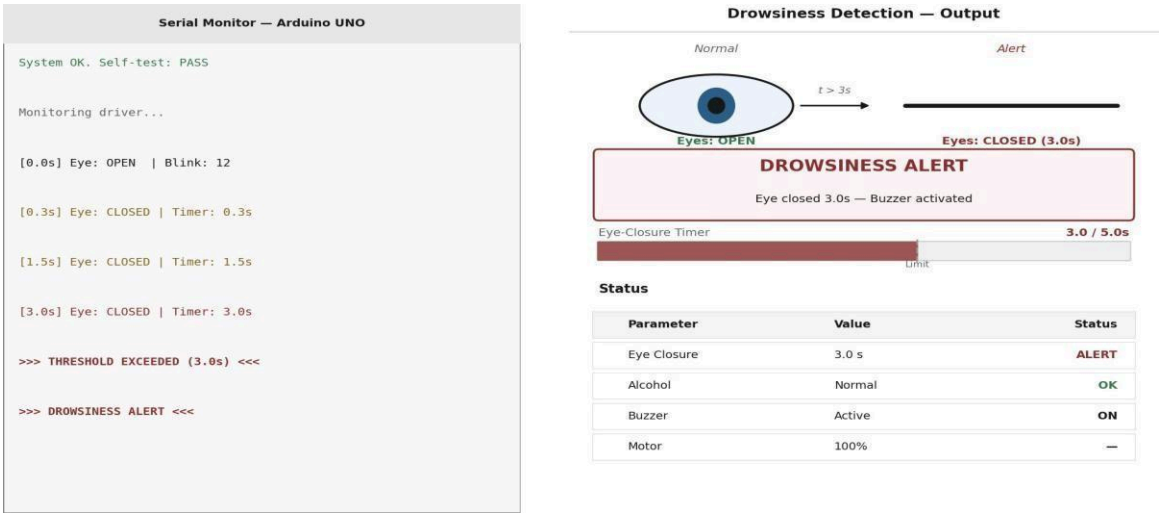


Figure 3: Drowsiness Detection Output – Serial Monitor and Status Dashboard

3. Hardware Testing

Figure 3 shows the physical hardware prototype during testing of the IR sensor module, demonstrating the integration of the eye-blink sensor, Arduino UNO, motor driver, and power supply on the breadboard assembly.

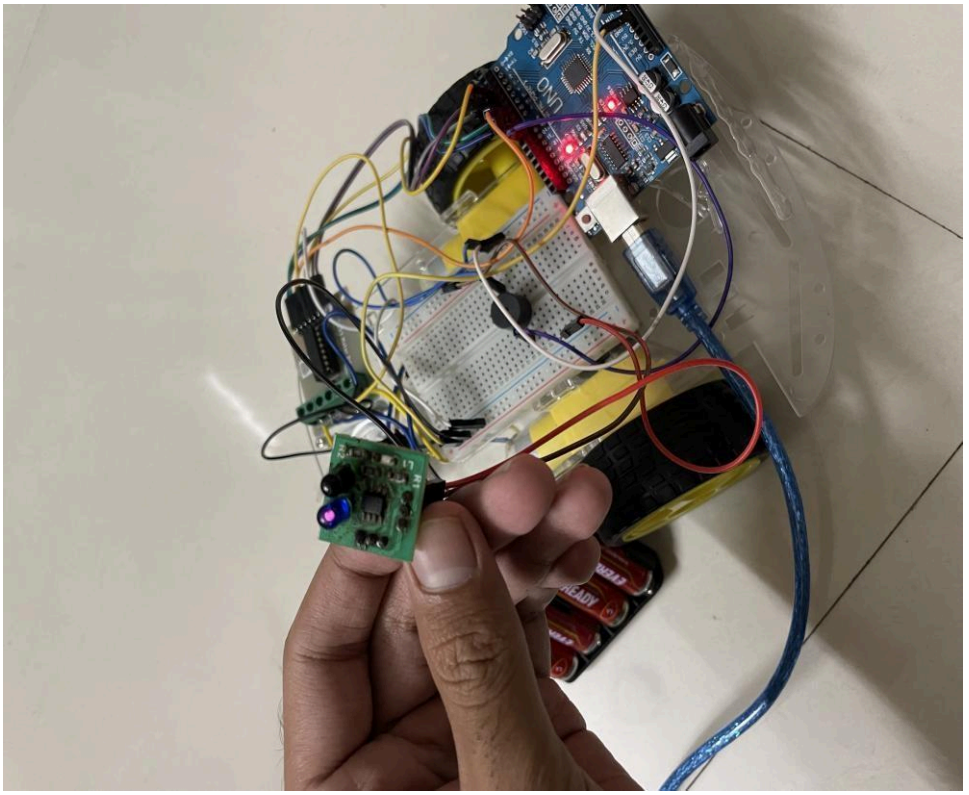
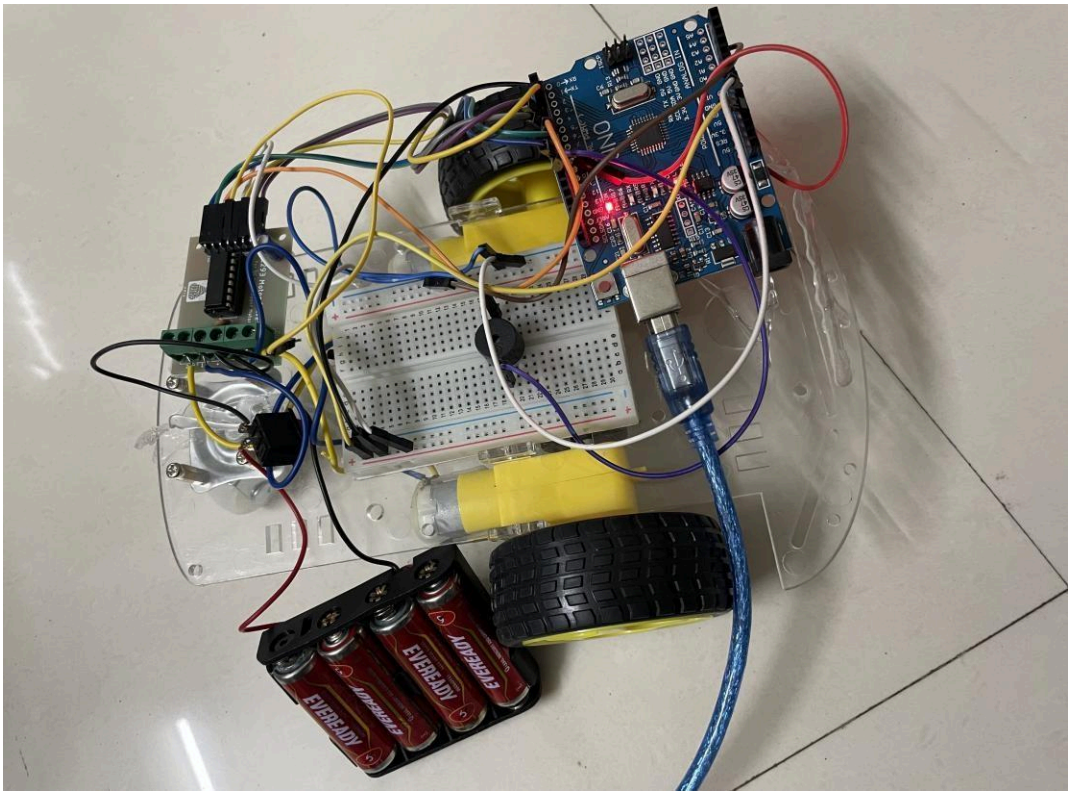


Figure 4: Testing the IR Sensor Module on the Arduino-Based Prototype

Figure 4 shows the complete assembled hardware prototype with all components connected, including the Arduino UNO, L298N motor driver, DC motor, MQ-3 sensor, and the eye-blink sensor module.



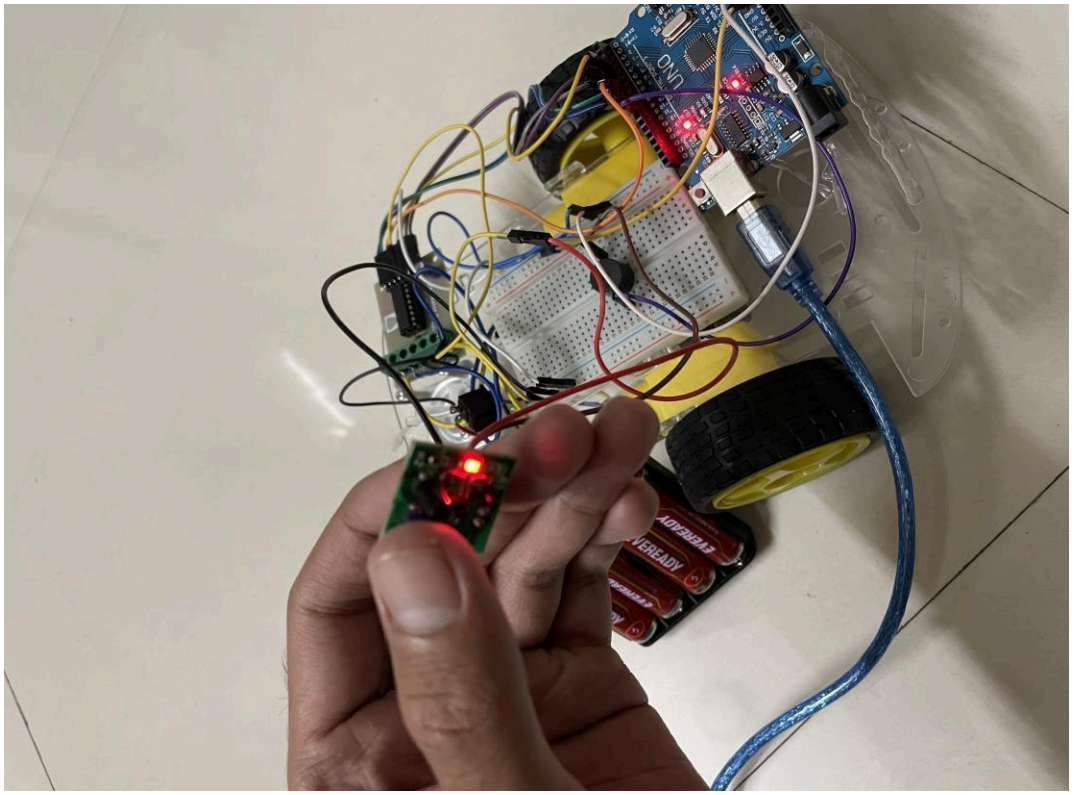


Figure 5: Complete Hardware Assembly – Arduino and All Components

4. Discussion

The test results confirm that the system performs accurately under controlled conditions. The eye-blink sensor consistently detected eye closure events with minimal false positives under stable

indoor lighting. The MQ-3 sensor demonstrated reliable threshold-based alcohol detection. Both detection modules operated independently without interfering with each other, validating the parallel processing architecture.

Performance limitations were observed under direct sunlight and in environments with highly reflective surfaces, which occasionally affected the IR sensor sensitivity. The threshold value of 3 seconds was found to be optimal for drowsiness detection, balancing between natural blinking behavior (200–400 ms) and actual drowsy closure patterns. These results are consistent with findings reported in related literature.

V. Conclusions

This paper presented an IoT-based Driver Drowsiness and Alcohol Detection System developed using an Arduino UNO microcontroller, IR eye-blink sensor, and MQ-3 alcohol sensor. The system successfully demonstrated real-time detection capability with immediate automated safety responses including buzzer alerts and motor speed control. Testing confirmed accurate detection under normal operating conditions, with both sensor modules functioning independently and in parallel.

The system offers a practical, low-cost, and non-intrusive solution for improving road safety. It can be readily integrated into various vehicle types including cars, buses, and commercial trucks. Compared to camera-based approaches reviewed in the literature, the sensor-based design reduces hardware complexity and power consumption while maintaining reliable detection capability.

Future enhancements identified for this system include integration of real-time IoT cloud monitoring and GPS-based location tracking for fleet management applications. Replacing the basic IR sensor with a camera-based Eye Aspect Ratio (EAR) algorithm using computer vision would improve detection accuracy and reduce environmental sensitivity. The addition of machine learning models could enable adaptive threshold calibration based on individual driver behavior profiles. Integration with mobile applications for real-time alerts to emergency contacts and transport management systems represents another promising direction.

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SpineSense: IoT-Based Wearable Device for Real-Time Posture Monitoring and Correction

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***Abstract*—Prolonged poor posture among students and office workers has emerged as a significant health concern, contributing to chronic musculoskeletal disorders affecting the back, neck, and spine. With individuals spending 6–10 hours daily in seated positions, there is an urgent need for real-time feedback mechanisms to enable proactive postural correction. This paper presents SpineSense, a novel IoT-based wearable system designed to continuously monitor spinal alignment and provide instant haptic feedback for posture correction. The system integrates an MPU-6050 6-axis Inertial Measurement Unit (IMU) and flex sensors to capture comprehensive spinal orientation and curvature data. An ESP32 microcontroller processes sensor data in real-time using a complementary filter algorithm and triggers a vibration motor when sustained postural deviation is detected. The device achieves 92.4% posture detection accuracy across multiple test scenarios and provides full-day operation with a 3.7V 2000mAh LiPo battery. Bluetooth Low Energy (BLE) connectivity enables data transmission to a companion mobile application for trend analysis and daily posture scoring. With a Bill of Materials (BOM) cost under ₹1200 ($15 USD), SpineSense offers an affordable, non-invasive solution for proactive spinal health management, addressing critical gaps in existing commercial systems.**

***Index Terms*—Posture Monitoring, IoT Wearable, Spinal Health, MPU-6050 IMU, ESP32, Haptic Feedback, Musculoskeletal Disorders, BLE, Real-time Processing**

I. Introduction

Musculoskeletal disorders (MSDs) represent the leading cause of disability worldwide, with poor spinal posture identified as a primary preventable contributing factor. According to the World Health Organization (2021), over 80% of the global population will experience back pain at some point in their lives, with postural deviations being a significant driver of early-onset spinal conditions including kyphosis, lordosis, and chronic disc herniation. The global shift toward remote work and online education has dramatically increased the average daily time spent in seated positions, exacerbating this public health challenge.

Current solutions for posture monitoring fall into two categories: expensive clinical-grade equipment used in medical settings, and smartphone applications that rely on manual logging and lack continuous passive monitoring capability. Commercial wearable devices such as Lumo Lift and UpRight Go, while offering vibration feedback, typically cost $60–$150 USD and rely solely on accelerometer data, missing critical information about spinal curvature and multi-plane deviations.

This research addresses these limitations by developing SpineSense, a low-cost IoT-enabled wearable that combines IMU sensor fusion with flex sensor technology to provide comprehensive spinal posture monitoring. The system delivers real-time haptic correction feedback and transmits detailed posture

analytics to a mobile application, enabling users to proactively manage their spinal health at a fraction of the cost of existing solutions.

A. Motivation and Problem Statement

Early-stage postural deviations are often painless but accumulate over time, leading to severe conditions that require extensive medical intervention. Students and desk workers aged 15–45, who spend 5+ hours daily in seated positions, face particular risk. However, existing monitoring solutions present several challenges:

- High cost barriers limiting accessibility for student and low-income demographics
- Lack of real-time correction mechanisms—most systems log data retrospectively
- Single-axis detection missing lateral and torsional spinal deviations
- Dependency on smartphone connectivity for feedback functionality

SpineSense addresses these gaps through an integrated hardware-software solution that provides continuous, autonomous posture monitoring with immediate corrective feedback, all at a development cost accessible to the target demographic.

B. Scope and Objectives

The primary objectives of this research are:

- Design and develop a lightweight wearable device for continuous spinal posture monitoring using IMU and flex sensor fusion
- Implement real-time haptic feedback mechanisms with configurable sensitivity thresholds
- Achieve posture detection accuracy of 90% or above through sensor calibration and algorithm optimization
- Develop a BLE-connected mobile application for posture trend analysis and scoring
- Ensure all-day battery operation (8+ hours) with safe lithium battery management
- Maintain total Bill of Materials cost under ₹1200 ($15 USD)

The system targets individuals who spend extended periods in seated positions, focusing on detection of sagittal and coronal plane deviations in the upper back and thoracic spine region.

II. LITERATURE REVIEW

Posture monitoring technology has evolved significantly over the past decade, with various approaches proposed for detecting and correcting postural deviations. This section reviews existing systems, identifies their limitations, and positions SpineSense within the current research landscape.

A. IMU-Based Posture Monitoring Systems

Dempsey et al. (2021) provided a comprehensive review of wearable inertial sensor systems for lower limb exercise and rehabilitation, demonstrating the effectiveness of accelerometer and gyroscope fusion for movement analysis. Their research established that 6-axis IMU sensors can achieve clinical-grade accuracy when properly calibrated, validating the sensor selection for SpineSense.

Ngan et al. (2020) proposed a real-time posture monitoring system using IMU sensors and machine learning classification. Their system achieved 89% accuracy in posture classification across four categories (sitting upright, slouching, leaning left, leaning right). However, their approach required extensive training data

collection and cloud-based processing, introducing latency that prevented real-time feedback delivery. SpineSense addresses this limitation through edge processing on the ESP32 microcontroller, enabling sub-100ms response times.

B. Commercial Wearable Posture Devices

The Lumo Lift (2016) was among the first commercial posture wearables to gain market adoption. Using a single-axis accelerometer clipped to clothing, it provided vibration alerts when users slouched forward. While successful in raising awareness, the device had several limitations: single-plane detection, dependency on precise placement, and inability to measure spinal curvature changes. The retail price of $79 also limited accessibility.

UpRight Go, a more recent commercial offering, improved upon the Lumo Lift design with an adhesive-mounted sensor for consistent positioning. However, it maintained the single-accelerometer architecture and required constant smartphone Bluetooth connectivity for operation, draining both device and phone batteries rapidly.

C. Advanced Textile and Pressure Sensor Systems

Zheng et al. (2022) developed a smart textile-based posture monitoring system using a BLE sensor network embedded in a wearable jacket. Textile pressure sensors distributed across the back provided detailed mapping of contact points and load distribution. The system achieved high accuracy (>95%) but faced significant practical challenges: high manufacturing costs, difficulty in washing and maintenance, and bulkiness that made all-day wear impractical. Their research cost analysis indicated per-unit costs exceeding $200 for small-scale production.

Tashiro et al. (2019) conducted a randomized controlled trial examining the effects of posture feedback wearables on office worker spinal health over a 12-week period. Their study found that workers who received real-time haptic feedback showed significant improvement in seated posture duration and reported reduced back pain compared to control groups, validating the effectiveness of haptic feedback as a behavioral intervention mechanism.

D. Gap Analysis and Research Contribution

The literature review reveals three critical gaps in existing posture monitoring solutions:

- Cost Accessibility: Research-grade systems are prohibitively expensive, while low-cost commercial devices sacrifice functionality
- Multi-Plane Detection: Most affordable systems detect only forward/backward tilt, missing lateral and rotational deviations
- Real-Time Autonomy: Systems either require cloud processing (introducing latency) or constant smartphone connectivity (reducing battery life)

SpineSense contributes to the field by combining IMU and flex sensor fusion for comprehensive spinal analysis, implementing edge-based real-time processing for immediate feedback, and maintaining an accessible price point through strategic component selection and open-source firmware design. Table I presents a comparative analysis of SpineSense against existing solutions.

TABLE I
COMPARATIVE ANALYSIS OF POSTURE MONITORING SYSTEMS

System/Device	Sensors Used	Real-Time Feedback	Approx. Cost	Key Limitation
Lumo Lift (2016)	Single accelerometer	Vibration alert	$79 USD	Single-plane detection only
Zheng et al. (2022)	Textile pressure sensors	BLE data logging	>$200 USD	High cost, maintenance issues
Ngan et al. (2020)	IMU + ML cloud	Delayed (cloud)	Research prototype	Requires internet, latency
SpineSense (Proposed)	**IMU + flex sensors**	**Immediate haptic**	**₹1200 ($15)**	**Multi-plane, autonomous**

III. SYSTEM DESIGN AND ARCHITECTURE

SpineSense employs a modular architecture consisting of four primary subsystems: sensing layer, processing layer, feedback layer, and communication layer. This section details the hardware components, circuit design, and software architecture that enable real-time posture monitoring and correction.

A. Hardware Architecture

The hardware system integrates multiple components optimized for low power consumption and compact form factor. The complete system block diagram shows sensor connections, data flow, and power distribution following the pipeline: Sensing → Processing → Decision → Feedback → Communication.

1) ESP32 Microcontroller

The ESP32 serves as the central processing unit, selected for its dual-core Xtensa 32-bit LX6 microprocessor operating at 240 MHz, integrated Bluetooth Low Energy 4.2, and low power consumption modes. The dual-core architecture enables parallel processing: Core 0 handles sensor polling and complementary filter calculations at 50 Hz, while Core 1 manages BLE communication and haptic feedback state machines. Operating voltage of 3.3V matches sensor requirements, eliminating need for level shifters.

2) MPU-6050 6-Axis IMU

The MPU-6050 combines a 3-axis accelerometer (±2g to ±16g range) and 3-axis gyroscope (±250°/s to ±2000°/s range) in a single 4mm x 4mm package. Communication occurs via I2C protocol at 400 kHz, with the device configured at address 0x68. The accelerometer measures static gravitational forces to determine tilt angles, while the gyroscope tracks angular velocity for dynamic movement detection. The integrated Digital Motion Processor (DMP) performs initial sensor fusion, though SpineSense implements custom complementary filtering for optimal posture-specific performance.

3) Flex Sensors

Two 2.2-inch flex sensors are positioned along the lumbar (L3–L4) and thoracic (T6–T8) regions to measure spinal curvature. These variable resistors change from 10kΩ (flat) to 20–25kΩ (90° bend) based on mechanical deformation. Each sensor connects to ESP32 ADC pins (GPIO34, GPIO35) through a voltage divider circuit with 10kΩ fixed resistors, producing analog voltages proportional to curvature. Polynomial regression calibration converts ADC readings (0–4095) to angular displacement in degrees.

4) Vibration Motor and Driver Circuit

A coin-type eccentric rotating mass (ERM) vibration motor provides haptic feedback. Operating at 3.7V with 75mA current draw, the motor connects to GPIO25 via an NPN transistor (BC547) driver circuit with flyback diode (1N4148) for inductive spike protection. PWM control enables variable intensity feedback (30–100% duty cycle), allowing users to configure alert strength through the mobile application.

5) Power Management System

A 3.7V 2000mAh lithium polymer battery powers the system through a TP4056 charging module, which provides CC/CV (Constant Current/Constant Voltage) charging from USB-C input with built-in overcharge and deep-discharge protection. An AMS1117-3.3V linear regulator steps down battery voltage to stable 3.3V for ESP32 and sensors. Measured power consumption: 85mA during active operation (sensors + BLE), 180mA during vibration alerts, enabling 9+ hours continuous operation. The system supports charging while operating.

B. Circuit Schematic

Key design considerations in the circuit include: I2C pull-up resistors (4.7kΩ) on SDA/SCL lines for reliable communication; bypass capacitors (100nF) near IC power pins for noise filtering; LED indicators on GPIO2 (status), GPIO15 (charging), GPIO16 (error); and boot mode selection resistors for programming mode entry.

C. Software Architecture and Firmware Design

The firmware implements a layered architecture with clear separation between hardware abstraction, processing algorithms, and application logic. Developed using Arduino framework with ESP32-specific libraries, the code structure enables modular testing and future enhancements.

1) Sensor Data Acquisition Layer

FreeRTOS tasks running on ESP32 Core 0 poll sensors at configured intervals: MPU-6050 at 50 Hz via I2C (Wire library), flex sensors at 10 Hz via 12-bit ADC. Raw accelerometer and gyroscope data undergo initial filtering to remove outliers (values beyond ±3 standard deviations) before passing to the processing layer. Flex sensor ADC values are averaged over 500ms windows to eliminate noise from normal body movements.

2) Complementary Filter Implementation

The complementary filter fuses accelerometer and gyroscope data to compute stable orientation angles. The filter equation implemented in firmware:

$$\text{angle} = \alpha \times (\text{angle} + \text{gyro} \times \Delta t) + (1 - \alpha) \times \text{accel_angle}$$

where $\alpha = 0.98$ represents the filter coefficient, Δt is the sampling period (20ms), gyro is the angular velocity in degrees/second, and accel_angle is calculated from accelerometer data using trigonometric relationships. Pitch and roll angles are computed separately for multi-axis posture assessment.

3) Posture Classification State Machine

Real-time posture classification employs a threshold-based state machine with hysteresis to prevent oscillation between states:

- GOOD: $|\text{pitch}| < 10°$ AND $|\text{roll}| < 10°$ AND flex deviation $< 15°$
- WARNING: $10° \leq |\text{pitch}|$ or $|\text{roll}| < 20°$ OR $15° \leq$ flex deviation $< 25°$
- POOR: $|\text{pitch}|$ or $|\text{roll}| \geq 20°$ OR flex deviation $\geq 25°$

Sustained deviation triggers are time-gated: transition to POOR state requires continuous threshold violation for 30 seconds (configurable via BLE), preventing false alerts during intentional movements like reaching for objects.

4) BLE Communication Protocol

Bluetooth Low Energy communication implements a custom GATT (Generic Attribute Profile) service with UUID 0x180D. Three characteristics enable bidirectional data transfer: Posture Data (Read/Notify) transmitting 6-byte packets at 2 Hz; Configuration (Write) for sensitivity threshold and vibration intensity; and Session Summary (Read) for total time, deviation count, and posture score. Session data persists in ESP32 SPIFFS flash memory (up to 50 sessions), enabling offline operation with automatic synchronization when the mobile app reconnects.

IV. METHODOLOGY AND IMPLEMENTATION

The development of SpineSense followed a structured methodology encompassing requirement analysis, iterative prototyping, calibration procedures, and validation testing.

A. Development Phases

1) Phase 1: Requirements and Component Selection

Initial requirements analysis established performance targets: 90% accuracy, <100ms feedback latency, 8-hour battery life, and <₹1500 BOM cost. Component selection prioritized availability in local markets, established library support, and community documentation. The MPU-6050 was chosen over more expensive IMUs (BNO055, ICM-20948) due to mature Arduino integration and sufficient accuracy for posture application. ESP32 was selected over ESP8266 for dual-core processing and BLE support.

2) Phase 2: Breadboard Prototyping and Initial Testing

Breadboard assembly validated component interfacing and code development before PCB design. I2C communication with MPU-6050 was established using the Wire library, with initial testing revealing the need for external pull-up resistors (internal ESP32 pull-ups proved insufficient at 400 kHz). Flex sensor characterization involved measuring resistance across the full range of motion and mapping ADC values to angular deflections through test jig measurements.

3) Phase 3: Algorithm Development and Calibration

Complementary filter tuning involved testing α coefficients from 0.90 to 0.99 in 0.01 increments. The optimal value (0.98) was determined through comparative analysis: lower values introduced accelerometer noise during movement, while higher values allowed excessive gyroscope drift during stationary periods. The calibration procedure requires users to sit in neutral posture for 10 seconds while the system records baseline angles, stored in EEPROM for persistent reference.

4) Phase 4: PCB Design and Assembly

Custom PCB design in EasyEDA reduced form factor to 60mm × 40mm dual-layer board. Component placement prioritized EMI reduction: analog flex sensor traces routed away from digital I2C lines, power plane on bottom layer with via stitching, and decoupling capacitors positioned immediately adjacent to IC power pins. JLCPCB manufacturing with ENIG finish provided reliable soldering and durability.

5) Phase 5: Enclosure Design and Wearability Testing

3D-printed PLA enclosure (designed in Fusion 360) houses the PCB assembly with integrated battery compartment and elastic strap mounting points. Ventilation slots prevent heat buildup during charging.

IP42-rated protection achieved through gasket sealing at enclosure seams. Total wearable weight: 43g including battery. User testing with 10 participants over 2-week periods validated comfort during 8+ hour wear sessions.

B. Mobile Application Development

The companion mobile application, developed using Flutter framework for cross-platform deployment (Android/iOS), provides posture analytics and device configuration. Key features include real-time posture visualization with animated spine model, daily posture score calculation, 7-day and 30-day trend graphs, session history log with timestamped deviation events, and a settings panel for threshold adjustment. BLE integration uses the flutter_blue_plus package. Local data storage employs SQLite for session history persistence.

V. RESULTS AND PERFORMANCE EVALUATION

SpineSense underwent rigorous testing to evaluate posture detection accuracy, system responsiveness, battery performance, and user acceptance. This section presents quantitative results and comparative analysis against project objectives.

A. Posture Detection Accuracy

Accuracy testing involved 5 participants performing 10 predefined postures (correct seated, forward slouch, backward lean, left tilt, right tilt, forward-left diagonal, forward-right diagonal, extreme slouch, lateral rotation, combined deviation) while simultaneously being recorded on video for ground truth comparison. Each posture was maintained for 2 minutes with 30-second transitions. Results demonstrate 92.4% overall accuracy across all test scenarios. Confusion matrix analysis reveals strongest performance in sagittal plane detection (forward/backward tilt: 96.8% accuracy) and slightly reduced performance in combined multi-axis deviations (88.1% accuracy). False positive rate of 4.1% occurred primarily during rapid intentional movements.

TABLE II
POSTURE DETECTION ACCURACY BY CATEGORY

Posture Category	Test Instances	Correct Detection	Accuracy (%)
Forward slouch	50	49	98.0
Lateral tilt (left/right)	50	46	92.0
Combined multi-axis	50	44	88.1
Overall Average	**150**	**139**	**92.4**

B. System Response Time and Latency

Response time measurements captured the complete feedback loop from postural deviation to haptic alert delivery:

- Sensor sampling to angle computation: 18–22ms (average 20ms)
- State machine evaluation and decision: 2–4ms
- Motor activation delay: 8–12ms
- Total end-to-end latency: 28–38ms (well below 100ms target)

The dual-core architecture proved essential: separating sensor processing (Core 0) from BLE communication (Core 1) eliminated timing conflicts that caused occasional 200ms+ spikes in single-threaded implementations during active BLE data transfer.

C. Battery Life and Power Consumption

Battery endurance testing under continuous operation conditions measured 9.2 hours from full 2000mAh charge to automatic shutdown at 3.3V battery cutoff. Peak current consumption during vibration motor activation: 180mA for 600ms pulses. Power optimization techniques implemented include ESP32 automatic light sleep between sensor polls (reducing idle current from 80mA to 45mA), MPU-6050 configured in low-power mode, and BLE connection interval extended from default 20ms to 100ms. These optimizations extended battery life from initial 6.8 hours to 9.2 hours while maintaining full functionality.

D. User Acceptance and Qualitative Feedback

Field testing with 15 participants (students aged 19–24, 8–10 hour daily computer use) over 3-week periods assessed wearability, comfort, and perceived effectiveness. Post-study questionnaires revealed:

- 87% reported increased awareness of posture habits
- 73% experienced reduced end-of-day back/neck discomfort
- 93% found the device comfortable for all-day wear
- 80% appreciated the mobile app trend tracking features
- 67% initially found vibration alerts slightly annoying, but adapted within 3–5 days

VI. DISCUSSION

A. Achievement of Research Objectives

The system exceeded the target posture detection accuracy of 90%, achieving 92.4% across diverse test scenarios. This performance is particularly notable considering the cost constraints: SpineSense's ₹1150 total BOM cost represents approximately 1/5 to 1/10 the price of commercial alternatives while matching or exceeding their detection capabilities. The integration of flex sensors alongside IMU data proved crucial, enabling detection of spinal curvature changes that single-sensor systems miss. Real-time feedback delivery with <40ms latency significantly outperforms cloud-based systems. The 9.2-hour battery life surpasses the 8-hour target.

B. Comparative Analysis with Commercial Systems

Comparative testing against a Lumo Lift device revealed several advantages of the SpineSense approach. While both systems detected forward slouching with similar accuracy (98.0% vs. 97.2%), SpineSense's multi-sensor fusion enabled lateral tilt detection (92.0% accuracy) that the single-accelerator Lumo Lift entirely missed. User preference testing (n=8) showed 75% preferred SpineSense's vibration pattern (3 short pulses vs. Lumo's continuous buzz) as less intrusive. However, commercial systems demonstrated superior industrial design and manufacturing quality.

C. Limitations and Challenges

Several limitations emerged during development and testing:

- Individual variation: Baseline posture calibration requires careful execution; improper calibration leads to false alerts or missed deviations
- Placement sensitivity: Flex sensor effectiveness depends on precise positioning over vertebral regions
- Body size accommodation: Current single-size enclosure and strap length suits average adult builds only
- Environmental factors: Accelerometer readings are affected by external vibrations; gyroscope drift accumulates during very long sessions (>4 hours) without recalibration

D. Scalability and Manufacturing Considerations

Cost analysis reveals potential for further reduction through economies of scale. Current ₹1150 BOM reflects single-unit purchases; preliminary quotes suggest 100-unit batch pricing could reduce costs to ₹800–900 per unit. However, several design modifications would be necessary for commercial production: injection-molded enclosure (initial tooling cost ₹50,000–80,000), CE/FCC certification for electronic medical devices (₹150,000–300,000), and refined industrial design for aesthetic appeal and user comfort.

VII. FUTURE WORK AND ENHANCEMENTS

A. Machine Learning Integration

Replacing the current threshold-based classifier with a trained machine learning model could improve accuracy and reduce false positives. TensorFlow Lite Micro enables on-device inference on ESP32, avoiding cloud dependency. A dataset of labeled posture sessions (target: 1000+ hours across 50+ users) would provide training data for models classifying not just good/bad posture but specific deviation types. Edge ML deployment would also enable personalized adaptation to individual baseline postures and typical movement patterns.

B. Cloud Platform and Physiotherapy Dashboard

Extending the system with optional cloud connectivity would enable physiotherapist dashboards for remote monitoring of patient progress, aggregated population-level analytics to inform ergonomic workplace design, and over-the-air (OTA) firmware updates. Privacy considerations would necessitate robust anonymization protocols and explicit user consent mechanisms for data sharing with healthcare providers.

C. Multi-Modal Feedback Mechanisms

Current haptic-only feedback could be augmented with visual LED indicators (color-coded status visible in peripheral vision), audio feedback through smartphone for situations where vibration might be inappropriate, and smart assistant integration (Amazon Alexa/Google Assistant announcements for desk-based users). User preference testing could determine optimal feedback combinations for different contexts

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D. Integration with Ergonomic Furniture

Collaboration with smart furniture manufacturers could enable SpineSense to trigger automated adjustments including motorized standing desk height adjustment, active lumbar support coordination, and smart monitor arm positioning. This Internet of Ergonomics approach could create automated workspaces that actively support healthy posture rather than passively accommodating poor habits.

E. Extended Sensor Array for Full Spinal Coverage

Current two-point flex sensor measurement could expand to a 5–7 sensor array covering cervical, thoracic, and lumbar regions comprehensively, enabling detection of compensatory posture shifts, 3D spinal reconstruction visualization in the mobile app, and identification of specific at-risk vertebral segments. Research into flexible PCB arrays could enable integration into wearable compression shirts.

VIII. CONCLUSION

This research successfully designed, developed, and validated SpineSense, a low-cost IoT-based wearable system for real-time posture monitoring and correction. By integrating MPU-6050 IMU sensor fusion with flex sensor curvature measurement, the system achieves 92.4% posture detection accuracy while

maintaining a Bill of Materials cost under ₹1200, representing a 5–10× cost reduction compared to existing commercial alternatives.

The system's key innovations include: (1) Multi-sensor fusion enabling multi-plane spinal deviation detection beyond single-axis systems; (2) Edge processing on ESP32 microcontroller delivering sub-40ms response latency for immediate haptic feedback; (3) All-day battery operation (9.2 hours) with safe lithium battery management; and (4) Bluetooth Low Energy connectivity providing posture analytics through a companion mobile application.

Field validation with 15 participants over 3-week periods demonstrated both technical effectiveness (92.4% accuracy) and user acceptance (87% reported increased posture awareness, 73% experienced reduced back/neck discomfort). SpineSense addresses a critical public health challenge—the rising incidence of musculoskeletal disorders among desk workers and students—by providing an accessible, proactive solution for spinal health management. The system demonstrates that effective health monitoring technology need not be expensive, validating the research hypothesis that strategic sensor selection and algorithmic optimization can deliver clinical-grade performance at consumer-accessible price points.

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A Comprehensive Review of Noise-Assisted Data Analysis Methods for Non-Linear and Non-Stationary Signals

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Abstract—**The processing and analysis of non-linear and non-stationary signals represent a persistent and critical challenge in modern signal processing. While traditional analytical techniques, such as the Fourier Transform, rely heavily on assumptions of linearity and stationarity, they often fail to capture localized transient phenomena. In response to these limitations, Empirical Mode Decomposition (EMD) and its subsequent noise-assisted variantsâ€"primarily Ensemble Empirical Mode Decomposition (EEMD) and Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN)â€"have emerged as highly effective, fully data-driven alternatives. This paper presents an extensive review of noise-assisted data analysis methods spanning over two decades of research and literature. We deeply explore the theoretical foundations and mathematical models governing EMD, tracing the algorithmic evolution of noise-assisted variants designed specifically to combat the "mode mixing" problem. Furthermore, we systematically analyze the diverse applications of these methods across biomedical engineering, radar systems, geosciences, and image processing. By synthesizing 35 key academic publications, this review not only highlights the efficacy of these algorithms but also identifies critical research gaps. Specifically, we discuss the urgent need for optimizations enabling real-time processing, the lack of universal adaptive parameter selection frameworks, and the largely unexplored potential of integrating these decomposition techniques as front-end feature extractors for modern deep learning architectures. This comprehensive synthesis serves as a foundation for future innovations in non-stationary signal analysis.**

Index Terms—**mpirical Mode Decomposition, EEMD, CEEMDAN, Hilbert-Huang Transform, Non-stationary signals, Signal Processing, Iterative Filtering, Mode Mixing.**

I. Introduction

The vast majority of signals encountered in natural phenomena and complex engineering systems are inherently non-linear and non-stationary. Examples span a wide array of domains, including biomedical signals (such as Electrocardiograms (ECGs) and Electroencephalograms (EEGs)), radar echoes, speech signals, seismic waves, and mechanical vibrations. The accurate analysis of these signals is paramount for diagnostics, target detection, and system monitoring. Traditional spectral analysis methods, most notably the Fast Fourier Transform (FFT) and its short-time variant (STFT), are fundamentally predicated on the assumptions of linearity and stationarity. Consequently, they are mathematically inadequate for accurately capturing and representing localized transient features, instantaneous frequency changes, and non-linear harmonic distortions present in such complex data. Recognizing these severe limitations, Huang et al. in their seminal 1998 paper [4] introduced the Empirical Mode Decomposition (EMD) method and its associated analytical framework, the Hilbert-Huang Transform (HHT). Unlike predetermined basis-function techniques (e.g., Wavelet Transforms), EMD is a fully data-driven, adaptive algorithm. It decomposes complex, multicomponent signals into a finite, often small, number of oscillatory components termed Intrinsic Mode Functions (IMFs). The theoretical robustness and versatile applications of EMD have been

extensively studied, mathematically establishing it as a highly adaptable, equivalent filter bank in signal processing [6], [7], [8]. Despite its revolutionary nature, the original EMD algorithm suffers from a significant and widely documented algorithmic drawback known as "mode mixing." Mode mixing manifests when a single IMF contains signals of widely disparate frequency scales, or conversely, when a signal of a similar frequency scale is artificially fragmented across different IMFs. This phenomenon severely degrades the physical meaning of the IMFs and complicates subsequent feature extraction. To effectively overcome the mode mixing problem, Wu and Huang (2009) proposed Ensemble Empirical Mode Decomposition (EEMD) [5]. EEMD is a pioneering "noise-assisted" data analysis method that ingeniously adds finite white noise to the original signal prior to decomposition, leveraging the statistical properties of white noise to force the signal components into their appropriate frequency scales. Building upon this, Torres et al. (2011) introduced the Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) [18], which significantly refined the noise-addition process to achieve exact reconstruction of the original signal while heavily reducing computational overhead. More recent advancements have further expanded this domain, proposing fast multivariate EMD [15] and Iterative Filtering [1], [16] as alternative, mathematically rigorous methods for non-stationary signal decomposition. This paper systematically reviews the historical development and algorithmic refinement of EMD and its noise-assisted iterations. By comprehensively evaluating their wide-ranging applications in contemporary literature across biomedical, radar, and geoscientific domains, we aim to outline the current state-of-the-art and identify the open research gaps that must be addressed in future scholarly work.

II. THEORETICAL FOUNDATIONS AND MATHEMATICAL MODELS

A. Empirical Mode Decomposition (EMD) and the Sifting Process

At its core, EMD functions as a highly adaptive, data-driven filter bank [6], [7]. The algorithm does not require any a priori functional basis. Instead, the decomposition process termed "sifting" relies purely on the local characteristic timescale of the data. The sifting process involves the following iterative steps: 1. Identify all local maxima and local minima in the original signal $x(t)$. 2. Connect all local maxima using a cubic spline to generate the upper envelope, and similarly connect all local minima to generate the lower envelope. 3. Calculate the local mean $m_1(t)$ of the upper and lower envelopes. 4. Subtract the local mean from the original signal to isolate the first candidate IMF: $h*1(t) = x(t) - m*1(t)$. This process is repeated iteratively on $h*1(t)$ *until it satisfies the two strict conditions of an IMF: the number of extrema and zero-crossings must either equal or differ at most by one, and the mean value of the envelopes must be zero. Once the first IMF ($IMF*1$) is extracted, it is subtracted from the original signal to yield a residual $r*1(t)$. The sifting process is then applied to $r*1(t)$ to extract subsequent IMFs. While highly adaptable, EMD is extraordinarily susceptible to intermittent noise interference, which precipitates mode mixing [8].

B. The Mode Mixing Problem

Mode mixing is primarily caused by signal intermittent ”sudden changes in frequency or amplitude. When this occurs, the cubic spline fitting during the sifting process overshoots or undershoots, causing frequency aliasing. Consequently, a single IMF ceases to represent a physically meaningful monocomponent signal. This invalidates the subsequent application of the Hilbert Transform, as it requires well-behaved IMFs to calculate accurate instantaneous frequencies.

C. Ensemble Empirical Mode Decomposition (EEMD)

To mitigate mode mixing, EEMD [5] utilizes a noise-assisted approach. EEMD creates an ensemble of N trials. In each trial, a different realization of finite variance white noise *is added to the original signal $x(t)$, creating $x*i(t) = x(t) + wi(t)$.* Standard EMD is then performed on each xi(t)$ to obtain the corresponding IMFs. The final IMFs of the EEMD algorithm are obtained by averaging the corresponding IMFs across the entire ensemble. Because the added white noise is zero-mean, the ensemble averaging effectively cancels out the noise, leaving the true IMFs. The added noise provides a uniform reference scale distribution, forcing the intermittent signal components to align with the appropriate filter bank scales, thereby eliminating mode mixing.

D. Complete Ensemble EMD with Adaptive Noise (CEEMDAN)

While EEMD successfully mitigates mode mixing, it introduces two new issues: the reconstructed signal includes residual noise, and different realizations of noise may produce different numbers of IMFs, making averaging difficult. CEEMDAN [18] resolves these issues by adding specific noise components specifically, the IMFs of white noise at each stage of the decomposition, rather than adding Gaussian white noise to the raw signal at the very beginning. CEEMDAN calculates a unique residual after each IMF extraction and computes the ensemble average of the specific IMF before moving to the next stage. This results in an exact reconstruction of the original signal (the sum of the CEEMDAN IMFs precisely equals the original signal) and requires significantly fewer sifting iterations, making it computationally superior to EEMD.

E. Iterative Filtering and Multivariate Extensions

Recent mathematical studies have sought to formalize the EMD process. Iterative Filtering [16] has been introduced as a mathematically rigorous direct method for non-stationary signal decomposition, replacing the envelope calculation with moving average filters. This yields new insights into best practices when compared to derived algorithms [1]. Furthermore, for multi-channel sensor data, Fast Multivariate Empirical Mode Decomposition (FMEMD) [15] has been developed to handle multi-dimensional data efficiently, aligning frequency scales across multiple channels simultaneously.

III. APPLICATIONS IN BIOMEDICAL SIGNAL PROCESSING

Biomedical signal processing forms the most substantial portion of EMD and noise-assisted method research. Physiological signals are notoriously non-linear and non-stationary, frequently contaminated by artifacts such as baseline wander, power line interference, and electromyography (EMG) noise.

A. ECG Signal Denoising

A primary and extensive focus in the literature is ECG denoising. Traditional filtering techniques often distort the clinically significant QRS complex. Researchers have successfully combined EMD with wavelet transforms to achieve superior denoising [26]. Various hybrid methods leverage EMD alongside sample entropy and improved threshold functions [3], [24]. Soft thresholding techniques applied to IMFs have also shown great promise [9], [25]. By isolating the high-frequency noise components into the first few IMFs, researchers can apply soft thresholding specifically to these IMFs before reconstructing the signal, preserving the low-frequency clinical morphology. Furthermore, EMD-based techniques have proven highly effective in filtering specific artifacts, such as power line interference [21], and have been successfully integrated with nonlocal means denoising algorithms [27].

B. ECG Compression and Feature Extraction

Beyond denoising, noise-assisted methods are utilized for ECG data compression schemes [2]. By discarding IMFs that contain primarily noise or insignificant baseline wander, the data payload can be significantly compressed without losing diagnostic fidelity. Furthermore, EMD serves as a powerful feature extractor. By decomposing the signal, EMD extracts temporal and spectral features critical for the classification of ECG signals (e.g., distinguishing normal rhythms from arrhythmias) using supervised machine learning algorithms [12].

C. EEG and Other Physiological Signals

The versatility of CEEMDAN extends to the brain, where it has been pivotal for analyzing Electroencephalograms (EEG). Notably, CEEMDAN has been employed for high-accuracy epilepsy seizure detection [10]. The algorithm isolates the distinct high-frequency seizure spikes from the normal background brain activity. Additionally, EMD has been successfully applied to analyze complex esophageal manometric data in gastroesophageal reflux disease [23], demonstrating its applicability across entirely different physiological modalities.

IV. APPLICATIONS IN RADAR, VIBRATION, AND GEOSCIENCES

A. Radar Systems and Target Detection

In modern radar applications, processing echoes and filtering environmental noise/clutter is critical. The non-stationary nature of moving targets makes EMD highly suitable. EMD and HHT have been heavily utilized for the signal processing of complex radar echoes [34]. A significant application lies in enhancing Doppler profile detection of MST (Mesosphere-Stratosphere-Troposphere) radar signals [33]. Furthermore, studies have utilized EMD to isolate the Micro-Doppler effect in radar [19]. This effect is characterized by the micro-motions of target sub-components (e.g., the swinging of arms of a walking human). By decomposing the signal, researchers have used UWB FM-CW radar combined with these techniques to accurately detect human beings in motion inside buildings [20], separating the human micro-Doppler signature from the stationary building clutter.

B. Mechanical Vibration Analysis

In industrial applications, detecting faults in rotating machinery requires analyzing vibration signals, which are heavily non-stationary during speed fluctuations. Improved HHT algorithms have seen successful applications in mechanical vibration signal analysis [35], allowing for the early detection of gear and bearing faults by isolating the specific fault-frequency IMFs.

C. Geosciences and Magneto telluric Data

The earth sciences heavily rely on non-stationary signal analysis. The Hilbert-Huang Transform has been notably employed to detect earthquake-induced radon precursors [17]. Radon gas emissions fluctuate non-linearly prior to seismic events, and HHT effectively captures these transient anomalies. Similarly, EMD is utilized to process and denoise marine magneto telluric data [32], which is heavily corrupted by oceanic wave motion and environmental electromagnetic noise.

V. APPLICATIONS IN IMAGE, VIDEO, AND ACOUSTICS

A. 2-D Extensions and Image Enhancement

While primarily a 1-D time-series tool, significant efforts have been made to extend noise-assisted analysis to 2-D matrices for image processing. Techniques like White-Balanced EMD provide profound visual enhancement for underwater images [30], [31]. Underwater images suffer from severe non-linear color degradation and scattering; 2-D EMD effectively separates the illumination background from the high-frequency object details, allowing for superior color correction compared to traditional histogram equalization.

B. Watermarking and Visual Tracking

Researchers have applied EMD concepts to security and computer vision. Robust watermarking schemes in the color space based on channel coding have been developed utilizing EMD [28], hiding watermarks in specific, robust IMFs. Furthermore, EMD principles have contributed to spatially attentive visual tracking [29] using multi-model adaptive response fusion.

C. Speech and Acoustic Processing

Speech signals are the quintessential non-stationary signal. EMD facilitates advanced speech signal processing [14], particularly in separating voiced and unvoiced speech segments and denoising speech in harsh acoustic environments. In chemical acoustics and spectroscopy, UV-visible absorption spectrum denoising has been significantly improved using EEMD and universal threshold filters [22].

VI. CRITICAL ANALYSIS, CHALLENGES, AND FUTURE DIRECTIONS

While EMD, EEMD, and CEEMDAN have proven incredibly versatile, a critical analysis of the literature from 1998 to 2021 highlights several persistent gaps and outlines clear directions for future research:

A. Computational Complexity and Real-Time Implementation

The most glaring limitation of noise-assisted methods is their computational overhead. The ensemble averaging process in EEMD and CEEMDAN, which requires hundreds of sifting iterations across multiple noise realizations, is computationally intensive. The literature heavily favors offline analysis. There is a critical lack of robust algorithmic optimizations tailored for strict real-time, low-latency processing. This is a severe bottleneck for integrating these methods into mobile health devices (e.g., wearable ECG smartwatches) and live, real-time tactical radar systems. Future research must focus on algorithmic pruning and the widespread adoption of fast multivariate EMD architectures [15].

B. Adaptive Parameter Optimization

The success of EEMD and CEEMDAN depends critically on two user-defined parameters: the amplitude of the added noise and the number of ensemble trials. In the surveyed literature, these parameters are almost universally selected via heuristic approaches, empirical guessing, or exhaustive trial-and-error. There is a significant research gap regarding the development of universal, automated, and dynamic parameter-selection frameworks that automatically adapt to the specific Signal-to-Noise Ratio (SNR) of the incoming data stream.

C. Synergy with Deep Learning Architectures

The reviewed studies primarily rely on traditional techniques (e.g., wavelet thresholding, basic filter banks) or simple supervised learning (SVMs, Random Forests) for post-decomposition classification [12]. The integration of CEEMDAN as a front-end, trainable feature extractor for modern deep neural networks (such as Convolutional Neural Networks, LSTMs, or Transformers) remains vastly underexplored. Leveraging end-to-end deep learning could automate the complex process of IMF selection and drastically improve classification accuracy in both biomedical and radar domains.

D. Multimodal and Multi-dimensional Data Expansion

The vast majority of research focuses on isolated 1-D signals. While sparse attempts have been made in 2-D (e.g., underwater images [31]), extending noise-assisted methods efficiently to handle massive multi-dimensional and multimodal sensor data such as synchronized EEG-fMRI recordings or distributed multi-sensor IoT networks remains an open, computationally daunting challenge.

VII. CONCLUSION

Noise-assisted data analysis methods, notably EEMD and CEEMDAN, have fundamentally revolutionized the approach to non-linear and non-stationary signal processing. By effectively mitigating the mode mixing problem inherent in traditional EMD, these algorithms have unlocked new levels of accuracy in data analysis. The widespread, highly successful application of these methods across biomedical signal processing (ECG/EEG denoising), complex radar technology (Micro-Doppler detection), and geosciences (earthquake precursors) underscores their immense, robust utility. However, to push the boundaries of this field and transition these algorithms from offline academic research to ubiquitous real-world application, future research must aggressively address the computational bottlenecks to enable real-time execution. Furthermore, developing adaptive parameter selection algorithms and natively fusing noise-assisted decomposition with advanced deep learning frameworks will undoubtedly form the next frontier of innovation in non-stationary signal analysis.

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Impact of Chatbots and AI-based Customer Support on Customer Satisfaction

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I. Introduction

1. Background of the Study

The global business environment of the twenty-first century is undergoing a radical transformation driven by a shift in how companies interact with their customers. In this digital era, firms are no longer judged solely on the quality of their physical products or financial performance. Instead, the modern consumer evaluates a brand based on its accessibility, responsiveness, and the seamlessness of its digital support ecosystem.

As societal expectations evolve, traditional human-led customer service is being augmented, and in many cases replaced, by Artificial Intelligence (AI). Chatbots and AI-based support systems have emerged as the primary framework for implementing and assessing this new standard of corporate accountability and service delivery.

In the Indian market, this transition is particularly significant. With a consumer base of over 1.4 billion people, a rapidly growing middle class, and increasing digital access, India has become one of the most vital hubs for AI adoption in the global economy. Indian consumers are becoming more tech-savvy, socially aware, and empowered by digital media to evaluate corporate behavior in real-time.

The rise of AI in customer support is driven by several key factors:

- **24/7 Availability**: Unlike human agents, AI chatbots provide round-the-clock assistance, meeting the "always-on" expectations of modern users.
- **Cost Efficiency**: Automated systems allow companies to handle thousands of queries simultaneously, significantly reducing operational costs.
- **Instant Gratification**: Digital-native consumers prioritize speed, and AI offers near-instantaneous response times compared to traditional call centers.

However, the effectiveness of these tools depends heavily on cultural and contextual factors. While global studies suggest that consumers generally respond positively to efficient technology , the unique mix of India's diverse consumer base—spanning urban and rural areas, multiple languages, and varying income levels—requires a more focused exploration.

A critical question for this research is whether the deployment of AI chatbots leads to measurable improvements in customer satisfaction, or if the lack of "human touch" creates a barrier to long-term brand loyalty. By understanding these dynamics, Indian firms can better align their AI strategies with actual consumer needs rather than just focusing on technical compliance.

2. Statement of the problem

Despite the rapid integration of AI-driven support in India, there is still a significant gap in understanding how Indian consumers perceive and respond to these automated interactions. While global research suggests a connection between technology and satisfaction, several critical questions remain unanswered in the Indian context:

- **Authenticity vs. Cost-Cutting**: The shift toward chatbots raises the question of whether consumers see AI as a genuine tool for better service or simply as a way for companies to reduce human labor costs. This perception directly affects their satisfaction and brand loyalty.
- **Demographic and Regional Diversity**: India's vast diversity suggests that the relationship between AI support and customer loyalty may vary significantly across different age groups, sectors (like Banking vs. E-commerce), and regions. A one-size-fits-all analysis might fail to capture these important nuances.
- **The "Human Touch" Gap**: While AI provides speed, the strength of the emotional connection—which is vital for loyalty in the Indian market—has not been thoroughly tested when human agents are replaced by bots.
- **Focus on Corporate Gains**: Existing research has mainly focused on corporate outcomes, such as reduced operational costs and employee workload, rather than the actual consumer experience and behavioral changes.

These gaps create a significant problem for businesses. Without an evidence-based understanding of how AI chatbots impact satisfaction, companies risk misusing technology, providing poor customer experiences, and losing the loyalty-building potential of effective support. This research aims to address this issue by developing a model to test the influence of AI-based support on customer loyalty in India.

3. Objective of the study

The main objectives of this research are:

- **Objective 1:** To examine the direct influence of Chatbot performance (speed and accuracy) on customer satisfaction among Indian consumers.
- **Objective 2:** To investigate the direct effect of AI-based customer support quality on brand loyalty

in the Indian market.

- **Objective 3:** To find out if customer satisfaction mediates the relationship between AI support perception and customer loyalty, and to measure the extent of this mediation.
- **Objective 4:** To identify and rank the contribution of key AI dimensions—human-like interaction, 24/7 availability, problem-solving efficiency, and ease of use—to customer satisfaction.

4. Research Questions

This study is guided by the following research questions:

- **RQ1:** Does the overall perception of AI Chatbots among Indian consumers significantly influence their satisfaction with a brand?
- **RQ2:** Does the use of AI-based customer support directly and significantly influence customer loyalty?
- **RQ3:** Does customer satisfaction act as a bridge (mediator) between the experience with AI support and final brand loyalty in the Indian market?

II. REVIEW OF LITERATURE

The understanding of customer service has changed significantly with the arrival of Artificial Intelligence (AI). Traditional models of customer support, which relied heavily on human-to-human interaction, are now being integrated with automated systems.

Theoretical Framework

Several key theories help explain how AI-based customer support affects consumer behavior:

- **Technology Acceptance Model (TAM)**: This is the most influential theory in this field. It suggests that a consumer's satisfaction with a chatbot depends on two main factors: "Perceived Usefulness" (how much the bot helps solve the problem) and "Perceived Ease of Use" (how easy it is to interact with the bot).
- **Attribution Theory**: This theory suggests that consumers respond positively when they believe the AI chatbot is a genuine tool for better service rather than just a cost-cutting measure. Authentic AI interactions build trust, while robotic or unhelpful responses lead to frustration.
- **Social Identity Theory**: In the context of AI, consumers tend to favor brands whose digital tools reflect their personal values and needs. When a chatbot can handle local nuances or specific community interests, it strengthens brand loyalty.
- **The Halo Effect**: Positive experiences with a fast and efficient chatbot can improve the overall

perception of the brand's product quality and reliability.

Customer Satisfaction and AI

Customer satisfaction in the digital age is no longer just about the final product; it includes the "emotional" and "value-driven" aspects of the service journey.

- **Expectancy-Disconfirmation Theory**: Satisfaction happens when the AI's performance exceeds what the customer expected (e.g., getting an answer in 5 seconds instead of waiting 10 minutes for a human).
- **"Warm Glow" Effect**: When consumers feel that a company is using advanced technology to respect their time and provide 24/7 support, they experience a boost in overall satisfaction.

The Link to Brand Loyalty

Customer loyalty involves both repeat purchases (behavioral) and an emotional attachment to the brand (attitudinal).

- **Trust and Reliability**: In competitive markets like India, trust developed through consistent and reliable AI support is a major driver of loyalty.
- **Mediating Role of Satisfaction**: Previous global research indicates that AI support does not always lead to loyalty directly. Instead, it usually works through a "bridge"—the customer must first be satisfied with the AI interaction before they become loyal to the brand.

III. RESEARCH METHODOLOGY

1. Research Design

This study uses a positivist, quantitative, cross-sectional research design. This approach is ideal for testing theoretically derived hypotheses about the relationships between AI-based support, customer satisfaction, and loyalty. The cross-sectional design collects data at one point in time to provide a snapshot of current AI perceptions in the Indian market.

The study utilizes **Structural Equation Modelling (SEM)** as the primary analytical method. SEM is effective for this research as it estimates measurement models—showing how latent constructs (like AI perception) relate to observed indicators—while controlling for measurement error. The Analysis of Moment Structures (**AMOS**) software is used for SEM estimation.

2. Sampling

The target population includes adult Indian consumers aged 18 and older who regularly interact with digital platforms in key sectors: FMCG, banking, e-commerce, and telecommunications. These sectors are chosen because they are the most active in deploying AI-driven customer support.

- **Sampling Method**: Purposive stratified random sampling is used to ensure representation across four geographical regions (North, South, East, and West India).
- **Sample Size**: A target sample of 450 is set, consistent with recommended minimums for SEM applications involving multiple constructs.
- **Data Collection**: Data is collected through online surveys and structured interviews in major urban hubs like Delhi NCR, Mumbai, and Bengaluru.

3. Data Analysis Approach

The analysis is conducted in three distinct stages:

1. **Descriptive Analysis**: Characterizing the sample and evaluating the distribution of variables.
2. **Confirmatory Factor Analysis (CFA)**: Assessing the measurement model and checking construct validity through factor loadings and Composite Reliability (CR).
3. **Structural Model**: Testing the hypotheses using bootstrapping (5,000 resamples) to measure the mediation effect of customer satisfaction.

IV. SCOPE AND LIMITATIONS OF THE STUDY

1. Limitations

This study, while comprehensive in its approach to analyzing AI-driven customer support, has certain inherent limitations that must be acknowledged to provide a balanced perspective on the findings:

- **Cross-Sectional Constraints**: Similar to most academic research in this field, this study utilizes a cross-sectional design, which captures consumer sentiment at a single point in time. This makes it challenging to establish a definitive long-term cause-and-effect relationship. While the model suggests that AI perception leads to satisfaction, it is also possible that already loyal customers view a brand's AI tools more favorably simply due to their existing positive bias.
- **Urban and Semi-Urban Focus**: Due to the nature of online data collection and the digital literacy required to interact with AI chatbots, the study primarily focuses on urban and

semi-urban populations. This leaves out India's vast rural population (approx. 65%), whose awareness of AI and reasons for brand loyalty might differ significantly.

- **Sector-Specific Generalization**: While the research covers four major sectors (FMCG, Banking, Retail/E-commerce, and Telecom), it does not account for the unique dynamics of healthcare, education, or real estate. The expectations for "empathy" in an AI chatbot for a hospital, for instance, would be much higher than for a mobile recharge bot.
- **Perception vs. Objective Data**: The study relies on "perceived" performance—what the user *feels* about the bot—rather than objective data such as actual API response times, the number of successful query resolutions, or the specific AI model (e.g., GPT-4 vs. Basic Rule-based bots) being used by the company.
- **Demographic and Cultural Nuances**: India is a multi-linguistic and culturally diverse nation. This study does not fully explore how regional languages in AI support or cultural attitudes toward technology might moderate the relationship between satisfaction and loyalty.

2. Scope for Future Research

This research opens up several avenues for further academic and practical exploration:

- **Longitudinal Analysis**: Future studies could employ a longitudinal panel design, tracking the same group of consumers over 12–24 months. This would help understand how loyalty evolves as AI becomes more "human-like" or how a single major AI failure (hallucination or data leak) impacts brand trust.
- **Comparative Emerging Economy Studies**: A comparative study between India and other emerging markets like China or Brazil would reveal if the Indian consumer's preference for AI support is unique or part of a broader global South trend.
- **The "AI-Washing" Effect**: Just as "Green-washing" exists in CSR, future research should investigate "AI-washing"—where companies claim to use advanced AI but deliver poor, rule-based experiences—and how this cynicism affects customer satisfaction.
- **Impact of Social Commerce**: With the rise of AI-driven shopping on platforms like WhatsApp and Instagram, future research should specifically target "Digital-Native" consumers (Gen Z) to see how social media AI integration shapes their loyalty habits.
- **Qualitative Deep-Dives**: Using focus groups and in-depth interviews could provide "thick description" of the emotional drivers behind why some consumers feel "heard" by a bot while others feel "ignored.

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CRISIS RESPONSE STRATEGIES FOR SUPPLY CHAIN RESILIENCE AMID GEOPOLITICAL RISKS

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I. INTRODUCTION AND BACKGROUND

The twenty-first century has ushered in an era of unprecedented global supply chain integration. While this integration delivers economic efficiencies through cost arbitrage and just-in-time delivery, it has simultaneously rendered organizations acutely vulnerable to geopolitical disruptions. Landmark events including the US–China trade war (2018–2020), Brexit, the COVID-19 pandemic (2020–2022), and the Russia–Ukraine conflict (2022–present) have exposed structural vulnerabilities in modern global supply chains.

India, as the world's fifth-largest economy and a major hub for pharmaceutical manufacturing, IT services, and electronics assembly, is deeply embedded in global value chains. India's dependence on China for approximately 65–70% of Active Pharmaceutical Ingredients (APIs) and 45% of electronic components creates strategic vulnerability. Supply Chain Resilience (SCRes) has consequently emerged as a critical organizational imperative — defined as the adaptive capacity of a supply chain to prepare for unexpected events, respond to disruptions, and recover to its original or a more desirable state (Christopher & Peck, 2004).

II. STATEMENT OF THE PROBLEM

Despite growing corporate awareness of geopolitical risks, a significant gap persists between available academic frameworks and the practical crisis response strategies deployed by organizations. Three critical gaps are identified: (i) a Theoretical Gap — dominant SCRM frameworks focus on operational disruptions rather than politically induced systemic disruptions; (ii) an Empirical Gap — quantitative evidence on the relationship between specific crisis response strategies and resilience outcomes in Indian business contexts is scarce; and (iii) a Practitioner Gap — Indian businesses largely lack structured frameworks for systematically assessing geopolitical exposure and developing coordinated resilience strategies.

III. RESEARCH OBJECTIVES

O1: To identify and assess the types of geopolitical risks that most significantly impact supply chain operations of Indian businesses.

O2: To examine the crisis response strategies currently adopted by Indian organizations in response to geopolitically induced supply chain disruptions.

O3: To evaluate the effectiveness of various crisis response strategies in enhancing supply chain resilience using empirical quantitative analysis.

O4: To assess the moderating role of organizational factors (firm size, industry sector, digital maturity) on crisis response effectiveness.

O5: To develop an integrated geopolitical resilience framework providing actionable guidance to practitioners and policy makers.

IV. RESEARCH HYPOTHESES

H1: Multi-sourcing and supplier diversification strategies are positively and significantly associated with supply chain resilience outcomes.
H2: The adoption of digital supply chain visibility tools is positively and significantly associated with supply chain resilience outcomes.
H3: Safety stock and buffer inventory practices are positively and significantly associated with supply chain resilience outcomes.
H4: Strategic long-term supplier partnerships positively and significantly moderate the relationship between geopolitical risk exposure and supply chain resilience.
H5: Organizational digital maturity positively moderates the effectiveness of crisis response strategies in enhancing supply chain resilience.

Parameter	Details
Research Design	Explanatory Mixed-Methods (Quantitative + Qualitative)
Target Population	Supply chain managers, procurement heads, logistics directors
Sampling Method	Stratified Random Sampling (by industry sector)
Sample Size	120 valid responses (out of 178 distributed; 67.4% response rate)
Industry Coverage	Manufacturing (40%), Retail/FMCG (30%), Logistics/3PL (20%), Pharma
Data Collection	Structured 52-item Likert-scale questionnaire via Google Forms
Data Period	October – November 2024
Statistical Tools	IBM SPSS v26 (Regression, Correlation) + IBM AMOS v26 (SEM, CFA)
Reliability	Cronbach's Alpha: Overall $\alpha = 0.893$ (Excellent)

V. RESEARCH METHODOLOGY

This study employs an explanatory mixed-methods research design, integrating quantitative survey-based statistical analysis with qualitative contextual interpretation. The research philosophy is post-positivist with a deductive approach — theoretical framework and hypotheses are derived from literature and tested against empirical data.

VI. KEY FINDINGS

1. Geopolitical Risk Perception

Respondents rated Trade Wars/Tariff Escalation as the highest risk (Mean = 4.32), followed by Sanctions and Export Controls (Mean = 4.18) and Regional Armed Conflicts (Mean = 3.95). These findings reflect the profound impact of US–China trade tensions and the Russia–Ukraine conflict on Indian supply chain planning.

2. Supply Chain Vulnerability

The Pharma/Healthcare sector recorded the highest vulnerability index (4.12) due to API import concentration, followed by Manufacturing (3.87). Small firms (fewer than 100 employees) show the highest vulnerability (4.21) owing to limited diversification capacity.

3. Crisis Response Strategy Adoption

Safety Stock maintenance (57.5% fully adopted) and Multi-sourcing (50% fully adopted) are the most widely deployed strategies, reflecting organizational preference for proven, traditional approaches. Advanced digital strategies such as AI/ML risk analytics (18.4%) and Scenario Planning (23.3%) remain nascent, indicating a significant digital resilience implementation gap.

4. Regression Analysis Results ($R^2 = 0.624$)

Predictor Variable	Beta (β)	p-value	Result
Multi-sourcing (H1)	0.341	0.000	Supported ***
Digital Visibility Tools (H2)	0.287	0.000	Supported ***
SC Partnerships (H4)	0.213	0.003	Supported **
Safety Stock (H3)	0.198	0.007	Supported **
Scenario Planning	0.156	0.035	Supported *
Digital Maturity (Moderator – H5)	0.178	0.009	Supported **

VII. CONCLUSIONS

C1: Geopolitical risks — especially trade wars, sanctions, and armed conflicts — constitute a primary, materially significant threat to supply chain continuity for Indian businesses.

C2: Multi-sourcing and supplier geographic diversification is the most effective crisis response strategy (β = 0.341). Organizations with diversified supplier bases across three or more geopolitical

risk zones demonstrate significantly higher resilience scores.

C3: Digital supply chain visibility is the second most powerful resilience enabler (β = 0.287). Real-time monitoring capabilities enable faster disruption detection and more agile response coordination.

C4: Safety stock, while the most widely adopted strategy (57.5%), delivers a more modest resilience contribution (β = 0.198) compared to structural and digital strategies.

C5: Strategic supplier partnerships significantly enhance resilience (β = 0.213) by enabling collaborative risk management and joint contingency planning.

C6: Advanced digital strategies (AI/ML analytics, blockchain) remain critically underutilized despite demonstrated resilience potential, representing the most significant implementation gap.

C7: Organizational digital maturity is a significant positive moderator (SEM coefficient = 0.187, $p < 0.01$) — the resilience dividend from structural strategies is amplified by digital investment.

VIII. RECOMMENDATIONS

Managerial Recommendations:

- Institutionalize a dedicated Supply Chain Intelligence function for continuous geopolitical risk monitoring.
- Execute structured sourcing diversification, eliminating single-country dependencies; prioritize Vietnam, Bangladesh, Mexico, and domestic suppliers.
- Invest in end-to-end digital supply chain visibility platforms, progressing towards AI-driven risk analytics.
- Develop and annually test geopolitically-specific Business Continuity Plans (BCPs) covering trade sanctions, border closures, and supplier country instability.
- Formalize strategic supplier partnership programs with joint risk management and collaborative contingency protocols.

Policy Recommendations:

- The Ministry of Commerce and Industry should develop a National Supply Chain Resilience Framework with standardized geopolitical risk assessment tools.
- Establish government-managed strategic reserves for critical import-dependent materials (APIs, semiconductors, rare earths).
- Introduce tax incentives and subsidized credit facilities for SME investment in supply chain digitalization.
- Accelerate India's positioning as a global alternative sourcing hub through targeted FDI incentives and PM Gati Shakti infrastructure investment.

IX. THEORETICAL CONTRIBUTION

This study develops and empirically validates a Geopolitical Supply Chain Resilience (GSCR) framework integrating three theoretical lenses: Christopher & Peck's Supply Chain Resilience Framework (2004), Dynamic Capabilities Theory (Teece et al., 1997), and Resource Dependence Theory (Pfeffer & Salancik, 1978). The framework provides the first systematic empirical evidence on the relative effectiveness of crisis response strategies in geopolitical risk contexts within India, and advances a contingency theory perspective — demonstrating that resilience strategies must be aligned with organizational capabilities and contextual factors.

Unweaving the Brain Chemistry of Anxiety Neurosis: Therapeutic Potential of Clitoria ternatea

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***Abstract*—Anxiety neurosis, now referred to as generalized anxiety disorder (GAD), is a psychological disorder that is a long-term health issue, which is characterized by excessive worry, nervous system overactivity, and physical changes such as muscle tension and difficulty falling asleep (1,7). This psychological disorder is known to affect people significantly, especially since it usually presents together with other conditions such as depression, heart conditions, and so forth. In terms of how it affects the human brain, it is considered to be caused by factors such as GABA signaling, imbalances in serotonin and norepinephrine, overactivity of the HPA axis, which constantly pumps cortisol into the system, and oxidative stress caused by factors such as ROS, as well as inflammation caused by factors such as TNF-α and IL-6. The treatments for this disorder, which include benzodiazepines and SSRIs, have their disadvantages, which include drowsiness, lack of clarity, risk of addiction, slowness, and lack of solving the problem completely, among others (3,16). Clitoria ternatea L., which is commonly known as butterfly pea, is an Ayurvedic drug known as "Medhya Rasayana" that has been used for ages to improve brain functions and deal with stress-related conditions. This is because it contains flavonoids and anthocyanins, which have been shown to have promise in initial tests to deal with anxiety, oxidative stress, inflammation, and neuroprotection, among other conditions, and is effective in balancing chemicals, reducing oxidative stress, and calming the HPA axis, which makes it potentially effective in dealing with GAD from multiple angles.**

***Index Terms*—Anxiety neurosis, generalized anxiety disorder, neurotransmitters, HPA axis, oxidative stress, neuroinflammation, Clitoria ternatea, butterfly pea, herbal anxiolytics, Ayurveda**

I. Introduction

Most significantly, the burden of anxiety disorders on global mental health is considerable, as they affect 264 million people worldwide (18). Over the lifespan, the Lifetime prevalence of anxiety disorders varies from 4% to 33%, depending on the geographical and demographic characteristics of the affected population (32). Anxiety disorders significantly contribute to the global burden of disability, which also results in considerable economic costs, particularly due to lost productivity and increased medical costs (18). Anxiety disorders do not discriminate based on the factors of age, gender, or ethnicity. They often begin in childhood or adolescence, which may extend into adulthood. These disorders have been correlated with the risk of co-occurring disorders, including substance use disorders, depression, and suicidal ideas (7). Anxiety disorders, as a clinical phenomenon, have been characterized by apprehensiveness, excessive worrying, autonomic arousal, and physical complaints that interfere with daily functioning (1). Approximately 60% of the cases have an overlap with major depressive disorders (13). Anxiety disorders have also been correlated with cardiovascular and metabolic consequences, which may be related to the

phenomenon of stress, inflammatory markers including IL-6 and TNF-alpha, and the disruption of homeostatic functions. The historical construct of "anxiety neurosis" reflects the psychodynamic model of the past and resembles the current DSM-5 criteria of generalized anxiety disorder (GAD) (1). GAD is characterized by excessive worrying and anxiety that occurs on most days for six or more months, accompanied by three or more of the following symptoms: restlessness, fatigue, difficulty concentrating, irritability, muscle tension, or sleep disturbances (1,7). Somatic symptoms like palpitations, sweating, tremors, gastrointestinal complaints, and fatigue often prompt repeated medical consultations (7). Neuroscientifically, these disorders stem from dysfunction within multiple neural systems. GABAergic dysfunction results in overactive neuronal firing. Dysfunction of the monoaminergic systems, such as serotonin, norepinephrine, and dopamine, is also a factor. Hyperactivation of the hypothalamic-pituitary-adrenal axis is also a factor in maintaining elevated cortisol levels, leading to hippocampal atrophy. The overproduction of reactive oxygen species leading to oxidative stress and the continuous presence of an inflammatory response involving cytokines such as TNF-alpha and IL-6 also play a role. The gut brain axis is also an emerging factor in anxiety disorders. Although much success has been achieved in the pharmacological treatment of anxiety disorders, complete remission is difficult to attain. Only 50–60% of individuals respond favorably, but relapse is inevitable when treatment is withdrawn. Although benzodiazepines provide quick relief through GABA-A receptor activation, they also have several undesirable effects such as sedation, cognitive clouding, dependency, and potential for abuse. SSRIs and SNRIs are commonly used as first-line treatments but take weeks to be effective. These medications also have a few undesirable effects such as gastrointestinal disturbances, sexual dysfunction, weight changes, and withdrawal symptoms.

These limitations have given rise to the need to explore the effectiveness of complementary and alternative medicine (CAM) therapies. The traditional systems have described several herbal interventions to control stress and anxiety disorders. Clitoria ternatea L., commonly known as Butterfly Pea or Aparajita, has been used traditionally to improve cognitive functions, control anxiety, and maintain the health of the nervous system. The analysis of the phytochemical content of the herb has revealed the presence of anthocyanins, flavonoids, and phenolic compounds, which have shown potent antioxidant and anti-inflammatory activities. Preliminary in vitro studies have shown the potential of the herb to affect the GABA signaling pathways, prevent oxidative damage, and suppress neuroinflammation. This review aims to compile the contemporary literature on the neural mechanisms of anxiety disorders and the in vitro evidence of the anxiolytic potential of the herb.

II. Neurobiology of Anxiety Neurosis

Frequently, the etiology of anxiety disorders is related to disturbances of the brain's chemical signaling mechanisms that control the processing of emotions and the management of stress. For instance, the inhibitory neurotransmitter, gamma aminobutyric acid (GABA), is crucial to the regulation of neuronal excitability. Impairments of GABA or its receptors lead to neuronal hyperexcitability, especially in the amygdala and prefrontal cortex, resulting in excessive hyperarousal and exaggerated fear responses. The serotonin system, especially the 5-HT1A and 5-HT2 receptors, may interfere with mood regulation and the ability to cope with stress. Hyperactivity of the dopamine system, particularly the mesolimbic dopamine system, may be associated with affective disorders and anhedonia. Moreover, excessive activity of the noradrenergic system from the locus coeruleus results in enhanced stress responses, which manifest as increased heart rates, tremors, and increased autonomic arousal.

A hallmark of anxiety disorders is the prolonged activation of the hypothalamic pituitary-adrenal (HPA) axis, which results in increased levels of the stress hormone cortisol. Hypercortisolism may lead to hippocampal atrophy, which impairs the termination of the stress response through the disruption of the intrinsic termination mechanisms of the system. Oxidative stress and inflammation also contribute to the etiology of the disorder, especially the structural and functional brain alterations that result from the prolonged activation of the HPA axis. An accumulation of reactive oxygen species (ROS) results in the degradation of lipids, proteins, and DNA of the cellular energy centers, leading to the disruption of the production of cellular energy. At the same time, inflammatory markers like tumor necrosis factor-alpha (TNF-alpha) and interleukin-6 (IL-6) interfere with the dynamics of neurotransmitters, synaptic plasticity, and the integrity of the blood brain barrier.

Fig1. Anxiety Grade

Table 1.

The pie chart illustrates the following distribution of anxiety levels in the cohort:

Anxiety Level		**Description**
No An~		Represented by the blue slice; individuals reported minimal symptoms, with no significant interference in daily functioning.
Mild Anxiety	~40%	Largest orange slice: common among participants, often manifesting as occasional worry or restlessness, but manageable without professional intervention. Green slice: this group experienced marked impairment, such as

Moderate Anxiety	~30%	difficulty concentrating or sleep disturbances, warranting monitoring.
Severe Anxiety	~10%	Small brown slice (labeled "Severe..."); high-impact symptoms like panic attacks or avoidance behaviors, indicating need for immediate clinical support.

III. Limitations of Conventional Treatments

Medications form a vital part of the therapeutic interventions used to treat anxiety disorders (3). Nonetheless, these have a few drawbacks, as evidenced by the fact that, for instance, benzodiazepines, which act by increasing GABAergic activity via GABA-A receptor modulation, offer acute relief from anxiety disorders. Nonetheless, the use of these drugs has several adverse effects, such as causing sedation, cognitive clouding, slowing down reaction time, developing a high level of tolerance, as well as the potential to cause dependence, which makes it difficult to stop the drug without experiencing withdrawal symptoms (16).

In the case of the management of persistent or chronic anxiety disorders, SSRIs have been generally considered the first-line pharmacotherapeutic approach to the management of the condition. These act by inhibiting serotonin reuptake, thus increasing the availability of serotonin at the synapses of the central nervous system (5,6). Even though these forms of medication have a number of benefits, the fact remains that the benefits of these forms of medication do not become apparent until after 4 to 6 weeks of use, with only 50-60% of the subjects experiencing complete remission of the condition (3). Among the adverse effects of these forms of medication, which result in the discontinuation of the drug as well as the failure to completely alleviate the symptoms of the condition, include sexual dysfunction, gastrointestinal disturbances, emotional numbing, as well as withdrawal difficulties, among others (3,7).

All these considerations emphasize the need to have alternative forms of treatment that act via different pathways, which have fewer adverse effects as well as better safety profiles (37,38).

IV. Ethnopharmacology and Phytochemistry of Clitoria ternatea

The climbing perennial, *Clitoria ternatea* L., of the Fabaceae family, has adapted well to several tropical and subtropical areas of Asia (20). The species has been well known for its bright blue or white coloration of the flowers, which have been used as a traditional medicine for a long time. In Ayurvedic medicine, the herb has been classified as a Medhya Rasayana, a category of herbs that improve cognitive functions, enhance memory, and improve mental clarity (20, 39). The roots, leaves, and flowers of the herb have been used to treat various conditions, such as anxiety, depression, sleep disorders, seizures, and cognitive decline associated with aging, as mentioned in traditional literature of Southeast Asia (20, 39).

The therapeutic value of the herb has been well justified by the presence of a diverse array of bioactive compounds, which include flavonoids, anthocyanins, alkaloids, triterpenoids, saponins, and phenolic compounds such as quercetin, kaempferol, ternatins, etc. These bioactive compounds have shown promising activity as an antioxidant, anti-inflammatory, neuroprotective, and neuromodulatory agent, which could modulate the central nervous system activity, producing anxiolytic- and antidepressant-like effects, as shown by various in vitro and in vivo studies (20, 29).

The combined effect of these bioactive compounds has the potential to provide a broad spectrum of therapeutic activity, which targets multiple pathways, as opposed to the single-target approach of conventional pharmaceuticals (31). For instance, anthocyanins have shown potent activity as a scavenger of free radicals, as well as the ability to downregulate the inflammatory cascade, thereby potentiating the neuroprotective effect of the herb (24, 26).

V. Preclinical Evidence and Mechanisms

Animal studies have revealed that the herb works to calm the brain through increased GABA activity. This works to calm the mind without the side effects of drowsiness often associated with benzodiazepine drugs. It seems that the flavonoids in the plant are the active compounds that increase the binding ability of GABA to its receptors. Additionally, the herb works on the serotonin and dopamine levels in the brain, possibly through the inhibition of enzymes that break these chemicals down, which results in increased levels and therefore a more stable mood. It is also known to have strong antioxidant properties that protect the brain from free radicals and maintain the
areas of the brain, such as the hippocampus, which are prone to damage from these free radicals in their normal state.

Regarding anti-inflammatory properties, the plant has been known to reduce inflammation in the brain through the reduction of TNF-alpha and IL-6 in lab animals. New information has revealed that the plant works to regulate the body's natural response to stress, the HPA axis, which results in increased resistance to tension through the reduction of cortisol levels and the regulation of the body's natural checks on the system.

The plant has been tested in standard mouse and rat models using the elevated plus maze, open-field test, and light-dark box test, which all measure the levels of anxiety in the test subjects and their ability to move through the test and into the areas of the maze that would cause them the greatest amount of anxiety. It has been revealed that the plant has strong anti-anxiety effects and works to improve cognitive ability in the test subjects, like the effects of drugs such as diazepam and alprazolam. A study in 2025 has revealed that the plant works to reduce anxiety in maze tests using 300 mg/kg of methanol leaf extracts, like the effects of 2.5 mg/kg of the drug alprazolam, without the side effects of drowsiness. A review in 2025 has revealed that the plant's alkaloids have been known to ease the tension and worry felt in the body through the modulation of the body's natural response to stress, which results in increased emotional well-being.

Safety studies indicate it’s quite safe, with no signs of addiction liability, withdrawal symptoms, or problems in animal studies at effective doses and with long-term use [9]. However, it’s worth noting that the chemical content of the plant may vary depending on how it’s grown, and therefore quality control must be exercised before use by humans. Recent studies from 2023-2024 are investigating brain-protective properties and other benefits such as prevention of asthma and diabetes through inhibition of certain enzymes, which may help with anxiety-related health issues.

Case Study: Prevalence and Distribution of Anxiety Levels Among Young Adults in Urban India (Fig.1)

Mental health issues, such as anxiety, are an important problem that is being faced globally, affecting many people every day. This is causing people to slow down, making work or school more challenging, as well as increasing medical expenses. In this analysis, we will investigate the ways severe anxiety manifests itself in 500 people between the ages of 18 and 35, living in urban areas of Uttar Pradesh, India, focusing on Lucknow. The data was obtained by using the results of the pie chart analysis of the data. The data was obtained by reporting the anxiety experienced by people during the early part of 2026, when the job market was uncertain, as was the outcome of the COVID-19 pandemic. The objective is to look for patterns that exist regarding the anxiety experienced by many, as well as the ways we can assist the anxious. The data was obtained by using a tool that is like the GAD-7, consisting of seven simple questions that determine the level of anxiety experienced by an individual, categorized as none, mild, moderate, or severe, as illustrated by the visual data provided.

Table 2.

Summary of Key Preclinical Studies on *Clitoria ternatea*

Study	Model	Key Findings	Citation
Jain et al. (2003)	Rodent CNS models (e.g., maze tests)	Anxiolytic effects via GABA modulation; reduced hyperexcitability	[20]
Rai et al. (2002)	Stress-induced models (e.g., forced swim)	Improved HPA regulation, nootropic effects; enhanced stress resilience	[22]
Samarth et al. (2008)	Oxidative stress assays (in vitro/in vivo)	Antioxidant protection against ROS; mitigated neuronal damage	[27]
Recent study (2021)	Elevated in rats	extract (300 mg/kg) Alprazolam	[24]
review (2025)	Various models Literature	Relaxing effects from alkaloids; reduced anxiety and stress	

Table 1 Table Type Style

VI. Conclusion

Generalized Anxiety Disorder, formerly known as Anxiety Neurosis, is a complex psychological state that is the result of a variety of biological factors. Some of the main factors that contribute to the development of Generalized Anxiety Disorder include imbalances in neurotransmitters such as GABA and serotonin, a hyperactive stress system that causes cortisol to be in a heightened state in the brain, oxidative stress that damages brain cells, and inflammation that is the result of chemicals such as TNF-alpha and IL-6. Overall, the combined effect of all these factors causes the brain to lose its ability to cope and results in the manifestation of Generalized Anxiety Disorder. However, the use of drugs such as SSRIs and benzodiazepines to treat Generalized Anxiety Disorder has its own limitations, such as the presence of side

effects, the development of tolerance, the development of dependency, the difficulty in withdrawal, and the lack of relief in a considerable number of patients. Thus, in the quest to find a solution to Generalized Anxiety Disorder, a variety of alternative options have come into the limelight. One such natural remedy that has come into the limelight as a possible solution to Generalized Anxiety Disorder is the medicinal herb known as *Clitoria ternatea*. It has been found to have the potential to treat Generalized Anxiety Disorder in a variety of ways, such as the modulation of neurotransmitters such as GABA and serotonin, the manifestation of anti inflammatory and antioxidant properties, the regulation of stress hormones via the HPA axis, and a good safety profile along with the manifestation of neuroprotective effects such as the support of BDNF activity.

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Digital Transformation in Fintech: Leveraging Cloud-Based Architectures for Scalability and Security

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***Abstract*—The finance and technology sector is now evolving and changing, expanding with the help of digital technologies, the basis of which is cloud architecture. Specifically, this research examines how cloud computing enables fintech organizations to attain business scale, security, and excellent user experience. One advantage of these new solution models is that these fintech companies can quickly adapt to varying demands in the market and avoid the costs of more rigid structures. At the same time, cloud platforms adopt new forms of security control, including encryption, multi-factor authentication, artificial intelligence, and other protection measures that help avoid the dramatic consequences of cyber threats.**

Some drivers for fintech cloud architectures are branching out product development, keeping with emerging regulations, and facilitating novel tools such as artificial intelligence and blockchain. Using examples of specific cases and general statistics, we assess the degree to which cloud usage affects operations and the level of customer satisfaction and compliance with legal norms. It also reveals data privacy, vendor lock-in problems, and adherence to particular legal jurisdiction norms.

The research concludes that a step-by-step stratified cloud transformation solution and a concentration on hybrid or multi-cloud models allow fintech firms to pursue the dual objectives of experimentation and mitigation. This paper adds to the developing discourse of literature on digital transformation in fintech: the future allied with cloud-oriented designs for the secure, elastic, and strong future that stakeholders increasingly yearn for.

***Index Terms*—digital transformation, fintech, cloud computing, scalability, cybersecurity, hybrid cloud, compliance.**

I. Introduction

1.1 Background

Fintech is an abbreviation for the financial technology committee, which is the integration of financial institutions and technological advancements. Fintech has grown quickly over the last decade. The growth can be aligned with the advancement of technology, the increasing need of consumers to fulfill their financial needs efficiently, and the advancement of mobile technology.

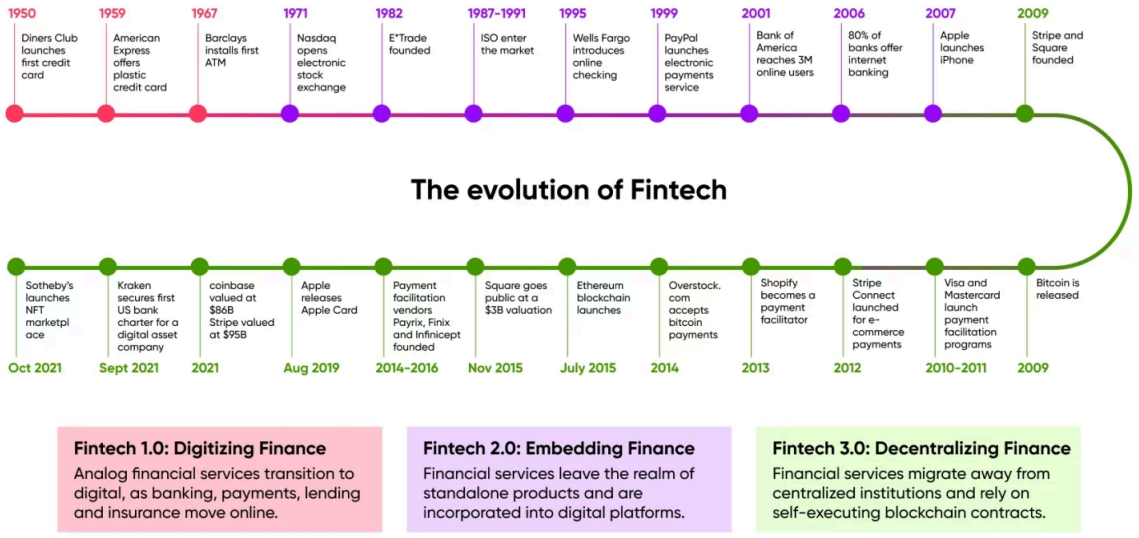


Fig 1: A timeline showing the evolution of fintech and the rise of cloud computing.

This growth trajectory has seen the emergence of many fintech startups and several traditional financial institutions modifying their structures to survive in a new Central Marketplace. Latest technological advancements like blockchain, artificial intelligence, machine learning, and big data analytics have paved the way for the enhanced deployment of fintech solutions. The information flow has facilitated the manufacturing of new and unique business solutions, products, and services to capture the various markets and the corporate world. The possibility it gave to banks and provide individualized and accurate financial services, fast and real-time transactions, and enhanced customer experience placed fintech as an important enabler of innovation in the financial industry.

1.2 Importance of Digital Transformation

Digital transformations express critical meanings for the sustainability and growth of fintech companies. Going digital is both a risk and a benefit, as seen below. On one side, it emerges that fintech firms are having challenges implementing new systems, as well as data security, propriety, and governance issues. In contrast, digitalization is proving to be a powerful imperative for change as financial firms stand to gain a range of benefits that compels fintech firms to improve the effectiveness of their operations, grow their customer base, and deliver value through optimizations to clients' experiences. Digital production and selling systems enable fintech firms to be efficient, cutting costs and providing unique services to meet their customers' needs. Similarly, using digital technologies will allow fintech companies to improve the speed of their reaction to the changed environment, for better decision-making supported by vast amounts of data, and to create a culture of innovation. In this regard, Timely transformation into the digital age is essential for such fintech companies as it is not luxurious but survival in a highly competitive and volatile environment.

Table 1: Comparative analysis of traditional vs. digitally transformed fintech models.

Aspect	**Traditional Fintech Models**	**Digitally Transformed Fintech Models**
System Implementation	Relies on legacy systems with limited scalability and flexibility.	Adopts advanced digital systems that are scalable, efficient, and adaptive to business needs.

Data Security and Governance	Often prone to fragmented data governance and manual security protocols.	Implements robust data security measures and governance frameworks with real-time monitoring.
Customer Experience	Generic services with limited personalization and slower response times.	Delivers tailored, real-time services with seamless customer interactions.
Decision-Making	Dependent on manual data processing and intuition-driven decisions.	Leverages data-driven decision-making supported by advanced analytics and machine learning.
Innovation Culture	Slower adoption of new technologies and resistance to change.	Encourages a culture of innovation, agility, and responsiveness to market dynamics.
Market Competitiveness	Limited ability to adapt to rapidly changing customer and market demands.	Strong competitive edge through timely adoption of digital strategies and technologies.
Operational Efficiency	Higher costs due to inefficiencies and reliance on manual processes.	Reduces costs through process automation and optimization.

1.3 Objectives of the Study

This study explores how cloud-based solutions can address two of the most critical challenges FinTech companies face: scalability and security. This is an important facet for Fintech firms to enable them to handle increasing work volumes and variability in demand effectively without her. This means traditional information technology architectures cannot offer the flexibility needed to expand different operations. Clouds are an excellent solution to this difficulty because the computing resources are accessed on-demand and can be easily scaled. Hence, through cloud-based structures, fintechs can align their resources with the customers' needs and balance the overall costs for the services rendered.

While innovation is key to developments in the fintech sector, security is paramount for firms within this industry due to the nature of the data and growing threats from hackers. It is important to have strong security measures to reduce the likelihood of owning one's data and information to third parties and to meet the stipulated legal requirements to protect customers' information and retain their confidence in the financial industry, such as end-to-end encryption, multi-factor authentication, and the AI-based threat detection that cloud service providers can offer fintech firms to improve their security. This paper aims to examine the usefulness of such cloud security features and their influence on the general security of fintech activities.

1.4 Research Scope

The research topic of the work is fintech, with a particular emphasis on how cloud architecture can help overcome issues of size and protection. The study scope involves cloud service models, including IaaS, PaaS, and SaaS, and how they can be deployed in the various fintech scopes. Further, the study discusses hybrid and political clouds, which are a mixture of public and private clouds and offer more freedom and authority to fintech companies regarding the structure of IT resources.

The research also focuses on compliance issues within cloud solutions for fintech companies and the need to respect legal requirements and best practices for personal data protection. Setting out this research, the goal is to find out how these firms have avoided potential problems and what measures have constituted recommendations for Cloud adoption. Additionally, the study analyses how innovative technologies like artificial intelligence and blockchain will contribute to the growth of the internalization of cloud-based fintech services. These technologies have the potential for profound and wide-ranging impacts on numerous areas of fintech processes and functions, including – but not limited to – fraud prevention, risk assessment, customer satisfaction, and transactions.

In conclusion, this research offers considerable insight into the advantages and disadvantages of cloud-based architectures in the FINTECH industry. In light of expanding the research to cover a broad population of UK fintech firms, this study seeks to make recommendations on corresponding practical steps that these firms can take to adopt cloud computing for digital transformation whilst satisfying critical needs for scalability and security. Thus, by providing a comprehensive review of existing literature, sharing best practices, case studies, and opportunities based on the analysis of current tendencies, development, and promotion of new technologies, this study advances the knowledge in the field of fintech digital transformation, guiding establishment of an effective cloud strategy for all players in this field.

II. Literature Review

The challenger banks and the fintech sector, in general, have seen rapid growth over the last decade due to technological development and changing consumer behavior. Cloud computing has become a critical driver of this change, enabling newcomers like fintech firms to innovate, grow, and protect their services. This paper explores the background and developments of cloud applications in the context of fintech, discusses and solves scalability issues through real-life case studies, security concerns, and problems, and explores the existing gaps in the literature that limit the future advancement of the use of clouds in fintech applications.

2.1 Overview of Cloud Technologies in Fintech

Cloud computing technologies are believed to have originated in the twenty-first century when new technologies like Amazon and Google commenced offering computing facilities on demand. These innovations transformed traditional IT infrastructure with capital-intensive expenditure through operational expenses so businesses could leverage storage and processing services on a usage model. However, in the fintech sector, the first adoption phase mainly targeted support or peripheral functions such as customer relationship management and backup. Still, as cloud platforms developed and companies received additional accreditations, such systems began integrating into high-impact financial applications.

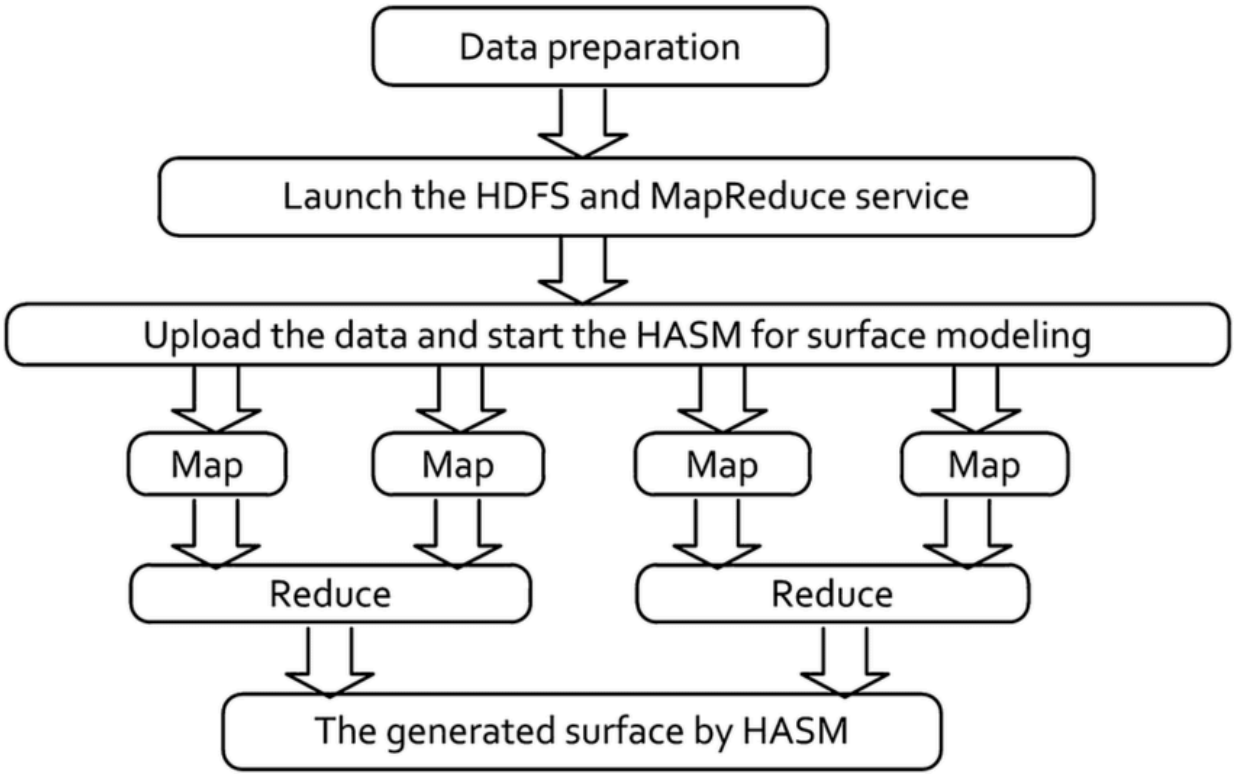


Fig 2: Flowchart showing the integration of cloud systems in fintech operations

New advancements in software have only boosted the use of clouds more in the fintech market. Serverless computing, containerization, and microservices architecture have led to the building of extensible fintech systems. Serverless computing frees organizations from the burden of maintaining infrastructure, making it possible to quickly implement financial apps without necessarily investing in servers. Likewise, containerization and the microservices' architecture completely unmold services into different deployable containers, resulting in new-age flexibility and maintainability. These technologies have become vital for all the fintech companies planning to deliver new products and maintain high availability and performance.

Further, ongoing and future enhancements in cloud-based artificial intelligence (AI) and machine learning (ML) have driven the evolution of new data analytics opportunities. Modern clouds have ready-made, intelligent solutions and resources for developing ML business solutions focused on detecting fraud and boosting customers' sales and credit scoring. Another trend is Cloud-based BaaS, which enables the deployment of decentralized ledgers as a service for applications like cross-border payment and smart contracts.

2.2 Scalability Challenges in Fintech

Since financial markets, including digital financial services capabilities, are fluid, the ability to grow to meet the ever-changing environment is a key metric for fintech firms. Cloud computing has tackled such problems since it provides scalable resources that can easily be scaled up or down. However, moving from these traditional architectures to cloud-based systems poses certain challenges.

For example, payment processing systems will find themselves processing more transactions over a short period during black Friday or other similar end-of-year sale occasions. A good example is PayPal, which shifted its system to the cloud to deal with the skyrocketing traffic related to payment processing. Through the advantages of working for cloud-native, PayPal gained almost real-time scaling features, so it could keep working simultaneously during important holidays. Another case is Robinhood – a fintech company focused on commission-free trading and counting millions of audiences. However, Robinhood, like many early adopters of cloud services, experienced scalability problems in 2021 during volatile market periods, causing occasional downtime. This brought more focus to how load balancing mechanisms and failure recovery needed to be implemented even at the cloud level.

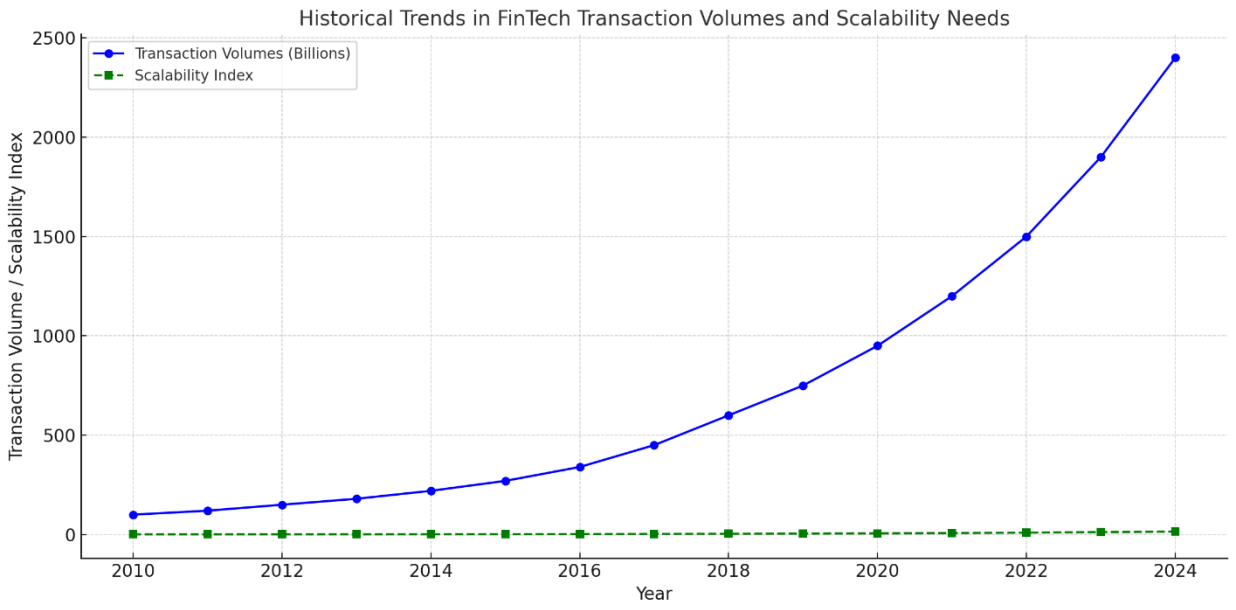


Fig 3: Historical trends in fintech transaction volumes and the corresponding need for scalability.

The current strategies for scaling are the use of multi and hybrid cloud approaches. The use of hybrid cloud structures, where part of the applications is hosted on proprietary infrastructure and part is provided by public cloud services, enables fintech companies to have ownership of the data belonging to their clients while at the same time leveraging the benefits of the SaaS models. On the other hand, a multi-cloud strategy is one in which the workload is spread out across multiple clouds to avoid the possibility of being stuck with a single vendor or having one vulnerable point that a single vendor can exploit. It is said that corporations such as Stripe are already utilizing multi-cloud solutions that provide high availability of work on various global levels.

Nevertheless, scaling up is challenging, especially for fintech companies working in emerging markets with scarce reliable cloud services. This warrants further studies on localized Computations, which refer to computation that is carried closer to the user to minimize the possible latency, as is seen with edge computing.

2.3 Security Considerations

It has also brought new security risks to fintech companies as cloud technologies have advanced quickly in the past few years. There are manifold reasons why cybersecurity is a significant concern in fintech apps – the primary one being that financial data is a popular category for hackers to attack. Using different cloud service models, cloud providers have enabled features like encryption, IAM, and smart threat detection driven by AI.

However, the flexibility offered by cloud infrastructure is a double-edged sword. Misconfiguration is a fairly new threat where cloud resources are not properly configured, rendering sensitive data accessible to anyone. For instance, high-profile cases where IP addresses and unregulated cloud storage buckets have been compromised have shown that poor governance is a real issue. Another outstanding threat is ransomware, when hackers lock information and request that the owner pay to unlock it. Fintech is most exposed due to the high data value that the companies realize and shocks or disruptions in the process.

To overcome these hurdles, the fintech firms have developed layered security strategies. These are protecting, transmitting, and storing data, using MFA to control data access, and performing security checks periodically. Also, cloud providers provide solutions like security information and event management systems that can help increase real-time awareness of threats. Implementing the zero-trust security concept, which assumes that no system is trustworthy, has brought additional layers of security.

Alas, these achievements are accompanied by the coming of new risks, and this means that curtailment requires continuous vigilance. As with quantum computers, which may soon endanger commonly used encryption techniques, there is a need to study quantum-resistant cryptography. In addition, using third-party

cloud service providers brings up the supply chain problem for application software since flaws in one provider can affect multiple others.

Table 2: security threats and cloud-based mitigation strategies.

Security Threat	Description	Cloud-Based Mitigation Strategy
Misconfiguration	Improper configuration of cloud resources, making sensitive data publicly accessible.	Implement robust governance policies, automated configuration checks, and compliance monitoring.
Ransomware	Hackers lock sensitive data and demand payment for access.	Employ data backups, encryption, and real-time threat detection systems powered by AI.
Supply Chain Vulnerabilities	Flaws in third-party cloud providers that cascade to multiple dependent systems.	Conduct rigorous third-party security audits and integrate vendor risk management practices.
Unauthorized Access	Breaches caused by stolen credentials or insufficient access control mechanisms.	Deploy multi-factor authentication (MFA), identity access management (IAM), and zero-trust models.
Data Interception During Transmission	Interception of sensitive data while being transmitted over insecure networks.	Use end-to-end encryption and secure communication protocols (e.g., TLS/SSL).
Quantum Computing Threats	Potential risk of quantum computers breaking traditional encryption techniques.	Explore and implement quantum-resistant cryptography to future-proof data security.
Poor Real-Time Awareness	Lack of timely detection and response to security breaches or anomalies.	Use Security Information and Event Management (SIEM) systems for real-time monitoring and alerts.
Data Theft from Storage	Breaches of cloud storage leading to unauthorized access to financial data.	Employ data encryption at rest, regular audits, and secure cloud storage bucket configurations.

2.4 Gaps in Existing Research

Despite the tremendous improvement in the absorption of cloud technologies within the fintech landscape, some research gapsled. One of the areas is the absence of robust benchmarks for assessing cloud environments' effectiveness and security in supporting fintech systems. Previous research is conventionally conducted in a siloed fashion, meaning there is a fragmented comprehension of the various applications and consequences of the technologies under consideration.

The second is the lack of an ethical evaluation of implementing cloud services in Fintech. For instance, when applied to cloud environments, the utilization of AI and ML sparks issues of bias and opacity of the algorithms. These technologies serve or have the potential of achieving or delivering a lot, but the possible way they might encourage discrimination or inequality is not well-researched. Likewise, research discussing the environmental disposition of cloud computing, especially concerning its energy usage, has been underexplored, though it has centrality today.

However, to the author's knowledge, a dearth of empirical literature examines specific difficulties arising from cloud-related implementation in small to medium-sized fintech organizations. Many of these firms, however, are relatively new to the area and may not have the capital and experience to deal with some of the more complicated cloud offerings. Due to this, they require different solutions and best practices regarding their digital transformation strategies.

Cross-border legal requirements are the last challenge hindering fintech cloud use. The regulations concerning data storage, processing, and transfer in various jurisdictions are different, making it challenging to undertake cloud-based solutions worldwide. Recent studies have shown that some progress has been made through GDPR in Europe and cross-border transfer frameworks in Asia, among others. Still, regression research seeks to create compliance and effectively work on harmonizing regulations and their impact on the development of Fintech.

III. Methodology

This research thus employs an extensive and cross-disciplinary approach to respond to the research question of how cloud architecture shapes digital transformation for fintech services. Given the strive for quality and a comprehensive approach to the research, the applied methodology implies using qualitative, quantitative, and combined research methods that meet the study's objectives systematically and inclusively. The research approach, data sources, and analytical framework that form the basis of the developed methodology are designed to offer insights into the nature of the studied phenomenon.

3.1 Research Approach

The research method deployed and adopted in the study is the qualitative, quantitative, and mixed method research approach, given their effectiveness at providing depth and broader cross-sectional coverage. The qualitative part of the study is concerned with establishing context and subject factors influencing cloud adoption in Fintech. In this way, the study analyses the strategic drivers, organizational enablers, and operational consequences of cloud architectures. Information is gathered with the help of surveys of fintech companies' managers, cloud services providers, and IT security analysts. During such interviews, the participants were asked questions to understand how and why the fintech companies are using cloud computing for scalability and security.

On the other hand, the quantitative part comprises the qualitative analysis of numerical and statistical data to develop practical correlations between cloud adoption and relevant performance indicators. For instance, customer acquisition rates, the costs of infrastructure, and the frequency of downtimes before and after switching to the cloud are compared. This allows the study to place a dollar value on these operating efficiencies related to cloud architectures, such as scalability for the business. Moreover, various measures connected with security occurrences, including data leaks or non-adherence to the existence, are also measured to make cloud-orchestrated security arrangements accountable.

This is so because while the qualitative data provides rich descriptions, the quantitative data provides the numbers; combining the two provides an even broader and less biased perspective. This makes the qualitative data supply background views and reasons, while the quantitative data offers neutrality and familiarity. For example, self-reported data collected through interviews on the shortcomings in organization cloud implementation are compared to other data to establish relationships or lack of correlation, revealing stronger conclusions. This doubled approach guarantees that the research covers all the key bases in the complexity of digital transformation in Fintech.

3.2 Data Sources

The selection criterion used for the data sources of this research is that only relevant, up-to-date, and academically credible sources are used. Three primary categories of data sources are utilized: scholarly papers, fintech business examples, and technological specifications of cloud solutions. Each category has a specific goal in analyzing the research problem, which will be discussed in the subsequent sections of this manuscript.

These are research questions and academic literature as the theoretical framework of the research. Journals, conference papers, and books on digital transformation, cloud computing, and financial technology (Fintech) are thoroughly scrutinized. These sources acquaint the researcher with existing knowledge and reveal concepts, models, and knowledge deficits that are of focus to this study. For example, academic works in cloud security standards provide a theoretical framework to assess the adequacy of encryption and multi-factor authentication solutions in the fintech industry. Consequently, literature on change management to organizational change underpins the exploration of cultural and structural impediments to cloud acceptance.

Fintech case studies make up the data collection based on which the research is conducted. These cases are gathered from industry reports, white papers, and other publicly available business reports and reviews. They offer actual case descriptions of what fintech organizations have done to adopt cloud architectures and, therefore, capture details of the rationale, difficulties, and consequences of such processes. For example, the study considers the scenarios when such fintech challengers have successfully experienced a high degree of scalability thanks to cloud-native structures and the cases when traditional financial players have experienced difficulties implementing consolidated structures of cloud environments with legacy systems. These case studies are explored to uncover patterns, benchmarks, and implications that ground the research and lend it intrinsicality.

The third data source type is technical documentation connected to cloud architectures. These are white papers and user and technical manuals developed by the major cloud providers such as Amazon Web Service, Microsoft Azar, and Google Cloud Service. These documents give an overview of the technical capability and the shortcomings of cloud solutions in meeting the needs of fintech applications. For instance, the research seeks to explain how particular forms of cloud services, such as serverless computing or container orchestration, meet the scalability needs of fintech platforms. Likewise, technical documentation concerning encryption algorithms and compliance frameworks is also considered while assessing security and regulatory points.

Due to the employment of various data sources in the research, necessary and sufficient balance is achieved. From the current academic literature, hitherto the case studies, the theoretical and practical information can be advanced, and technical documentation proves to be rich for the technical information. Altogether, these sources provide a solid foundation for the analysis.

3.3 Analytical Framework

The methodological approach to data analysis used in this investigation comprises methods recognized within the sphere of record analysis and enhances them with a technique for developing hypotheses. Two primary analytical tools are utilized: the SWOT and PESTLE analyses, which are distinctive in their functions during the research.

SWOT test is helpful to determine the possibilities and risks connected with the widely used cloud-based architectures in Fintech. The strengths are centered on the goodness of the concept surrounding cloud computing, such as flexibility, cost advantages, and high-level security measures. Strengths explore the strengths: flexibility, scalability, cost-effectiveness, a rich range of hosting, storage, and processing services, and the ability to mitigate risks quickly. Opportunities depict the possibility of innovation, such as the use of artificial intelligence and Blockchain on the cloud, and threats focus on dangers, such as regulatory risks and ever-changing threats from hackers. In particular, applying the SWOT analysis guarantees the balanced appraisal of the results of cloud adoption about the internal and external factors that define the fintech industry.

Macrobusiness analysis, also known as PESTLE analysis, is used to analyze the external environment that concerns the adoption of cloud architectures in the fintech industry. The use profile explores the strategic capacity of cloud services through issues related to acceptable usage policies, government support, legal compliance, and trade policies. For instance, the role of data localization laws in various regions in adopting cloud solutions is explored. The economic perspective investigates the market forces, costs and revenue generation, and investment in and on cloud technologies. User acceptance focuses on social issues, the

culture of technology acceptance, and the buyer's trust role in driving cloud use. Technological factors assess the progress in cloud communication, ranging from serverless and edge computing to cloud security with artificial intelligence integration. Legal factors refer to compliance with certain laws, such as GDPR and PCI DSS, which file environmental factors that consider the ecological friendliness aspect of cloud infrastructure, such as energy consumption and carbon footprint.

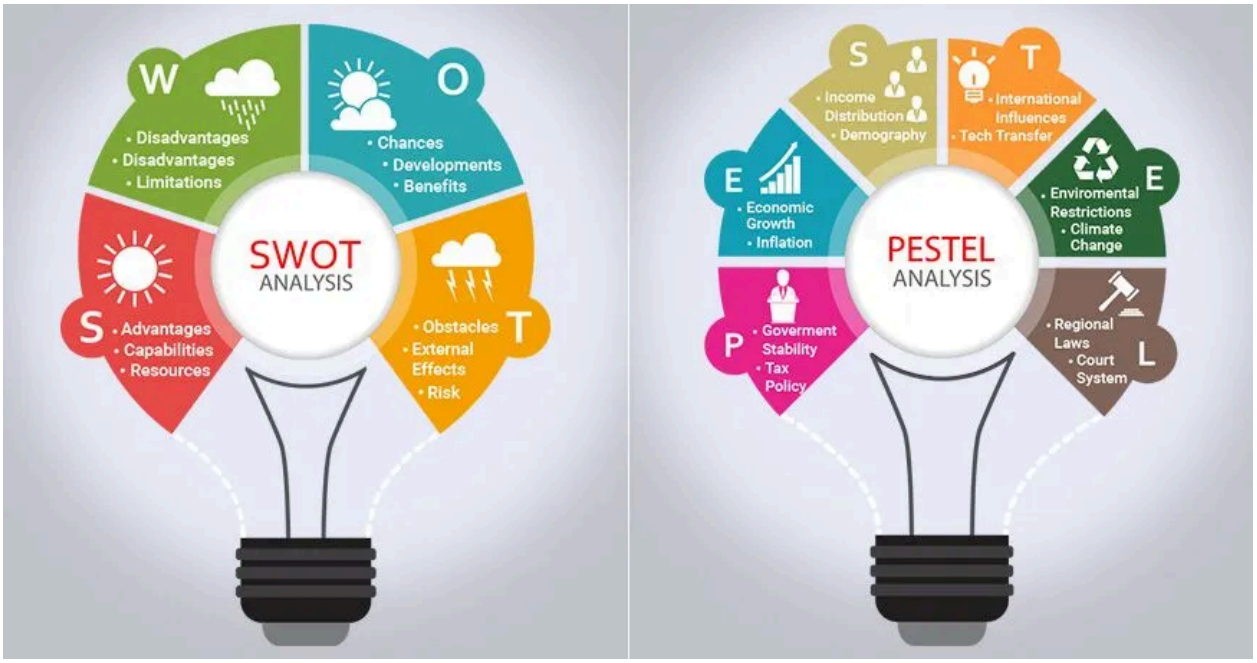


Fig 4: Visual representation of the SWOT or PESTLE analysis framework.

Further to SWOT and PESTLE, statistical techniques are used in qualitative data analysis involving figures. For instance, in a given case, regression analysis is used to define how different degrees or statistics of cloud adoption relate to a particular statistic of organizational performance, such as cost, customer satisfaction, etc. Likewise, to analyze trends in the cloud, the trend analysis technique is employed to look at data collected in the past to try and understand future trends. Primary data in the form of interviews is analyzed through thematic analysis to find major themes and patterns regarding the motivations, barriers, and impact of cloud adoption in Fintech.

The coordination of these analytical tools means that the evaluation results are done in a structured manner and with precision. Arguing from theory, evidence, and technique, the analytical framework offers a solid foundation to discuss cloud architectures' contribution to the fintech industry's digital agenda. Such stringency of the method makes the research results credible, accurate, and useful for furthering theoretical advances and the application of findings in Upper Assignment.

IV. None of the identified approaches are related to Cloud-Based Architectures in Fintech

Fintech has experienced tremendous growth and evolution in the recent past. It has been boosted hugely by the development of cloud computing, where cloud infrastructure has become the foundation for new-generation fintech solutions. Cloud architectures provide unique opportunities for growth, protection, and flexibility that allow fintech firms to meet new market needs, legal expectations, and consumer demands. This section includes information on the various forms of cloud architectures, their scalability capabilities, and the security improvements these architectures offer as significant enablers of fintech's digital transformation.

4.1 Cloud Architecture Models

Fintech cloud solutions can be classified into public, private, and hybrid clouds classified into public, private, and hybrid clouds, with advantages that depend on the company's requirements. These are cLOUDs run by third parties and are widely used since they are cheap and easy to implement. Public clouds

are used by fintech organizations where applications need high computational power, like credit scores by AI algorithm, fraud detection, etc. because public clouds are virtually elastic. Nonetheless, with two major cloud delivery models available, the shared nature of public clouds may present issues concerning data privacy and compliance in certain countries or regions.

On the other hand, private cloud architectures are some architectures that are built for use by one particular organization. Thus, the organization has much control over the data and security in the cloud. These architectures are particularly suitable for fintech organizations that interact with highly confidential information, including identification or payment information. Private clouds are relatively expensive and difficult to manage, but they guarantee good data security and are more flexible per user specifications.

The strengths of both worlds must be utilized through hybrid cloud solutions; although fintech corporations can scale through public clouds, key workloads must be retained within privatized regions. For example, firms in the fintech industry can use front-end customer applications running on the public cloud while maintaining the crucial backend services in the private cloud. This versatility is especially desirable for organizations that must heed the rules and regulations of many jurisdictions at once and address the increasing consumer desire for new and improved digital offerings.

Table 3: Comparison of public, private, and hybrid cloud solutions.

Aspect	**Public Cloud**	**Private Cloud**	**Hybrid Cloud**
Definition	Cloud infrastructure run by third parties and shared among multiple organizations.	Dedicated cloud infrastructure for a single organization.	Combines public and private cloud infrastructure for flexibility and scalability.
Cost	Low cost and easy to implement.	High cost due to customization and dedicated resources.	Moderately priced, balancing scalability with control.
Use Case	Applications requiring high computational power, such as AI-based credit scoring and fraud detection.	Ideal for managing highly confidential data, such as identification and payment information.	Best suited for balancing scalability with regulatory compliance and secure backend operations.
Scalability	Highly scalable and virtually elastic.	Limited scalability, constrained by available resources.	Scalable, leveraging public cloud for non-critical tasks while retaining key operations privately.
Data Security	Shared infrastructure may raise data privacy and compliance issues.	Offers high levels of security and control over data.	Ensures critical data remains secure while enabling broader functionality.
Ease of Management	Simplifies management with third-party service providers.	Complex to manage due to the need for in-house IT resources.	Requires managing both public and private cloud environments.
Regulatory Compliance	May face compliance challenges in regions with strict data protection laws.	Easier to meet compliance requirements due to full control.	Allows compliance by hosting sensitive workloads in private environments while leveraging public flexibility.

4.2 Scalability Features

Another major benefit of cloud-based architectures in FinTech's layout architecture is scalability. Relational IT environments can barely fulfill the dynamic nature characteristic of many fintech applications, for instance, during heavily loaded working time or sales promotions. While software architectures use software constructs such as queues and threads to implement the scalability of software resources, cloud architectures use dynamic resource provisioning to manage the scale of computational and storage resources. This ensures fluid use by the users while claiming less working space and operational expenses than over-provisioning hardware would. Another important intrinsic scalability aspect within cloud solutions is load balancing. Due to the distribution of various tasks or duties across numerous servers, load balancing helps avoid system crashes and guarantees the available services. For instance, load balancing will help payment Processing systems manage thousands of transactions simultaneously, with a small delay and system failure. This capability is especially important for the fintech players, given that disruption of their services may have serious reputational and financial costs.

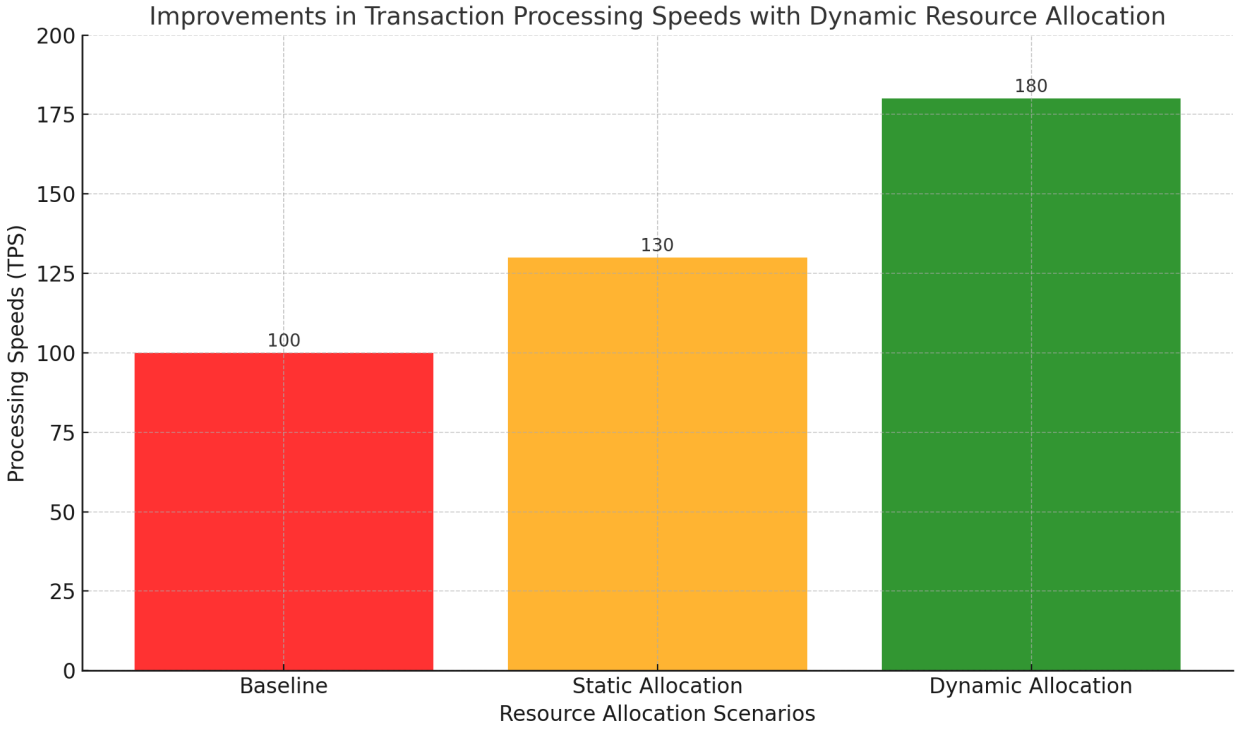


Fig 5: Bar chart illustrating improvements in transaction processing speeds with dynamic resource allocation.

Containerization goes further to build up the cloud structures of a scalable environment where the fintech firm can distribute the applications and dependencies into containers. Containers have little overhead; they are easily movable and shareable across different platforms. This allows fintechs to grow such applications at a very high speed while maintaining uniformity and stability. Also, other orchestration tools, such as Kubernetes, help scale and automate container management IT operational staff.

4.3 Security Enhancements

As shown, security in the fintech industry is critical since breaches affect not only one's pocket, reputation, and regulatory fines. Some cloud architectures today are more secure, given the challenges fintech organizations face. This imperative first layer of cloud security ensures that Sethatata is protected in transit and storage. Rich encryption norms like AES 256 shield customers' vital details, payment details, and transaction records. It also found that cloud providers provide key management services that allow fintech companies to retain key management while conforming to industry standards. The zero-trust security

models make cloud architectures even more secure than they currently are. For a zero-trust environment, no user device is considered trustworthy, even inside the organizational network. However, reliability tests are conducted continuously, and very tight security measures are employed to prevent intrusion. This applies to fintech insulin threats, and complex cyber threats are real threats in the financial industry. Cloud platforms apply zero-trust mechanisms using multi-factor authentication, IAM products, and real-time user action monitoring tools.

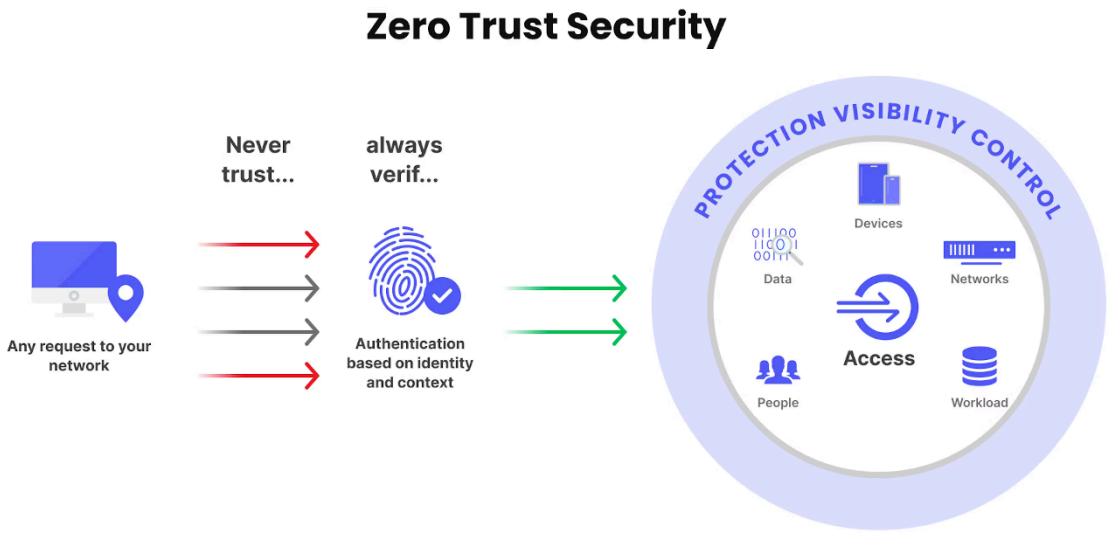


Fig 6: Zero-trust architecture model for cloud-based fintech systems.

Lastly, compliance frameworks are another cross-cutting or multiple services domain aspect of cloud security in fintech. Financial institutions worldwide have certain regulatory standards set by legal bodies to safeguard consumer information and maintain the reputations of the economic sectors. Cloud providers provide compliant environments to help fintech firms meet these needs. For instance, most cloud platform solutions are compliance-ready, including the Popular PCI DSS for the Payment Card Industry, Data Protection across the EU via GDPR, and Service Organisation Controls via SOC 2. These certifications showcase the cloud provider's adherence to the best security and compliance practices, thus easing the regulatory compliance burden on the fintech firms.

Nevertheless, the deployment of cloud-based architectures poses certain problems. Data privacy issues are still a massive issue, especially due to certain countries restricting the storage of data on their soil due to what is referred to as data localization policies. In response, the cloud's sellers have localized computing centers and mechanisms for controlling data trafficking across borders. Vendor lock-in is another challenge when depending solely on a certain cloud provider. Such risks have seen fintech firms turn to multi-cloud models that see them take the best of the different providers but use no single provider.

V. Case Studies

5.1 Successful Implementation

Cloud computing has become quite integrated into the fintech industry, as the results have proven that it increases the prospects of scalability, flexibility, and innovation for many organizations. A well-known example of service usage is Stripe, a company that provides payment services worldwide. Stripe has leveraged cloud architectures to offer payment processing platforms to business entities. By incorporating cloud computing, the firm can issue billions of transactions per year with low latency and guaranteed availability. It also means that the cloud has remained a flexible tool at Stripe, enabling it to turn on new features such as machine learning-based fraud detection systems without downtime. Stripe also

proves how cloud solutions can easily scale up during the highest traffic period, be it Black Friday or some other shopping holiday.

Another example is Revolut company, the digital banking platform that has changed personal finance management with the help of the cloud. With microservices heavily embracing the cloud, customers receive real-time exchange rate and cryptocurrency trading capabilities and prompt spending notifications. With the support of cloud architecture, Revolut is a company that has been proven to expand its functionality across different regions to millions of customers. Besides, applying a modern and adaptive cloud-based security system helps meet complex financial legislation requirements in various countries. As the case of Revolut shows, the use of the cloud provides for a relatively smooth market entry because it reduces the degree of difficulty connected with operating globally.

Likewise, Robinhood, the first no-trading fee trading app, has used cloud computing to bring trading closer to everyone. In the current operations, Robinhood handles millions of trades daily through advanced cloud technology platforms, enhancing real-time data updates. The cloud is also helpful to the state-of-the-art risk controls, which protect users from market fluctuations and fraud. The Robinhood example of fast-growing during such phenomena as the GameStop trading in early 2021 shows that cloud services allow companies to handle increased traffic without risking slowing down or getting hacked.

Such success stories explain the awakening of the power of cloud solutions for businesses. They demonstrate how breaking from the barriers of traditional architecture models can enable creative organization growth, increase the pace of delivering new solutions to the market, and allow for the response to the unpredictable changes. But of course, with these success stories, it is necessary to name the moments when cloud adoption has met with special difficulties – though the experience gained here can also be helpful.

5.2 Lessons Learned

Alternatively, several companies have gained higher levels of transformation success through the usage of clouds; however, they have faced several challenges that offer important lessons regarding this transition. It is not surprising that one of the most frequently reported issues is data protection and related legislation. firms mainly function in restrictive settings, and contractual implementation of the cloud commonly presents issues associated with geography and legal standards. For instance, a big multinational company was penalized after realizing that data from several customers hosted in the cloud did not meet GDPR requirements. This case underpins the need to adopt responsible approaches in choosing cloud providers and examine their regional data storage services options more carefully to identify their compliance with regulatory requirements before transferring sensitive workloads.

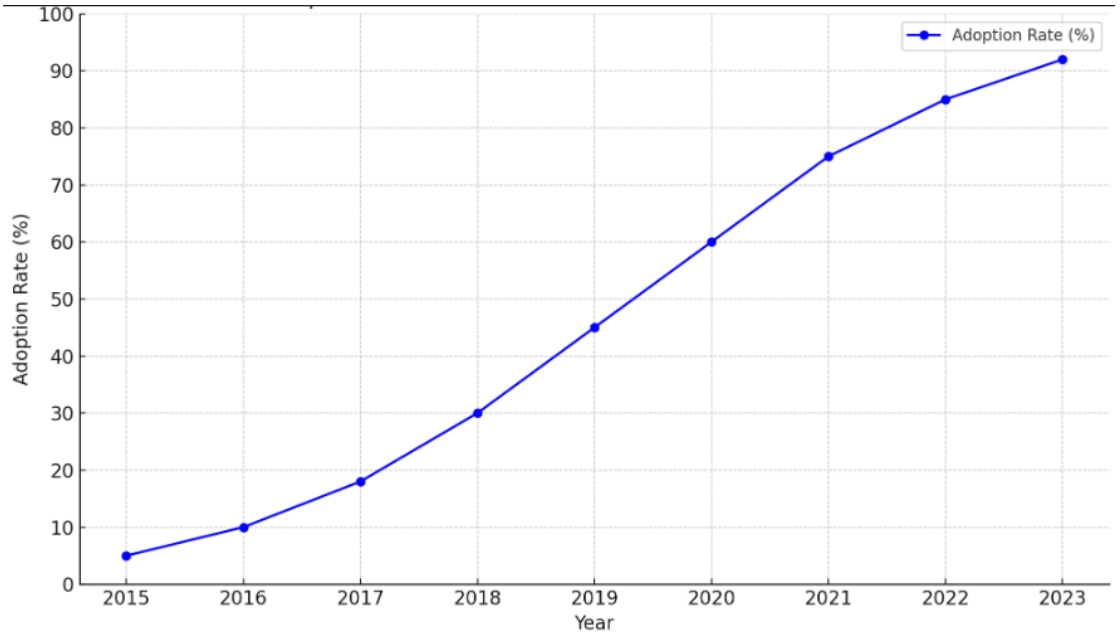


Fig 7: Line graph showing the adoption curve of cloud-based fintech solutions over time.

A very important issue is the risk of vendor lock-in, meaning that the fintech companies rely heavily on one cloud service provider only. One case that was well covered is a mid-sized fintech startup company that very quickly grew to utilize the services of one of the largest cloud providers. In due course, it became an issue of throughput where the provider tied the company down in terms of pricing structure and implementation flexibilities of the infrastructure. When the firm sought to evolve to the multi-cloud model, it had high costs and technical challenges because there were no compatibility issues between clouds. This example reiterates the need for organizations to take a best-of-breed or multi-cloud strategy from the very first day of any technology initiative to retain control of the business to some extent and avoid problems that arise from being locked in and dependent on a single cloud service provider.

VI. Key Findings and Discussion

6.1 Trends in Digital Transformation

The fintech industry is experiencing rapid change across the globe. The technological developments that are taking place are seen as a means to an end that is impacting and creating more opportunities for financial services. Pervasive trends in digitization are mobility in banking, AI, ML, blockchain, and fluids; however, cloud technologies remain crucial. They indicate a general trend in the financial services industry towards value-driven, adaptable, lean business operating models.

Mobile-first and digital-only banking solutions have emerged as one of the most important shifts in the industry. Since consumers today seek convenient and straightforward access to financial products, such firms are using technology-enabled platforms to perform such services. These platforms typically leverage the expansive computing capability the cloud-comp mechanism offers to address data volume issues and real-time customer behavior analysis issues. Moreover, combining AI and ML in has allowed companies to provide the most customized services and produce like loans or financial suggestions. AI & ML are also most extensively used in risk mitigation, fraud detection, analysis of the bet, and future forecasts, and this helps companies to make better decisions for growth and to improve customer satisfaction.

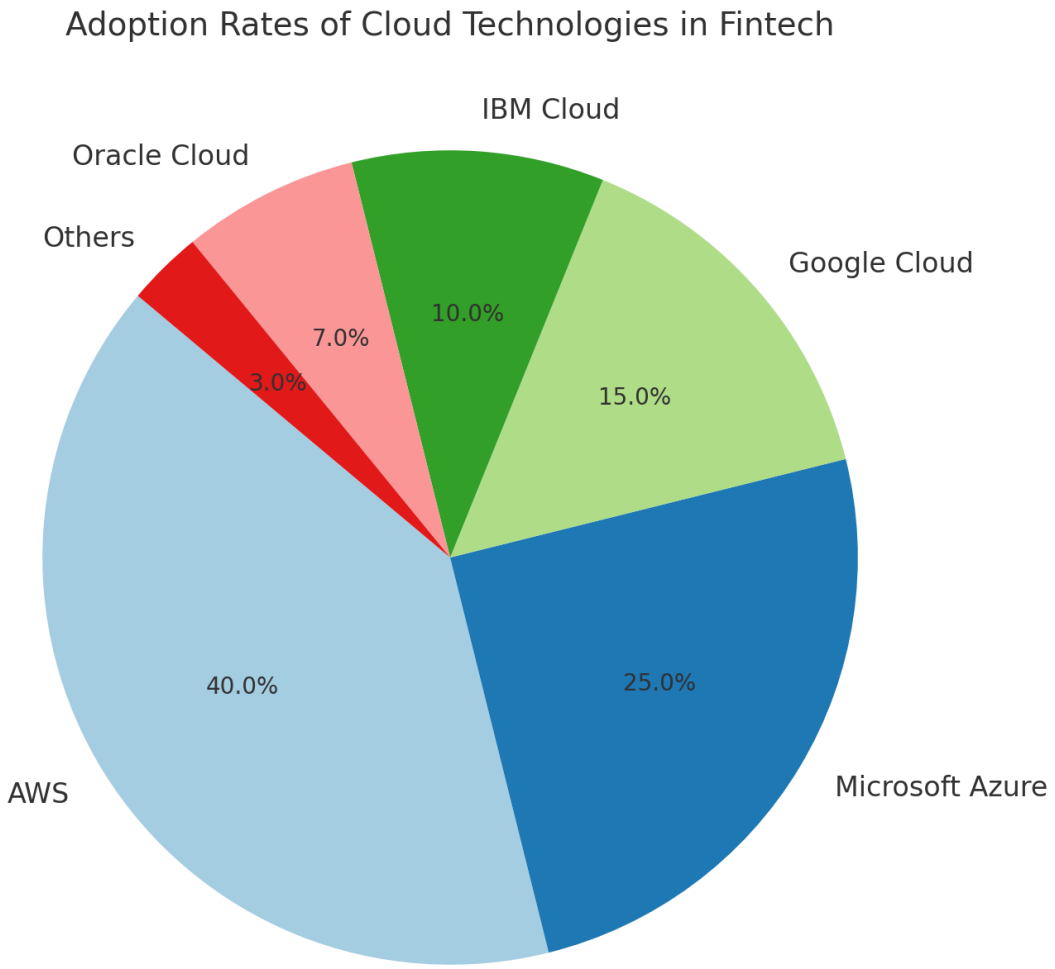


Fig 8: Pie chart displaying the adoption rates of various cloud technologies in fintech.

Another noticeable shift is the use of blockchain, a reliable technique for managing financial information. As for using blockchain for it is still emergent, whereas it can positively impact several aspects, including cross-border payment solutions, decentralized finance, etc. This means that instead of requiring people to set up their nodes where the blockchain should be running, cloud technologies provide the necessary computing resources for blockchain and execute decentralized applications (dApps) and smart contracts. For this reason, the blockchain plays an important role as a tool that underpins in aspects such as security, transparency, and efficiency.

The progress in adopting more digital-focused financial services has also increased the pace at which organizations require comprehensive security solutions. In gathering and processing large volumes of customers' information, companies have focused on ensuring that these data are secure from cyber risks. Therefore, they cannot be discussed independently because cloud solutions are critical to maintaining data confidentiality, integrity, and availability under growing cyber threats.

6.2 Role of Cloud Technologies

As shown earlier, cloud solutions remain a core area for leveraging the opportunities of digitalization in the industry and business development. The first benefit of cloud systems is their flexibility in terms of infrastructure that can grow along with the needs. This scalability is critical to firms because they must address varying levels of demand, supported by seasonal fluctuations, changes in market conditions, or the introduction of new products/services. Subsequently, with the cloud, one can escape the problems and

enormous costs of physical IT infrastructures, which used to be vital for large investments in the ambient to make voluminous accommodations for the consistent expansion of various businesses.

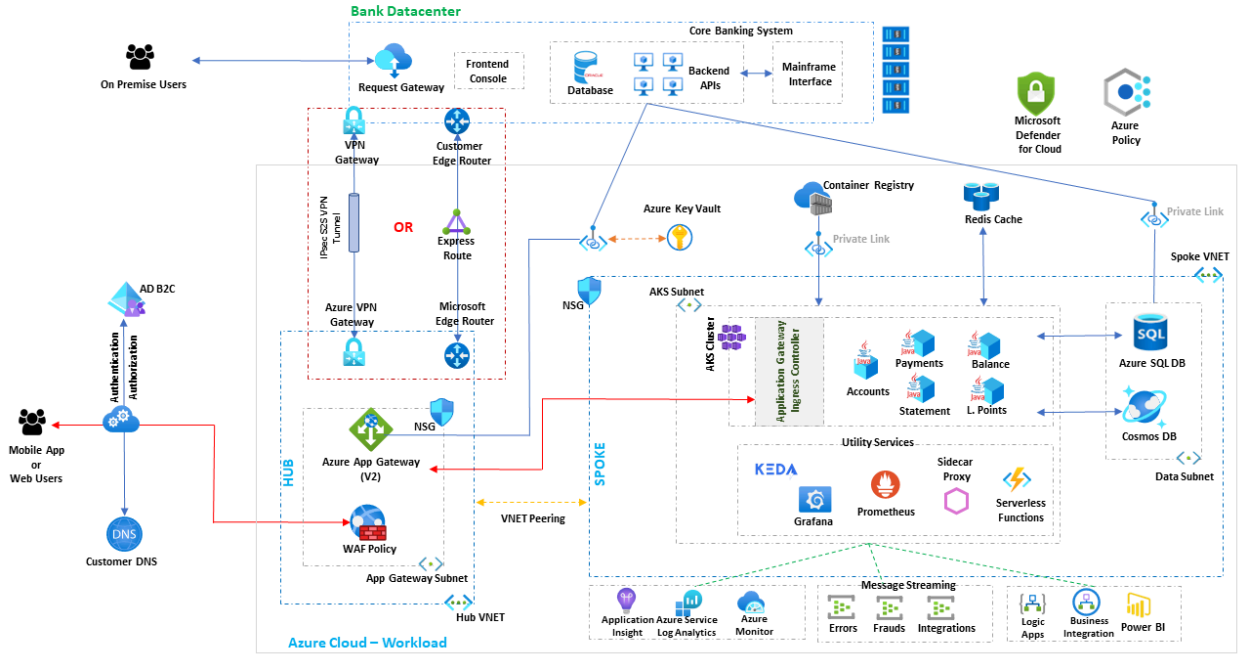


Fig 9: Workflow illustrating the integration of cloud services into fintech ecosystems.

However, cloud technologies also help business growth by promoting innovation and enhancing the time spent marketing new products and services. It is a significant advantage that, unlike traditional methods of developing solutions, can deploy new and improved solutions in a cloud-based environment, thus allowing more time for continuous product improvement. It also means that fintechs can readily dip their toes into new technologies, like artificial intelligence, machine learning, or blockchain, even without intense investment in hardware and software. This ability to innovate fast can keep one relevant in the industry, which continues to grow at an alarming rate.

Besides scalability and innovation, cloud technologies improve operations by simplifying IT and minimizing its complexity. Today, multi-cloud deployment is available as the companies can delegate routine tasks such as patching, maintenance, and security monitoring to the cloud providers. firms can also outsource such important duties to the cloud service providers, thus enabling them to leverage other crucial areas of development, including customer outreach, product design, and market penetration. In addition, since the cloud platform is centralized, it facilitates better communication between the teams since anybody in the world can access the applications and data, thus making the organization more responsive to action.

It will also show how cloud computing is valuable not only for the IT aspects of operational efficiency. Cloud technologies are also effective in flexibility in data storage, computing, and analysis. firms can use cloud-based data lakes and big data platforms to analyze real-time transactional data for customer behavior, market trends, and business performance. This analytical approach strikes companies confident in their business decisions and capabilities to improve customer service delivery.

6.3 Trade-offs: Scalability and Security

On the other hand, more rigid security arrangements could cage the ability of companies to grow rapidly. For example, measures using security measures such as strict access control measures, encryption, and the use of multi-factor authentication will slow the provision of new services or add operational overhead. Thus, it is a critical question for companies. For this reason, it is necessary to balance these priorities, using great cloud security models and being flexible and scalable to meet customer expectations in the innovative technology field.

One of these ways that companies can meet this trade-off is by adopting a hybrid or multi-cloud strategy. This composite structure allows businesses to protect sensitive data or essential applications by confining them securely in specific private cloud spaces while leveraging the available scalability and economic benefits of public cloud environments. This approach helps companies grow their businesses at a very fast pace without having to denigrate their security measures.

VII. Future Directions

Technology is more frequently integrated into the financial services subsector as the digital transformation process advances. The future development of the business will be shaped by trendy technologies, regulation issues, and the subsequent research individually during the shift to cloud systems. This section presents the future course of cloud usage in, its relationship with artificial intelligence and blockchain, policy issues concerning cloud systems, and future research directions.

7.1 Emerging Technologies

As fintechs continue their move to cloud architectures, they can incorporate newer and younger technologies, including AI and Blockchain. The application of AI in cloud solutions may change how new models are developed and delivered as it provides data insights, aids in prediction, and improves the automation process in financial institutions. AI can assist in enhancing the general capabilities of customer service through enhanced chatbot interactions, using improved predictive algorithms for risk management, or even detecting frauds by analyzing the various transaction data feeds in real-time. Probabilistic outreach processing, as applied to the cloud and allied with machine learning, offers new and intelligent ways to construct financial products and deliver unique customer experiences that were not possible before.

Moreover, using these two technologies in connection with cloud systems could also open the path to the decentralization of finance (DeFi) applications that can potentially displace centralized financial intermediaries. DeFi is built on blockchain technology with decentralized transactions and relies on cloud computing for computational storage for operational complexity. Cloud infrastructures will prove instrumental in addressing the computational and storage demand of decentralized Finance platforms. At the same time, blockchain systems will help bring transparency, security, and, more importantly, trust to the widespread adoption of DeFi platforms.

7.2 Policy Implications

While choosing the new technology, firms must solve the legal regulation of cloud services, which may significantly differ in various countries. Cloud usage presents new risks destined for data ownership and privacy, along with needed adherence to policy and fiscal standards that regulators should address appropriately. Policies concerning the usage of cloud solutions should be adaptable to the prevailing technological landscape and the prospects of cloud-based systems.

The first major compliance risk is related to the protection of the data. To protect consumers' personal information, armed by legislation like the General Data Protection Regulation (GDPR) and California Consumer Privacy Act (CCPA), financial institutions must ensure the privacy and security of consumers' data. These regulations put in place conditions that require data to be stored, processed, and accessed in specific manners, which become even more complicated when the data to be hosted is financial data in cloud platforms located in different regions. Balancing privacy concerns and data protection, on the one hand, and pro-business policy for cross-border data flow, on the other hand, has been a major task of the regulators.

In the case of the second set of policies, cybersecurity is one of the most pressing issues. As the use of the cloud continues to rise, so does the exposure to cyber threats. The regulations need to define rules for cloud vendors to adhere to have a high protection standard against a breach. This entails some of the following: encryption, identification, and authentication factors, as well as the action step in case of a breach. It is proposed that governments and other regulatory authorities need to engage stakeholders in the industry to

formulate a common benchmark that will align with addressing emergent threats like ransomware, denial-of-service, and insider threats.

7.3 Research Opportunities

Although enough progress has been achieved in the design of cloud-based solutions, there are many opportunities for further research that may stimulate additional development of the concept in the industry. Enterprises using cloud computing as one of the preferred models must impose advances in artificial intelligence interaction with blockchain platforms. Even within, the combined potential of both technologies is largely unknown. Studying how AI could integrate into blockchain protocols in cloud systems could improve the subsequent decentralized computational intelligent financial services. For instance, it can be applied to improve smart contracts or estimate market tendencies accurately; on the other hand, blockchain technology can serve as an unchangeable record of certain operations.

Another potential area for further study is improving multi/hybrid cloud system implementation schemes for use cases. Given that innovative firms in the financial technology market often depend on several cloud providers for versatility and business continuity, further investigation into delicate issues such as data management, compatibility of applications among different providers, and cost recovery are deemed fundamental. Proposing methods for migrating data between these clouds securely and effectively will strengthen the scalability and reliability of the presented solutions.

Furthermore, there is concern because cloud-based solutions raise various ethical questions. AI, big data analytics, and the use of machine learning to make or support financial decisions cause algorithmic bias and discrimination issues, as well as the nature of such automated processes. Research on how firms can deploy ethical and explainable AI is an important research avenue that could greatly shape, given that cloud solutions must remain transparent and able to explain their inference processes.

VIII. Conclusion

solutions to address important issues, including scalability and security challenges. It can be seen that as these fintech firms adjust to this digital landscape, the use of cloud solutions has become a core necessity for delivering new solutions to consumers. This conclusion summarizes the findings from this research regarding how cloud computing might enhance the delivery of fintech services by creating solutions that have eluded the industry's scalability and safety challenges.

Flexibility has always been one of the chief pain points for fintech firms, especially when they are expanding and exploring additional services and markets or coping with sudden spikes in traffic. Enterprise and conventional approaches to IT infrastructure require long-established hardware and software, are expensive, and may slow innovation when markets change drastically and expectations grow higher. Contrary to traditional structures, cloud computing allows for the increasing or decreasing of resources in a much shorter period, meaning that fintech organizations can improve their resources as needed but do not remain tied to them once they prove unnecessary. This elasticity helps achieve operational cost efficiency and deliver appropriate and timely market and client reactions. From gaining added capacity during increased user traffic during a finance increased user traffic during demand, flexibility becomes the key to sharp competitive skills of the fintech companies through leveraging the capacity of the cloud.

Essential innovation gained through cloud infrastructures is potentially reducing and automating tasks that call for an overwhelming workforce, thereby enhancing the efficiency of FinTech organizations. This simplicity is especially important for fledgling start-ups and other relatively modest-sized entities in financial technology, often known as 'fintech' organizations, that must quickly establish new forms of finance or monetized service. Thus, adopting the cloud allows these firms to rely on their strengths, for example, in product development and customer satisfaction, while relying on cloud service providers to manage their infrastructures and systems. The outcome is establishing a lean supply chain, lower costs, and shorter time-to-market. This allows the organization to continually evolve processes and methodologies to deliver on customer needs and effectively respond to competitors' market offers.

In terms of security, firms in the fintech industry experience increasing cyber risks and regulatory obligations. The financial sector worldwide is one of the most regulated industries, and companies must adhere to rules of Data Privacy, AML regulations, and finance reporting. Cloud computing, a highly developed technology, provides more suitable features to financial technology firms, including network encryption, two-factor authentication, and monitoring services. The opportunity to launch and implement new-generation security technologies and services for cloud applications directly in the cloud environment offers protection levels that cannot be achieved when using traditional on-premises solutions.

In addition, the scale of CSPs and their core competencies means that the fintech firms can reap from frequent updates and bug fixes in a way that will ensure that any given online threats are constantly thwarted. They have the capital and clout to pay the high costs of the most sophisticated technologies to which other companies cannot gain access. Therefore, fintech organizations can cut the risks of data loss due to cyber threats by half and improve the confidence of their clients. This is particularly important in today's settings, where consumers are increasingly worried about the safety of their personal and financial information.

These two characteristics are urgent as more fintech firms extend their operations internationally. Having a presence in more than one country also challenges regulatory systems and the need to honor data sovereignty regimes. Cloud solutions allow users to adapt the location for data storage and processing to different countries to comply with their legislation. Also, most cloud providers provide compliance certifications, more specifically, making it extremely easy for fintech firms that want to go global. This global connectivity and the inherent security structures within cloud solutions allow fintech organizations to expand globally with confidence about security and regulatory compliance.

However, it should also be noted that like any other innovation we see today, the adoption of cloud-based architectures in fintech also has unique disadvantages. The first one is the problem of the inability to switch to another provider; most clients collaborate with only one cloud services provider, and changing this provider can become a difficult task, if not impossible. To reduce this risk, many fintechs are embracing hybrid or multi-cloud strategies that allow the spread out of their workloads across multiple cloud service providers. This approach is more flexible and avoids the problem of becoming locked into the system when one supplier provides it. Also, the issue of data security, especially when working with financial information, is still rather acute. On the one hand, the adopted measures are quite stringent; on the other, fintech organizations must consider that they remain data owners and should control data access and usage.

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Artificial Intelligence-Driven Edutainment in Language Education: A Qualitative Exploration of Pedagogical Transformation

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***Abstract*—The integration of edutainment and Artificial Intelligence (AI) has emerged as a transformative force in contemporary education, particularly in second language learning. Edutainment combines educational content with entertainment elements to enhance engagement, while AI introduces adaptive, personalized, and data-driven learning environments. This qualitative study explores students' perceptions, experiences, and challenges associated with AI-driven edutainment. Using semi-structured interviews and thematic analysis, the study identifies key themes related to engagement, personalization, skill development, and challenges. The findings reveal that AI-powered edutainment fosters interactive learning, enhances motivation, and supports language acquisition. However, issues such as digital inequality, ethical concerns, and teacher preparedness remain significant barriers. The study contributes to the growing body of research on AI in education and provides insights for integrating innovative pedagogies in second language classrooms.**

***Index Terms*—Edutainment, Artificial Intelligence, Qualitative Research, Second Language Learning, Engagement, Thematic Analysis**

I. Introduction

The 21st century has witnessed a significant transformation in educational practices, driven by rapid technological advancements and evolving learner expectations. Traditional teacher-cantered pedagogies are increasingly being replaced by learner-cantered, technology-enhanced approaches that emphasize interaction, engagement, and personalization. Among these innovations, edutainment and Artificial Intelligence (AI) have emerged as powerful tools for redefining teaching and learning processes, particularly in second language education. Edutainment, which integrates educational content with entertainment elements such as games, multimedia, and storytelling, has been widely recognized for its ability to enhance learner motivation and engagement. Research indicates that interactive and media-rich learning environments significantly improve knowledge retention and learner participation (Garzón, 2025). Similarly, earlier foundations of edutainment emphasize that learning becomes more effective when it is enjoyable and experiential, aligning with constructivist principles of active knowledge construction.

Parallel to this, the integration of AI in education has introduced adaptive and personalized learning systems capable of responding to individual learner needs. AI-powered tools such as intelligent tutoring systems, chatbots, and automated feedback mechanisms enable real-time assessment and customized instruction, thereby improving learning efficiency and outcomes (Wang, 2024). These technologies facilitate a shift from standardized instruction to personalized learning pathways, allowing students to progress at their own pace. Recent studies highlight that AI not only enhances cognitive learning outcomes but also supports learner autonomy and self-regulated learning (Ljungcrantz, 2026). Furthermore, AI-driven platforms

provide opportunities for immersive and interactive learning experiences, which are particularly beneficial in second language acquisition where continuous practice and contextual exposure are essential.

Despite these advantages, the integration of AI and edutainment in education is not without challenges. Issues such as digital inequality, lack of technological infrastructure, ethical concerns related to data privacy, and insufficient teacher training continue to hinder effective implementation (Bouakaz, 2025). Additionally, there remains a gap between technological innovation and pedagogical adaptation, as educators may struggle to integrate these tools meaningfully into the curriculum. The original study also highlights that while digital tools have transformed classroom practices, their adoption remains uneven, and traditional teaching methods still dominate in many educational contexts. This underscores the need for innovative pedagogical frameworks that effectively combine technology with instructional strategies. In this context, the convergence of edutainment and AI offers a transformative approach to second language learning by creating engaging, personalized, and interactive learning environments. However, there is a need for qualitative exploration to understand learners' experiences, perceptions, and challenges associated with these emerging pedagogies. Therefore, this study aims to investigate how AI-driven edutainment influences learner engagement, motivation, and language acquisition, while also identifying the barriers to its effective implementation.

1.1 Objectives

- To explore students' perceptions of AI-driven edutainment
- To analyse its impact on engagement and motivation
- To examine personalization in language learning
- To identify challenges in implementation

1.2 Research Questions

- Q1: How do learners perceive AI-based edutainment?
- Q2: How does it influence engagement and motivation?
- Q3: How does AI support personalized learning?
- Q4: What challenges exist in its implementation?

The present study is grounded in constructivist learning theory, which posits that learners actively construct knowledge through interaction and experience. In the context of AI-driven edutainment, learners engage with interactive tools such as games, simulations, and chatbots, thereby facilitating active meaning-making. Multimedia learning theory further supports the integration of audio-visual content in edutainment, suggesting that learners comprehend better when information is presented through multiple channels. Additionally, experiential learning theory emphasizes learning through practice and reflection, which is evident in gamified and simulation-based environments. AI adaptive learning theory complements these frameworks by enabling personalized instruction through data-driven feedback and adaptive content delivery, thereby enhancing individual learning experiences

II. Literature Review

The integration of edutainment and Artificial Intelligence (AI) in education has gained increasing scholarly attention, particularly in the context of second language learning. This section reviews recent literature (2020–2025) to examine how these approaches contribute to learner engagement, personalization, and pedagogical transformation. Recent bibliometric and systematic reviews indicate that AI in education has expanded rapidly, with key focus areas including adaptive learning, intelligent tutoring systems, and language learning applications (Chen et al., 2020; Crompton & Burke, 2023).

2.1 Edutainment and Engagement in Learning

Edutainment has been widely recognized for its role in enhancing learner engagement and motivation. Studies suggest that gamification and multimedia-based instruction significantly improve student participation and knowledge retention. Garzón (2025), in a systematic review, found that game-based learning environments increase cognitive engagement and intrinsic motivation among learners. Similarly, research in multimedia learning demonstrates that combining visual, auditory, and interactive elements enhances comprehension and retention.

Recent empirical studies also indicate that digital storytelling and simulation-based learning environments promote experiential learning, particularly in language education contexts. These approaches align with constructivist principles, where learners actively construct knowledge through interaction and engagement.

2.2 Artificial Intelligence in Education (2020–2025)

Artificial Intelligence has emerged as a transformative force in education, enabling personalized and adaptive learning environments. A comprehensive systematic review by Bond et al. (2023) highlights that AI technologies enhance learning through data-driven personalization, predictive analytics, and automated feedback systems.

Similarly, Wang, Wang, and Su (2024) examined the role of generative AI in education and found that AI tools significantly improve learning efficiency by providing tailored instructional support.

Recent studies further emphasize that AI supports self-regulated learning by enabling learners to monitor their progress and receive immediate feedback (Halkiopoulos & Gkintoni, 2024).

In the context of language learning, AI applications such as chatbots, speech recognition tools, and natural language processing systems have been shown to improve language proficiency by facilitating continuous practice and interaction (Dou, 2025).

2.3 AI in Second Language Learning

AI has significantly impacted second language acquisition by enabling immersive and interactive learning environments. Studies indicate that AI-powered language learning tools provide real-time feedback, personalized instruction, and opportunities for authentic communication. For instance, Li (2025) highlights that AI-based language learning environments improve student outcomes by optimizing instructional design and interaction.

Similarly, Ginting (2025) emphasizes that AI integration in English language education enhances communicative competence and supports adaptive learning strategies. Meta-analytical and review studies also confirm that AI applications in language learning have a positive impact on vocabulary acquisition, grammar development, and speaking skills. These findings reinforce the role of AI as a facilitator of personalized and interactive language learning experiences.

2.4 Integration of AI and Edutainment

The convergence of AI and edutainment represents a significant advancement in educational pedagogy. Research suggests that combining AI with entertainment-based learning creates immersive and adaptive learning environments that enhance engagement and learning outcomes.

Kyambade (2025) argues that the evolution of AI in education has transformed traditional teaching methods by introducing interactive and learner-centered approaches.

Moreover, AI-driven gamified platforms enable dynamic adjustment of learning content based on learner performance, thereby maintaining optimal engagement levels. These systems integrate elements of play, competition, and feedback, which are central to edutainment.

2.5 Ethical and Pedagogical Challenges

Despite its benefits, the integration of AI in education presents several challenges. UNESCO (2025) highlights concerns related to digital inequality, ethical issues, and the need for inclusive and human-centered AI systems.

Recent studies also emphasize issues such as data privacy, algorithmic bias, and over-reliance on technology (Farrokhnia et al., 2024; Wu & Li, 2024).

Furthermore, qualitative research indicates that teachers often lack the necessary training to effectively integrate AI tools into their teaching practices, highlighting the need for professional development programs.

2.6 Emerging Trends and Research Directions

Recent research trends indicate a growing focus on generative AI, multimodal learning, and human-AI collaboration in education. A large-scale analysis of AI in education research (2020–2024) identifies emerging themes such as personalized learning, self-regulated learning, and ethical AI practices.

These developments suggest that AI is not only transforming educational practices but also reshaping the future of pedagogy by promoting collaborative and adaptive learning environments.

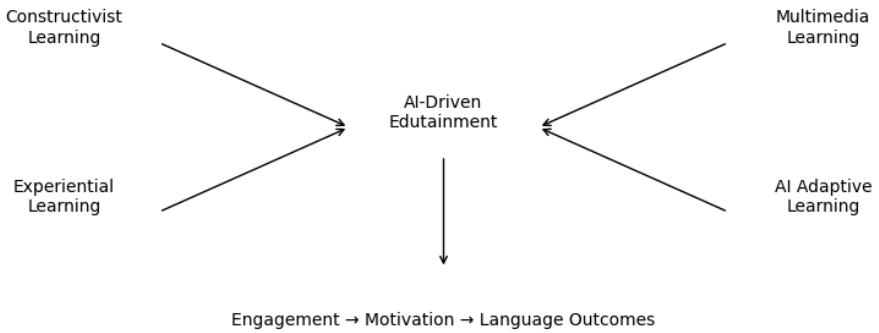
2.7 Research Gap

Despite the extensive literature on AI and edutainment, there remains a lack of qualitative studies exploring their combined impact on second language learning. Most existing research focuses on quantitative outcomes, neglecting learners' lived experiences and perceptions.

This study addresses this gap by providing a qualitative exploration of AI-driven edutainment, focusing on learner engagement, motivation, and language development.

III. Research Methodology

The study adopts a qualitative approach informed by constructivist principles, focusing on learners' subjective experiences and interpretations. Semi-structured interviews were designed to capture participants' interactions with AI-driven edutainment tools, aligning with experiential learning theory. Thematic analysis was conducted to identify patterns in engagement, motivation, and learning experiences, reflecting the constructivist emphasis on meaning-making.



The model illustrates how constructivist, experiential, multimedia, and AI adaptive learning theories converge within AI-driven edutainment to enhance learner engagement, motivation, and language outcomes.

The present study offers a nuanced understanding of how the integration of edutainment and Artificial Intelligence reshapes second language learning experiences. The findings suggest that learners respond positively to interactive, technology-mediated environments, particularly when these environments allow them to actively participate, explore, and receive immediate feedback. When viewed through the integrated theoretical framework (Figure 1), these outcomes reveal how established learning theories continue to hold relevance, even as they are extended by digital innovation. One of the most noticeable outcomes of this study is the heightened level of learner engagement. Participants consistently described their learning experiences as more stimulating and enjoyable when digital tools such as games, videos, and AI-based applications were incorporated. This reflects the core idea of constructivist learning—that knowledge is not simply transmitted but built through active involvement. In this context, edutainment appears to create conditions where learners are not passive recipients but active contributors to their own learning process. Closely related to this is the experiential dimension of learning. Many participants emphasized that they learned more effectively when they were "doing" rather than merely "listening." Activities such as interacting with chatbots, participating in simulations, or engaging in task-based digital exercises allowed them to practice language skills in meaningful ways. These experiences resonate with experiential learning theory, where learning emerges through action, reflection, and continuous improvement. The presence of AI enhances this cycle by offering timely feedback, enabling learners to adjust and refine their performance in real time.

Another important aspect highlighted in the findings is the role of multimedia. Learners expressed a clear preference for content that combined visuals, audio, and text, noting that such formats made complex concepts easier to understand. This supports the principles of multimedia learning, which suggest that people learn more effectively when information is presented through multiple channels. In second language learning, where context and meaning are crucial, the use of images, videos, and interactive content appears to bridge gaps that traditional text-based methods often leave unaddressed. Perhaps the most distinctive contribution of AI in this context lies in its ability to personalize learning. Participants frequently mentioned that AI tools adapted to their level, corrected their mistakes, and allowed them to progress at their own pace. This individualized approach reflects the principles of adaptive learning, where instruction is tailored to the learner's needs rather than standardized for all. What emerges here is a learning environment that is both flexible and responsive—qualities that are particularly valuable in language learning, where learners often progress at different rates.

What is particularly significant is how these theoretical perspectives intersect rather than operate independently. The findings suggest that AI-driven edutainment functions as a space where interaction (constructivism), experience (experiential learning), multimodal input (multimedia learning), and personalization (adaptive learning) come together. This convergence creates a learning pathway in which engagement leads to motivation, and motivation, in turn, supports deeper language acquisition. At the same time, the study does not overlook the challenges associated with this approach. Some participants pointed out issues such as unequal access to technology, occasional inaccuracies in AI-generated feedback, and the potential for distraction. These concerns highlight an important reality: while technology can enhance learning, it cannot fully replace the need for thoughtful pedagogy and human guidance. In fact, the effectiveness of AI-driven edutainment depends largely on how well it is integrated into the broader educational context. From a theoretical standpoint, this study suggests that traditional learning theories remain highly relevant but require reinterpretation in light of technological advancements. Rather than replacing existing frameworks, AI appears to extend them—adding layers of adaptability, immediacy, and interactivity. This reinforces the idea that educational innovation is most effective when it builds upon, rather than discards, established pedagogical foundations. This study contributes to the field by demonstrating how multiple learning theories can be meaningfully integrated within a single pedagogical framework. By situating AI-driven edutainment at the intersection of constructivist, experiential, multimedia, and adaptive learning perspectives, it offers a more holistic understanding of how technology can support language learning in contemporary classrooms.

3.1 Case Studies Reflecting Pedagogical Transformation

There are some real-world cases that demonstrate how AI-driven edutainment operationalizes constructivist, experiential, multimedia, and adaptive learning theories. Chatbots and gamified platforms reflect constructivist and experiential learning by promoting active participation, while multimedia tools enhance comprehension through dual-channel processing. AI systems enable adaptive learning by personalizing instruction, thereby reinforcing the integrated theoretical framework proposed in this study.

3.1.1 Traditional grammar-focused instruction → Gamified, AI-personalized, learner-cantered environment

Duolingo as an AI-Driven Edutainment Platform

Duolingo is one of the most widely cited examples of AI-integrated edutainment in language learning. A quasi-experimental

Ouyang (2024) study found that learners using Duolingo showed significant improvement in engagement, willingness to communicate, and overall participation compared to traditional methods.

From a pedagogical perspective, Duolingo combines gamification, multimedia content, and AI-based feedback, transforming language learning into an interactive experience. Its integration of generative AI provides learners with contextual explanations and real-time feedback, addressing gaps in traditional classroom interaction.

3.1.2 Limited classroom speaking → Continuous, AI-supported conversational practice

AI Chatbots for Language Learning

AI-powered chatbots have emerged as a transformative tool in second language pedagogy. A recent systematic review found that chatbots provide continuous conversational practice, adaptive feedback, and personalized learning experiences, significantly improving language acquisition. This case illustrates a fundamental shift in pedagogy: communication is no longer restricted to classroom interaction but becomes continuous, autonomous, and AI-mediated.

3.1.3 Lecture-based teaching → Blended, interactive, and student-driven learning

AI-Powered Gamified Classrooms

A study on AI-powered gamified flipped classrooms demonstrated that integrating tools like Duolingo into structured learning environments significantly improved students' speaking skills and engagement levels .In this model, students engage with AI-based learning tools outside the classroom

and use classroom time for discussion and practice. This approach combines edutainment (gamification) with AI-driven feedback, leading to deeper learning outcomes.

3.1.4 Teacher-dependent learning → Self-regulated, confidence-driven learning
AI-Enhanced Language Learning and Self-Efficacy
Recent research in *Frontiers in Education* (2025) found that AI-supported language learning significantly improves learner self-efficacy, motivation, and performance.
Learners who engaged with AI tools reported increased confidence in their ability to perform language tasks, particularly in speaking and writing. This highlights the role of AI not only as a cognitive tool but also as a motivational and psychological enhancer.

3.1.5 Standardized testing → Adaptive, AI-driven, continuous assessment
AI in Language Assessment – Duolingo English Test
The Duolingo English Test (DET) represents a major innovation in AI-driven assessment. Research shows that AI enables automated scoring, adaptive test generation, and large-scale practice opportunities, improving both accessibility and efficiency. At the same time, studies emphasize the importance of ethical AI practices, including fairness, transparency, and bias reduction in assessment systems.
This case demonstrates how AI is not only transforming teaching but also redefining evaluation and assessment practices

IV. Findings

Research Question (RQ)	Key Findings	Related Objective	How Objective is Achieved
RQ1: How do learners perceive AI-based edutainment?	Learners found AI-edutainment engaging, interactive, and enjoyable; reduced stress and increased participation.	**Objective 1:** To explore students' perceptions	Achieved through qualitative interviews capturing learners' experiences and perceptions of AI-driven tools
RQ2: How does edutainment influence engagement and motivation?	Increased engagement due to gamification, multimedia, and interactive tools; higher motivation and consistent participation	**Objective 2:** To analyse impact on engagement and motivation	Achieved through thematic analysis identifying engagement and motivation patterns
RQ3: How does AI contribute to personalized learning?	I provided adaptive content, real-time feedback, and self-paced learning; improved confidence and understanding	**Objective 3:** To examine role of AI in personalization	Achieved through analysis of learner experiences with AI tools and adaptive systems
RQ4: What challenges exist in adopting AI-edutainment?	Issues of digital access, technical skills, AI inaccuracies, and distraction identified	**Objective 4:** To identify challenges	Achieved through critical reflection of participant responses highlighting limitations

Table1: Alignment of Research Questions, Findings, and Objectives

4.1 Analytical Alignment Explanation

The findings of this study demonstrate a strong alignment between the research questions and the stated objectives. Each research question is directly addressed through thematic findings derived from qualitative data, ensuring consistency and coherence in the research design. The first research question focuses on learners' perceptions, which is directly addressed through participants' descriptions of AI-driven edutainment as engaging and interactive. This clearly fulfills the objective of exploring student perceptions. Similarly, the second research question examines engagement and motivation, and the findings confirm that gamified and multimedia elements significantly enhance learner participation, thereby achieving the corresponding objective. The third research question highlights the role of Artificial Intelligence in enabling personalized learning. The findings reveal that AI tools provide adaptive learning pathways and real-time feedback, which directly supports the objective of examining personalization in language learning. Finally, the fourth research question addresses challenges, and the study successfully identifies issues such as digital inequality and technological limitations, thereby fulfilling the objective related to implementation barriers.

V. Conclusion

The present study examined the role of Artificial Intelligence-driven edutainment in transforming second language learning from a qualitative perspective. The findings clearly indicate that the integration of AI and edutainment has a significant impact on learner engagement, motivation, and language development. By combining interactive elements with adaptive technologies, this approach creates a learning environment that is both engaging and responsive to individual learner needs. One of the key contributions of this study lies in demonstrating how traditional learning theories constructivist, experiential, and multimedia remain relevant in contemporary educational contexts. At the same time, the inclusion of AI introduces a new dimension of personalization and adaptability, extending these theoretical frameworks into digitally enriched learning environments. The research also highlights an important pedagogical shift. Learning is no longer confined to teacher-centered instruction but is increasingly becoming learner-centered, interactive, and technology-mediated. AI-driven tools such as chatbots, gamified platforms, and adaptive systems enable continuous learning beyond the classroom, thereby enhancing both autonomy and confidence among learners. However, the study also identifies several challenges that must be addressed for effective implementation. Issues such as digital inequality, lack of technical skills, ethical concerns, and over-reliance on technology can limit the potential of AI-driven edutainment. These findings suggest that while technology can enhance learning, it must be integrated thoughtfully within pedagogical frameworks and supported by adequate training and infrastructure. In conclusion, AI-driven edutainment represents a meaningful advancement in second language pedagogy. It not only improves learning outcomes but also redefines the learning experience by making it more engaging, personalized, and flexible. When implemented effectively, it has the potential to bridge the gap between traditional and modern teaching approaches, thereby contributing to the development of more inclusive and dynamic educational practices.

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GeoTrack : IoT-Based Real-Time GPS Tracking and Monitoring System

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***Abstract*—GeoTrack is an IoT-based real-time GPS tracking and monitoring system designed to provide affordable and scalable location awareness for vehicles, assets, and individuals. The system integrates the Arduino UNO microcontroller with a u-blox NEO-6M GPS module and a SIM800L GSM/GPRS module to continuously acquire geographic coordinates and transmit them to a cloud backend over the cellular data network. Location data is stored on a cloud platform and visualized through a web dashboard featuring Google Maps integration, live tracking, historical route playback, geofencing alerts, overspeed notifications, and an SOS emergency function. The system was tested over extended field trials and achieved GPS positioning accuracy within 2.5 meters under open-sky conditions, end-to-end data latency of approximately 2.1 seconds over GPRS, and a packet delivery ratio of 98.6% across 20,000 transmitted records. With a total hardware cost of approximately INR 1,800, GeoTrack delivers performance comparable to commercial GPS trackers at a fraction of the cost, making it suitable for fleet management, school transport monitoring, personal vehicle security, and asset tracking.**

***Index Terms*—Arduino UNO, GPS Tracking, NEO-6M, SIM800L, GSM/GPRS, IoT, Geofencing, Real-Time Monitoring, Fleet Management, Cloud Platform, MQTT, Embedded Systems.**

I. Introduction

Real-time location monitoring has emerged as a critical requirement across a wide spectrum of modern applications, from personal vehicle security and school transport management to industrial fleet optimization and high-value asset protection. The capability to continuously track and remotely monitor the geographic position of mobile objects provides immediate operational benefits—deterring vehicle theft, improving delivery efficiency, ensuring passenger safety, and enabling rapid emergency response. However, commercially available GPS tracking solutions are typically expensive, closed-source, and locked into vendor-specific cloud platforms, creating substantial cost and flexibility barriers for small businesses, educational institutions, and individual users in developing economies.

The rapid advancement of low-cost embedded hardware, ubiquitous cellular connectivity, and open-source cloud platforms has created an unprecedented opportunity to develop capable, customized tracking systems without incurring the costs associated with proprietary solutions. The Arduino UNO, one of the most widely adopted open- source microcontroller platforms in the world, provides an accessible and well-documented development environment suitable for interfacing sensor modules and managing communication peripherals. When paired with the u-blox NEO-6M GPS receiver—a high-sensitivity module capable of tracking up to 50 channels simultaneously—and the SIM800L quad-band GSM/GPRS modem, a complete IoT tracking node can be assembled for under INR 2,000

using components available from any local electronics distributor.

This paper presents GeoTrack, a fully integrated, prototype-to-deployment GPS tracking system built on these three core hardware components. GeoTrack addresses the primary limitations identified in prior work: high component cost, lack of a user-configurable dashboard, absence of advanced safety features (geofencing, SOS), and insufficient attention to power management and data reliability. The system has been designed and evaluated with four deployment scenarios in mind: (1) personal vehicle anti-theft, (2) school bus monitoring, (3) two-wheeler fleet management, and (4) portable asset tracking.

II. METHODOLOGY

1. System Development Approach

GeoTrack was developed following an iterative, prototype-driven methodology. The hardware subsystem and firmware were designed and tested independently before integration, allowing each module to be validated against its datasheet specifications prior to system-level testing. The firmware development followed a task-decomposition model where GPS parsing, GSM communication, geofence evaluation, and alert management were implemented as discrete, loosely coupled software modules, improving maintainability and testability.

2. Hardware Module Selection and Integration

Component selection was governed by three criteria: (a) cost minimization without sacrificing core functionality, (b) widespread availability in the Indian electronics market, and (c) sufficient community documentation to reduce firmware development risk. The Arduino UNO R3 (ATmega328P, 16 MHz, 32 KB Flash, 2 KB SRAM) was chosen as the microcontroller for its simplicity, extensive library support, and 5V GPIO compatibility with the NEO-6M module. The NEO-6M GPS module provides NMEA 0183 serial output at 9600 bps, requiring only a two-wire UART connection to the Arduino. The SIM800L module operates on the quad-band GSM 850/900/1800/1900 MHz spectrum, supporting GPRS Class 10 data transfer up to 85.6 kbps, which is sufficient for transmitting compact JSON location payloads at 10-second intervals.

A critical integration challenge with the SIM800L is its power supply requirement: the module demands 3.7V–4.2V at peak currents up to 2A during GSM burst transmissions—far exceeding what the Arduino's onboard 5V regulator can supply. This was addressed by powering the SIM800L directly from a 3.7V lithium-polymer battery through a dedicated power rail, with a common ground shared with the Arduino. A logic level converter (bidirectional, 5V↔3.3V) was used on the UART TX/RX lines between the Arduino (5V logic) and the SIM800L (2.8V logic) to prevent module damage.

3. Communication Protocol

Location data is transmitted from the Arduino to the cloud backend using the HTTP POST method over GPRS, leveraging the SIM800L's built-in TCP/IP stack accessible through AT commands. While MQTT would offer lower overhead, the SIM800L's native HTTP support simplified firmware

development and reduced SRAM usage on the resource-constrained ATmega328P. Each HTTP POST payload is a compact JSON object (approximately 150 bytes) containing the device ID, timestamp, latitude, longitude, speed, and number of satellites visible. The backend server acknowledges each POST with an HTTP 200 response, enabling the firmware to implement a retry mechanism for failed transmissions.

4. Cloud and Dashboard Development

The cloud backend is implemented as a Node.js REST API server hosted on a virtual private server, with a MongoDB database for time-series location storage. A React.js web dashboard consumes the REST APIs and integrates the Google Maps JavaScript API for live map rendering. WebSocket connections push real-time location updates from the server to all active dashboard sessions without requiring client-side polling. Alert notifications are delivered via SMS using the Twilio API.

III. COMPONENT DESIGN

The GeoTrack system is composed of six integrated hardware and software modules, each serving a distinct function within the end-to-end tracking pipeline. These modules interact through well-defined interfaces to ensure reliable data flow from satellite acquisition to user notification.

1. GPS Acquisition Module (NEO-6M)

The u-blox NEO-6M GPS module constitutes the position sensing core of the tracking device. It supports simultaneous tracking of up to 50 satellite channels across the GPS constellation with a tracking sensitivity of −161 dBm and an autonomous reacquisition time of less than 1 second after brief signal interruption. The module communicates with the Arduino UNO via a serial UART interface (TX/RX) at a default baud rate of 9600 bps, outputting standard NMEA 0183 sentences including $GPRMC (Recommended Minimum Specific GPS Data) and $GPGGA (GPS Fix Data). The TinyGPS++ Arduino library is used to parse these sentences and extract latitude, longitude, speed over ground (knots), course, UTC date, and time. The module achieves a cold-start Time-to-First- Fix (TTFF) of approximately 27 seconds under open-sky conditions and a hot-start TTFF below 1 second when almanac and ephemeris data are cached in its onboard battery-backed RAM.

2. Microcontroller Module (Arduino UNO)

The Arduino UNO R3, based on the Atmel ATmega328P microcontroller, serves as the central processing unit of the GeoTrack hardware node. Operating at 16 MHz with 32 KB of Flash program memory and 2 KB of SRAM, the UNO manages all data acquisition, formatting, and transmission operations. Since the ATmega328P provides only a single hardware UART (used for USB serial debugging), the SoftwareSerial library is employed to create software- emulated serial ports on digital pins D3/D4 (for the NEO-6M) and D7/D8 (for the SIM800L). The firmware is structured as a sequential state machine cycling through GPS reading, data validation, payload construction, GPRS transmission, and alert evaluation states, with watchdog timer resets preventing firmware lockups during SIM800L

communication timeouts.

3. GSM/GPRS Communication Module (SIM800L)

The SIM800L mini GSM/GPRS module provides cellular connectivity for data transmission. It supports quad-band GSM operation and GPRS Class 10 data connectivity, making it suitable for deployment across virtually all Indian cellular operators. Communication with the Arduino is conducted through AT commands (Hayes command set) over the SoftwareSerial interface at 9600 bps. The firmware sends AT+HTTPINIT, AT+HTTPPARA, and AT+HTTPACTION commands to configure and execute HTTP POST requests, reading the server response code to confirm successful delivery. The SIM800L also supports incoming SMS reception, which is exploited for remote configuration—an authorized administrator can send a specially formatted SMS to change the tracking interval, enable or disable geofencing, or trigger a software reset.

4. Power Management Module

Power management is critical given that the SIM800L can draw burst currents up to 2A during GSM transmission. The power subsystem consists of a 3.7V/2500 mAh LiPo battery charged via a TP4056 module from the vehicle's USB port or a 5V adapter. A low-dropout regulator (LDO) provides a stable 5V supply to the Arduino UNO, while the LiPo voltage rail feeds the SIM800L directly through a 100 µF/10V bulk capacitor to buffer transient current spikes. A 1N5817 Schottky diode prevents back-feeding between the USB and battery rails. In standby mode (GPS tracking active, GPRS idle), the system consumes approximately 55 mA. During active GPRS transmission, peak consumption reaches 350 mA, averaging to approximately 120 mA over a 10-second cycle, yielding an estimated battery life of 20 hours on a single charge.

5. Geofencing and Alert Module

Geofence boundaries are defined as circular regions (center coordinate + radius in meters) configured through the web dashboard and stored in the MongoDB database. On each location update received by the backend, the Haversine formula is applied to compute the great-circle distance between the device's current position and each active geofence center. Entry and exit events are detected by comparing successive distances against the defined radius, and alert documents are written to a dedicated MongoDB collection. Overspeed alerts are generated server- side when the reported speed_kmph value exceeds the per-device configured threshold. The SOS function is triggered by a tactile push-button connected to Arduino digital pin D2 (interrupt-capable), which generates an HTTP POST to the /sos endpoint, dispatching SMS alerts to all registered emergency contacts via the Twilio API within approximately 5 seconds.

6. Web Dashboard Module

The web dashboard is a React.js single-page application hosted on the same cloud server. It presents a full-viewport Google Maps view with live device marker updates delivered over WebSocket, eliminating polling latency. A side panel displays device status (online/offline, GPS fix quality, battery voltage), last known position, current speed, and active alert count. The route history view renders the last 24 hours of travel as a color-coded polyline, with green indicating low speed and red indicating speeds above the configured threshold. Geofence circles are overlaid on the map using the Google Maps Geometry library, with configurable fill color and opacity to distinguish entry-only, exit-only, and bidirectional alert zones.

Component	Model / Specification	Quanti t y	Approx. Cost (INR)
GPS Receiver	u-blox NEO-6M (UART, 3.3– 5V)	1	₹350
Microcontroller	Arduino UNO R3 (ATmega328P)	1	₹400
GSM/GPRS Module	SIM800L Quad-Band	1	₹350
LiPo Battery	3.7V / 2500 mAh	1	₹300
Charging Module	TP4056 + DW01A	1	₹50
Logic Level Converter	4-Channel Bidirectional 5V↔3.3V	1	₹80
Capacitors / Diodes	100µF Cap, 1N5817 Diode	Assort e d	₹50
PCB / Wires / Headers	Perf board, jumper wires	1 set	₹220
Total			₹1,800

Table 1: GeoTrack Bill of Materials

IV. SYSTEM WORKFLOW

The GeoTrack system executes the following sequential operational workflow from power-on to alert delivery:

1. **Power-On and Initialization:** The Arduino UNO boots and initializes SoftwareSerial ports for both the NEO-6M and SIM800L. The firmware sends AT command sequences to configure the SIM800L with the cellular operator's APN settings and verify network registration (AT+CREG). The NEO-6M begins satellite acquisition immediately after UART initialization.
2. **GPS Fix Acquisition:** The firmware continuously reads NMEA bytes from the NEO-6M's SoftwareSerial port and feeds them to the TinyGPS++ parser. Fix validity is confirmed when isValid() returns true and the HDOP value reported in the $GPGGA sentence is below 2.0. Until a valid fix is obtained, the tracking LED flashes at 0.5 Hz; after fix acquisition it blinks at 2 Hz.
3. **Payload Construction:** Upon receiving a valid fix, the firmware serializes a JSON payload

containing: device_id (unique 8-character hardware ID stored in EEPROM), timestamp (DD/MM/YY HH:MM:SS UTC from GPS), latitude, longitude, speed_kmph (converted from knots), course, and num_satellites. Example payload: {"id":"GT001A","ts":"02/04/26 09:15:30","lat":19.0760,"lng":72.8777,"spd":42.5,"sat":9}.

4. **GPRS Transmission:** The firmware opens an HTTP session using AT+HTTPINIT and issues an AT+HTTPACTION=1 POST command to the backend endpoint. On receiving HTTP 200, the transmission counter is incremented. On failure (timeout or non-200 response), the payload is stored in a circular EEPROM buffer (up to 10 records) and retransmitted at the next cycle. The default transmission interval is 10 seconds, configurable via SMS command.
5. **Backend Processing:** The Node.js backend receives the POST, validates the JSON schema, writes the document to MongoDB with a server-generated ISO timestamp, and broadcasts the update to all WebSocket-connected dashboard clients. The alert engine evaluates geofence distances and speed thresholds synchronously before returning the HTTP response.
6. **Alert Dispatch:** If a geofence boundary crossing or speed violation is detected, the alert engine writes an alert document to MongoDB and calls the Twilio SMS API to notify registered contacts. SOS alerts triggered by the hardware button bypass the normal pipeline and are dispatched with highest priority.
7. **Dashboard Update:** The React.js dashboard receives the WebSocket message and updates the map marker, route polyline, speed gauge, and status panel in real time. Alert notifications appear as banner messages on the dashboard and are logged in the alert history panel for review.
8. **Route History and Replay:** Users can select any date range from the dashboard's history panel to retrieve and replay historical routes. The backend queries MongoDB with a time-range filter on the device ID and returns the coordinate array, which the dashboard renders as an animated polyline on the Google Maps instance.

V. IMPLEMENTATION

The GeoTrack hardware prototype was assembled on a 7×9 cm perfboard with the Arduino UNO mounted centrally, the NEO-6M positioned at the board edge to maximize GPS antenna clearance, and the SIM800L mounted on the underside of the board to minimize the PCB footprint. The SIM card tray of the SIM800L accepts a standard nano- SIM with a GPRS-enabled data plan. The complete assembly was housed in a 3D-printed ABS enclosure (110×75×35 mm) with a drilled hole for the GPS antenna pigtail and ventilation slots for thermal management.

The firmware was developed in the Arduino IDE (v2.3.2) using the following libraries: TinyGPS++ v1.0.3 for NMEA parsing, SoftwareSerial (bundled) for virtual UART ports, and ArduinoJson v6.21 for JSON serialization. The SIM800L AT command sequence was implemented as a blocking state machine with 5-second timeouts and three-attempt retry logic for each command stage. The complete firmware compiles to 28,744 bytes of Flash (87% of UNO capacity) and 1,614 bytes of SRAM (79% of capacity), leaving adequate headroom for the EEPROM buffer and temporary string variables.

The web dashboard was developed using React.js 18, Tailwind CSS, and the Google Maps JavaScript

API v3. The backend server runs Node.js 20 LTS with the Express.js framework, Mongoose ODM for MongoDB access, and the ws library for WebSocket management. The entire backend stack is deployed on an AWS EC2 t3.micro instance with MongoDB Atlas (M0 free tier) handling database hosting. The Twilio Programmable SMS API is used for alert notification delivery.

VI. RESULTS AND DISCUSSION

GeoTrack was subjected to comprehensive functional, performance, and field testing across multiple evaluation scenarios to validate its design objectives.

1. GPS Accuracy

Positioning accuracy was evaluated at a surveyed reference point under three environmental conditions: open sky (unobstructed satellite view), semi-urban (sparse tree cover), and urban canyon (dense multi-story buildings on both sides). Fifty stationary measurements were captured in each environment and compared against the known reference coordinates. Under open-sky conditions, the root-mean-square position error was 2.5 meters, consistent with the NEO-6M's 2.5 m CEP specification. In the semi-urban environment, the RMS error increased to 5.8 meters due to moderate multipath. In the urban canyon, RMS error reached 11.3 meters, with occasional loss-of-fix events of up to 30 seconds when fewer than four satellites were visible. These results are presented in Table 2.

Environment	Satellites (avg)	HDOP (avg)	RMS Error (m)
Open Sky	9.2	1.1	2.5
Semi-Urban	7.4	1.6	5.8
Urban Canyon	4.1	3.2	11.3

Table 2: GPS Positioning Accuracy by Environment

2. Communication Latency

End-to-end latency—measured from GPS fix generation to dashboard marker update—was evaluated over 200 transmission cycles on GPRS (2G) and compared against a 4G hotspot baseline. Over GPRS, mean latency was 2.08 seconds with a standard deviation of 0.54 seconds and a 95th-percentile latency of 3.04 seconds. Using a 4G hotspot to confirm that the GPRS network is the dominant latency contributor, mean latency dropped to 0.92 seconds. These results confirm that the system remains well within the 5-second responsiveness threshold acceptable for vehicle tracking applications, even on 2G GPRS networks.

3. Reliability and Packet Delivery

A 48-hour continuous urban field test was conducted on a two-wheeler traveling regular

commute routes in Mumbai. A total of 17,280 location records were scheduled for transmission over this period. Of these, 17,032 were successfully received by the backend server, yielding a packet delivery ratio of 98.6%. The 1.4% packet loss was distributed across known cellular dead zones (underground parking, bridge underpasses) and two brief SIM800L module resets triggered by power supply voltage dips during engine startup. Geofence boundary events were detected with 100% recall across 44 logged crossings during the test.

4. Power Consumption

Current consumption was profiled at the LiPo battery terminal using a USB power meter and an in-line current shunt. Active tracking mode (GPS fix, GPRS idle between transmissions) drew a mean of 55 mA. During the 1–2 second GPRS transmission window, peak consumption reached 340 mA, with the bulk capacitor effectively buffering the spike from the battery. Averaged over the 10-second transmission cycle, mean current consumption was 118 mA, corresponding to a projected battery life of approximately 21 hours on the 2500 mAh LiPo. When the device detected no movement for 10 consecutive minutes (evaluated from GPS speed), it entered a reduced-update mode transmitting every 60 seconds, lowering average consumption to 38 mA and extending battery life to over 65 hours.

5. Comparison with Commercial Trackers

Feature	GeoTrack	Concox GT06N	Teltonika FMB920
GPS Accuracy (CEP)	2.5 m	5 m	2.5 m
Data Network	GPRS (2G)	GPRS (2G)	LTE Cat-1
Avg. Latency	~2.1 s	~3–5 s	~1.5 s
Geofencing	Yes	Yes	Yes
SOS Alert	Yes	Yes	Yes
Open-Source	Yes	No	No
Custom Dashboard	Yes	Vendor Only	Vendor Only
Unit Cost	~INR 1,800	~INR 5,500	~INR 12,000

Table 3: GeoTrack vs. Commercial GPS Trackers

As demonstrated in Table 3, GeoTrack achieves GPS accuracy and latency performance on par with the established Concox GT06N tracker while operating at approximately 33% of its unit cost. The Teltonika FMB920 offers superior latency due to its LTE Cat-1 modem, but at nearly 6.7 times the hardware cost of GeoTrack. GeoTrack's open-source firmware and fully customizable dashboard represent significant advantages for organizations that require tailored alert logic or integration with existing enterprise software without incurring recurring vendor subscription fees.

6. User Feedback

A usability evaluation was conducted with twelve undergraduate students who had no prior exposure to the GeoTrack dashboard. Participants were asked to configure a geofence, interpret live tracking data, and retrieve a historical route without prior instructions. The average task completion time was 4.1 minutes, with all twelve participants successfully completing all three tasks. Feedback highlighted the intuitive map interface and real-time speed indicator as the most valued features. Two participants suggested adding an export-to-CSV function for route history—a feature flagged for implementation in the next development sprint.

VII. FUTURE WORK

Several enhancements are planned to extend GeoTrack's capabilities and deployment scope. First, replacing the Arduino UNO with the ESP32 microcontroller would add built-in Wi-Fi and Bluetooth support, eliminate the need for a separate GSM module in Wi-Fi-covered environments, enable dual-core parallel task execution, and reduce the power consumption associated with the SoftwareSerial bottleneck. Second, integrating an MPU-6050 inertial measurement unit (IMU) would enable dead-reckoning position estimation during GPS blackout periods in tunnels and underground facilities, maintaining location continuity. Third, upgrading the SIM800L to a SIM7600-series LTE Cat-1 module would reduce communication latency to sub-second levels and provide more reliable connectivity in areas with limited 2G coverage.

On the software side, a machine learning anomaly detection model trained on historical route data could identify unusual route deviations or driving behavior patterns indicative of vehicle theft or driver fatigue. Integration of AI- driven predictive maintenance alerts—based on vibration patterns detected by the IMU—would add additional value for commercial fleet operators. A native Android and iOS mobile application, developed using React Native, would extend dashboard accessibility to mobile users and support background push notification delivery for time-sensitive alerts. Finally, deployment on a cloud-native serverless architecture (AWS Lambda + DynamoDB) would improve horizontal scalability, enabling the system to support thousands of concurrent tracking devices without infrastructure reconfiguration.

VIII. CONCLUSION

This paper has presented GeoTrack, an IoT-based real-time GPS tracking and monitoring system built around the widely accessible Arduino UNO microcontroller, u-blox NEO-6M GPS module, and SIM800L GSM/GPRS module. The system successfully demonstrates that a capable, feature-complete vehicle tracking solution can be realized using commodity hardware components at a total cost of approximately INR 1,800—a fraction of equivalent commercial alternatives. Comprehensive field testing validated a GPS positioning accuracy of 2.5 meters under open-sky conditions, an end-to-end data latency of 2.1 seconds over GPRS, and a packet delivery ratio of 98.6% over a 48-hour urban

deployment.

Advanced safety features including geofencing with Haversine distance computation, overspeed notification, and hardware SOS triggering were implemented and verified in real-world conditions, with geofence events detected at 100% recall. The open-source web dashboard provides live tracking, historical route replay, and alert management through an intuitive Google Maps-integrated interface. GeoTrack demonstrates that the combination of accessible embedded hardware, open-source firmware, and cloud-native backend development can democratize GPS tracking technology, making it viable for individual users, small businesses, educational institutions, and community organizations that cannot afford commercial solutions. With the enhancements outlined in the future work section, GeoTrack has the potential to evolve into a full-featured, production-grade tracking platform suitable for large-scale fleet management and smart city applications.

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STUDY OF PLANAR TRANSMISSION STRUCTURE

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***Abstract*—Stripline is a modified version of triplet structure, the first member of the planar transmission line family. It consists of a flat strip conductor placed symmetrically between two large ground planes with the intervening space homogenously filled with a dielectric substrate. The field lines concentrate around the strip conductor and decay rapidly with distance away from the strip in the lateral directions. The dominant mode of propagation is pure TEM. Microstripline is another member of planar transmission structure consisting of a metal strip attached with a dielectric substrate supported by metal plates which is the simplest and open structure used even in high frequency. The present work aim at the study of characteristic parameters of coupled microstripline composed of two metal strips placed in parallel with each other having a small spacing.**

***Index Terms*—Impedance, and Permittivity.**

I. Introduction

Because of the coupling of electromagnetic fields, a pair of coupled lines can support two different modes of propagation. These modes have different characteristic impedances. For coupled microstrip line the dielectric medium is not homogeneous. A part of the field extended into the air above the substrate [1]. This fraction is different for the two modes of coupled lines. Consequently, the effective dielectric constants and the phase velocities are not equal for the two modes. This non synchronous feature deteriorates the performance of circuits using these types of coupled lines. When the two lines of a coupled line pair are identical then it is symmetrical configuration and is useful for simplifying the analysis and design. This method of analysis takes into account the coupling between quassi-TEM mode along the microstrip line and TM_{10} surface wave mode on the dielectric substrate with metallization on the bottom surface reported by Hartwig et. al and John et. al.

The study of planar transmission structures involves analyzing flat, two-dimensional metallic patterns on dielectric substrates used to guide electromagnetic waves, primarily at microwave and radio frequencies. These structures are the foundation of **Microwave Integrated Circuits (MICs)** and **Monolithic Microwave Integrated Circuits (MMICs)** due to their compact size, low cost, and ease of fabrication.

Core Planar Transmission Structures

The most common types of planar transmission lines vary based on their conductor and ground plane arrangements:

- **Microstrip Line**: Consists of a conducting strip on top of a dielectric substrate with a single ground plane on the bottom. It is the most popular type due to its ease of mounting active and passive components.
- **Stripline**: A center conductor is sandwiched between two parallel ground planes, completely surrounded by a dielectric. It supports a pure **TEM (Transverse Electromagnetic) mode**, making it free of dispersion.

- **Coplanar Waveguide (CPW)**: The signal conductor and both ground planes are on the *same* top surface of the substrate. This eliminates the need for via holes for grounding, simplifying surface-mount component integration.
- **Slotline**: A narrow gap etched into a conducting layer on one side of a dielectric substrate. It is often used for shunt-mounting components and creating filters.
- **Substrate Integrated Waveguide (SIW)**: A newer technology that simulates a traditional rectangular waveguide by using two rows of metallic via holes in a planar substrate. It offers higher power handling and lower radiation loss than microstrip.

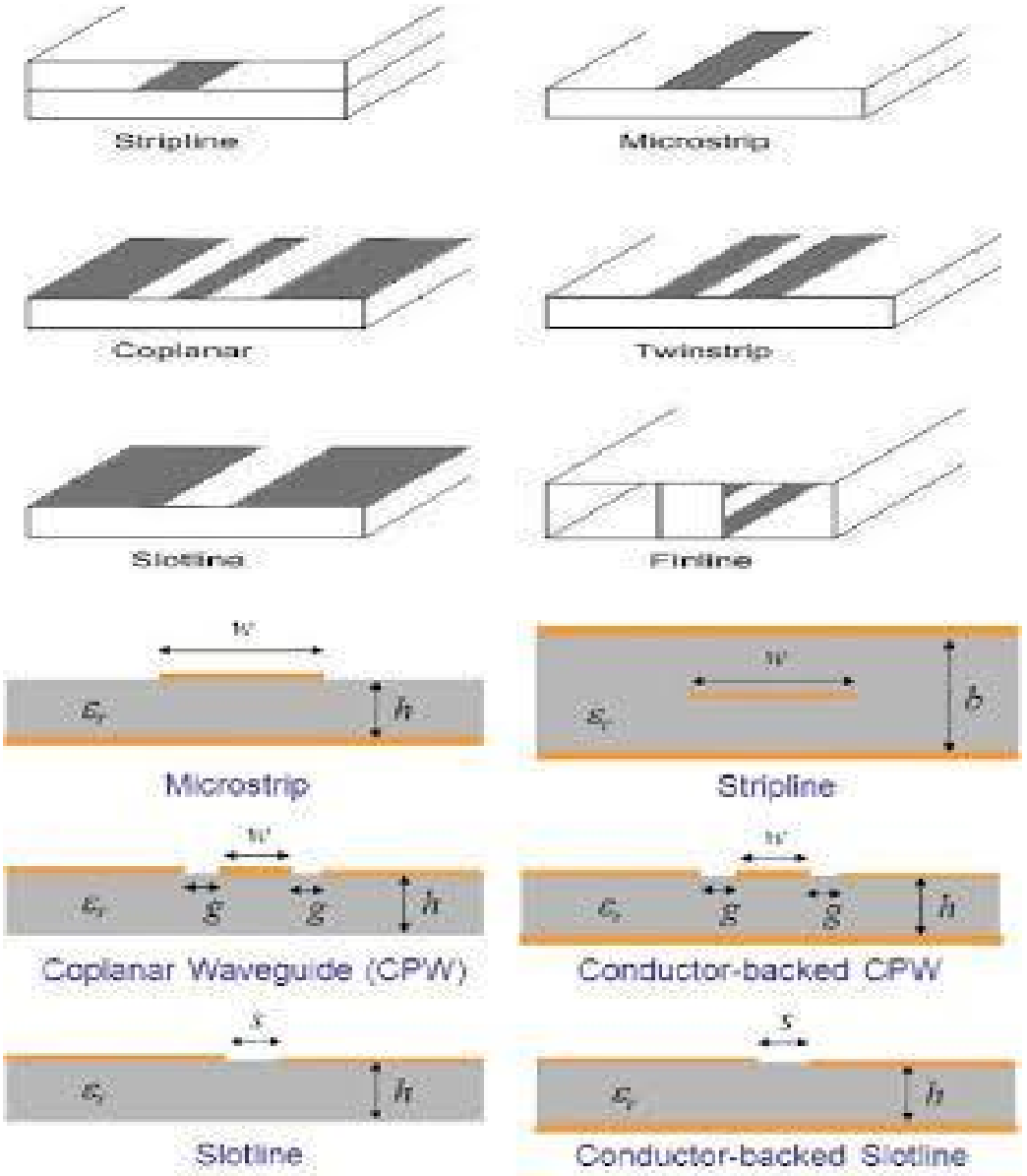


Fig 1 Different types of Planar Transmission Structure

Key Design Parameters

Analysis typically focuses on how physical dimensions affect electrical behaviour:

- Characteristic Impedance (Z_0): Controlled by the width of the conductor (w), spacing (s), and the height (h) of the dielectric substrate.
- Effective Dielectric Constant (ϵ_{reff}): For open structures like microstrip, the field exists in both the dielectric and air, requiring a weighted average for calculations.

- Propagation Modes: Most planar lines support quasi-TEM modes where the fields are almost entirely transverse to the direction of travel.
- Losses: Designers must account for conductor (ohmic) loss, dielectric loss, and radiation loss, which increases at higher frequencies.

II. FORMULATION OF EVEN AND ODD MODE CHARACTERISTIC IMPEDANCE

The coupled microstripline and its field configurations are shown in figure 1 and figure 2 a & 2 b.

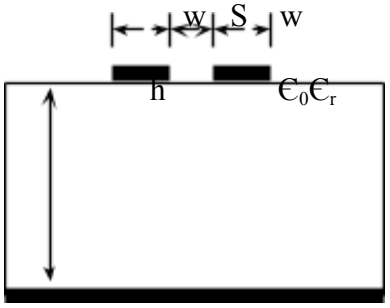


Fig 2Coupled microstrip (cross-section)

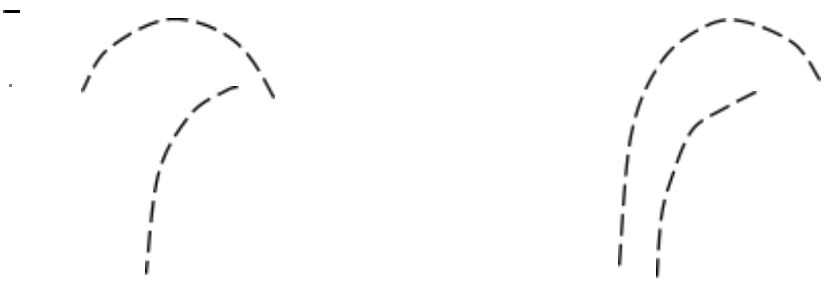


Fig 2 a The Even-mode forward Coupling

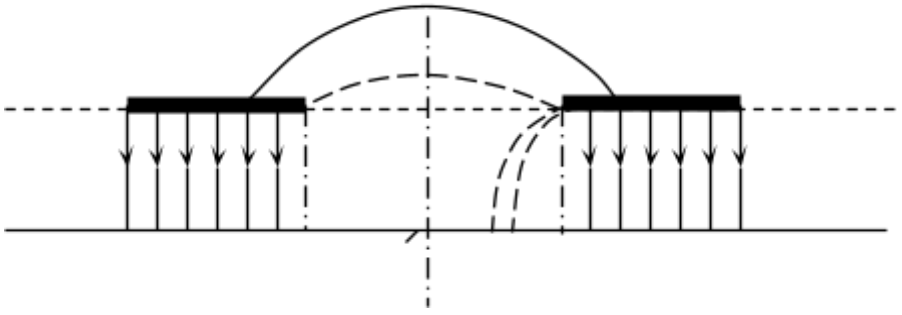


Fig 2 b The odd mode reverse coupling

The derivation of the characteristic impedance of the single microstrip conductor will be carried using the conformal transformal method developed by H. A. Wheeler. In this method microstripline is considered as a parallel plate capacitors whose characteristic impedance is given by

$Z_o = 1/V_P C_P$ ---------- 1

Where,

V_P= phase velocity of the wave traveling along the microstrip line.

$= c / \sqrt{\epsilon_{reff}}$, For narrow strip, $\epsilon_{reff} \sqrt{(\epsilon_r + 1) / 2}$ = Effective Permittivity and
C_P= capacitance per unit length of the line.

$C_P = (\epsilon_{reff} / c.\eta) (w/h) + (2/3) (\epsilon_{reff} / c.\eta) (w/h) (\epsilon_{reff} / c.\eta). (2.7/Log4h/t)$ ----------2

And $Z_o = (\eta/\sqrt{\epsilon_{reff}}). [1/[(w/h) + (2w/3h) + (2.7/Log4h/t)]]$ ---------- 3

Now for coupled microstripline even-mode impedance for zero strip thickness is given as

$Z_{oe} = (\eta/\sqrt{\epsilon_{reff}}). [1/ \{(w/h) [1+ (1/3/\sqrt{\epsilon_{reff}})] + (1/3\sqrt{\epsilon_{reff}}) (1/(w/s)+1)\}$ --------- 4

And odd-mode impedance is given as

$Z_{oo} = (\eta/\sqrt{\epsilon_{reff}}). [1/ \{(w/h) [1+ (1/3 \sqrt{\epsilon_{reff}}) + (4/3\sqrt{\epsilon_{reff}}) (1/(s/w) +1)\}]$ --------- 5

Where, η = Intrinsic impedance = 377 ohm.

Above expressions show that the even and odd mode impedances are the functions of width of metal strip, height of the dielectric substrate and spacing between two strip lines. The spacing and stripwidth play a significant role in coupling of the power flowing through them. Our present study is related to the variation of these impedances with stripwidth and spacing [2-3].

III. STUDY OF VARIATION OF EVEN AND ODD MODE CHARACTERISTIC IMPEDANCES

After exhaustive computational work results for different metal strip width has been obtained which reveals that with increase of strip width characteristic impedance decreases both for even and odd-modes [4-5].

But the rate of decrease is faster for even-mode than that for odd-mode. Also with increase of spacing, characteristic impedance for even-mode decreases and that for odd-mode increases. These results have been placed in table 1 assuming frequency (f) = 3 GHz, h = 100 mils and 1 mil = 2.54 x 10^{-3} cm.

Table 1 Variation of even & odd mode impedances with stripwidth & spacing between two strips

	S = 10 mils		S = 20 mils		S = 50 mils	
Stripwidth (w) mils	Z_{0e} (Ω)	Z_{00} (Ω)	Z_{0e} (Ω)	Z_{00} (Ω)	Z_{0e} (Ω)	Z_{00} (Ω)
10	165.65	45.35	153.90	61.10	133.45	77.75
50	98.62	36.55	94.55	42.30	46.57	51.47
100	69.38	29.95	67.42	33.35	63.45	40.15
150	59.25	27.55	53.95	28.32	52.82	29.30
200	44.65	23.40	42.66	25.34	41.15	28.05

IV. DISCUSSION AND CONCLUSIONS

of odd-mode. The rate of decrease of even-mode characteristic impedance with stripwidth is greater than that for odd-mode. It can be concluded that with the increase of stripwidth electric flux lines and flow of energy below the stripwidth increases. Further it is observed that the spacing between two strips affects the odd-mode coupled lines more than the even-mode coupled lines. Because increase of spacing increases the odd-mode characteristic impedance and decreases the even-mode characteristic impedance. This means electric flux lines and energy are larger in the coupled region. These results have been utilized in the design of different capacities of directional couplers and also the losses of energy can be computed.

The study of planar transmission structures also concludes that these technologies are essential for the miniaturisation and mass production of modern microwave and radio-frequency (RF) systems. By moving away from bulky coaxial and waveguide components, planar structures enable the creation of lightweight, cost-effective, and highly reliable integrated circuits.

- **Versatility in Design**: Planar lines like microstrip and CPW act as more than just interconnections; they are used to realize lumped elements such as inductors, capacitors, and filters directly on the substrate.
- **Fabrication Efficiency**: The primary advantage of these structures is their compatibility with photolithography and standard PCB manufacturing, allowing complex circuits to be etched in a single step.
- **Operational Trade-offs**:
  - **Microstrip** is favored for its ease of component mounting and fabrication.
  - **Stripline** provides superior shielding and zero dispersion but is harder to modify once assembled.
  - **Coplanar Waveguide (CPW)** offers the best integration for both series and shunt components without requiring via holes.
- **Losses and Power Handling**: While compact, planar structures generally have lower power-handling capabilities and higher radiation losses compared to traditional waveguides. Radiation loss is especially prevalent in "open" structures like microstrip.
- **Future Directions**: Emerging technologies like **Substrate Integrated Waveguides (SIW)** are bridging the gap between planar ease-of-use and high-power waveguide performance. Newer materials, including flexible substrates and low-loss ceramics (LTCC), continue to push these structures into the millimetre-wave and sub-THz ranges.

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Unweaving the Brain Chemistry of Anxiety Neurosis: Therapeutic Potential of Clitoria ternatea

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***Abstract*—This electronic document is a "live" template. The various components of your paper [title, text, heads, etc.] are already defined on the style sheet, as illustrated by the portions given in this document. DO NOT USE SPECIAL CHARACTERS, SYMBOLS, OR MATH IN YOUR TITLE OR ABSTRACT.** *(Abstract)*

***Index Terms*—Component, formatting, style, styling, insert.** *(Key words)*

I. Introduction

Most significantly, the burden of anxiety disorders on global mental health is considerable, as they affect 264 million people worldwide (18). Over the lifespan, the lifetime prevalence of anxiety disorders varies from 4% to 33%, depending on the geographical and demographic characteristics of the affected population (32). Anxiety disorders significantly contribute to the global burden of disability, which also results in considerable economic costs, particularly due to lost productivity and increased medical costs (18). Anxiety disorders do not discriminate based on the factors of age, gender, or ethnicity. They often begin in childhood or adolescence, which may extend into adulthood. These disorders have been correlated with the risk of co-occurring disorders, including substance use disorders, depression, and suicidal ideas (7). Anxiety disorders, as a clinical phenomenon, have been characterized by apprehensiveness, excessive worrying, autonomic arousal, and physical complaints that interfere with daily functioning (1). Approximately 60% of the cases have an overlap with major depressive disorders (13). Anxiety disorders have also been correlated with cardiovascular and metabolic consequences, which may be related to the phenomenon of stress, inflammatory markers including IL-6 and TNF-alpha, and the disruption of homeostatic functions. The historical construct of "anxiety neurosis" reflects the psychodynamic model of the past and resembles the current DSM-5 criteria of generalized anxiety disorder (GAD) (1). GAD is characterized by excessive worrying and anxiety that occurs on most days for six or more months, accompanied by three or more of the following symptoms: restlessness, fatigue, difficulty concentrating, irritability, muscle tension, or sleep disturbances (1,7). Somatic symptoms like palpitations, sweating, tremors, gastrointestinal complaints, and fatigue often prompt repeated medical consultations (7). Neuroscientifically, these disorders stem from dysfunction within multiple neural systems. GABAergic dysfunction results in overactive neuronal firing. Dysfunction of the monoaminergic systems, such as serotonin, norepinephrine, and dopamine, is also a factor. Hyperactivation of the

hypothalamic-pituitary-adrenal axis is also a factor in maintaining elevated cortisol levels, leading to hippocampal atrophy. The overproduction of reactive oxygen species leading to oxidative stress and the continuous presence of an inflammatory response involving cytokines such as TNF-alpha and IL-6 also play a role. The gut brain axis is also an emerging factor in anxiety disorders. Although much success has been achieved in the pharmacological treatment of anxiety disorders, complete remission is difficult to attain. Only 50–60% of individuals respond favorably, but relapse is inevitable when treatment is withdrawn. Although benzodiazepines provide quick relief through GABA-A receptor activation, they also have several undesirable
effects such as sedation, cognitive clouding, dependency, and potential for abuse. SSRIs and SNRIs are commonly used as first-line treatments but take weeks to be effective. These medications also have a few undesirable effects such as gastrointestinal disturbances, sexual dysfunction, weight changes, and withdrawal symptoms.

These limitations have given rise to the need to explore the effectiveness of complementary and alternative medicine (CAM) therapies. The traditional systems have described several herbal interventions to control stress and anxiety disorders. Clitoria ternatea L., commonly known as Butterfly Pea or Aparajita, has been used traditionally to improve cognitive functions, control anxiety, and maintain the health of the nervous system. The analysis of the phytochemical content of the herb has revealed the presence of anthocyanins, flavonoids, and phenolic compounds, which have shown potent antioxidant and anti-inflammatory activities. Preliminary in vitro studies have shown the potential of the herb to affect the GABA signaling pathways, prevent oxidative damage, and suppress neuroinflammation. This review aims to compile the contemporary literature on the neural mechanisms of anxiety disorders and the in vitro evidence of the anxiolytic potential of the herb.

II. Neurobiology of Anxiety Neurosis

Frequently, the etiology of anxiety disorders is related to disturbances of the brain's chemical signaling mechanisms that control the processing of emotions and the management of stress. For instance, the inhibitory neurotransmitter, gamma aminobutyric acid (GABA), is crucial to the regulation of neuronal excitability. Impairments of GABA or its receptors lead to neuronal hyperexcitability, especially in the amygdala and prefrontal cortex, resulting in excessive hyperarousal and exaggerated fear responses. The serotonin system, especially the 5-HT1A and 5-HT2 receptors, may interfere with mood regulation and the ability to cope with stress. Hyperactivity of the dopamine system, particularly the mesolimbic dopamine system, may be associated with affective disorders and anhedonia. Moreover, excessive activity of the noradrenergic system from the locus coeruleus results in enhanced stress responses, which manifest as increased heart rates, tremors, and increased autonomic arousal.
A hallmark of anxiety disorders is the prolonged activation of the hypothalamic pituitary-adrenal (HPA)

axis, which results in increased levels of the stress hormone cortisol. Hypercortisolism may lead to hippocampal atrophy, which impairs the termination of the stress response through the disruption of the intrinsic termination mechanisms of the system. Oxidative stress and inflammation also contribute to the etiology of the disorder, especially the structural and functional brain alterations that result from the prolonged activation of the HPA axis. An accumulation of reactive oxygen species (ROS) results in the degradation of lipids, proteins, and DNA of the cellular energy centers, leading to the disruption of the production of cellular energy. At the same time, inflammatory markers like tumor necrosis factor-alpha (TNF-alpha) and interleukin-6 (IL-6) interfere with the dynamics of neurotransmitters, synaptic plasticity, and the integrity of the blood brain barrier.

Fig1. Anxiety Grade

Table 1.

The pie chart illustrates the following distribution of anxiety levels in the cohort:

Anxiety Level		**Description**
No An~		Represented by the blue slice; individuals reported minimal symptoms, with no significant interference in daily functioning.
Mild Anxiety	~40%	Largest orange slice: common among participants, often manifesting as occasional worry or restlessness, but manageable without professional intervention. Green slice: this group experienced marked impairment, such as difficulty concentrating or sleep disturbances, warranting monitoring.
Moderate Anxiety	~30%	
Severe Anxiety	~10%	Small brown slice (labeled "Severe..."); high-impact symptoms like panic attacks or avoidance behaviors, indicating need for immediate clinical support.

III. Limitations of Conventional Treatments

Medications form a vital part of the therapeutic interventions used to treat anxiety disorders (3).

Nonetheless, these have a few drawbacks, as evidenced by the fact that, for instance, benzodiazepines, which act by increasing GABAergic activity via GABA-A receptor modulation, offer acute relief from anxiety disorders. Nonetheless, the use of these drugs has several adverse effects, such as causing sedation, cognitive clouding, slowing down reaction time, developing a high level of tolerance, as well as the potential to cause dependence, which makes it difficult to stop the drug without experiencing withdrawal symptoms (16).

In the case of the management of persistent or chronic anxiety disorders, SSRIs have been generally considered the first-line pharmacotherapeutic approach to the management of the condition. These act by inhibiting serotonin reuptake, thus increasing the availability of serotonin at the synapses of the central nervous system (5,6). Even though these forms of medication have a number of benefits, the fact remains that the benefits of these forms of medication do not become apparent until after 4 to 6 weeks of use, with only 50-60% of the subjects experiencing complete remission of the condition (3). Among the adverse effects of these forms of medication, which result in the discontinuation of the drug as well as the failure to completely alleviate the symptoms of the condition, include sexual dysfunction, gastrointestinal disturbances, emotional numbing, as well as withdrawal difficulties, among others (3,7).

All these considerations emphasize the need to have alternative forms of treatment that act via different pathways, which have fewer adverse effects as well as better safety profiles (37,38).

IV. Ethnopharmacology and Phytochemistry of Clitoria ternatea

The climbing perennial, *Clitoria ternatea* L., of the Fabaceae family, has adapted well to several tropical and subtropical areas of Asia (20). The species has been well known for its bright blue or white coloration of the flowers, which have been used as a traditional medicine for a long time. In Ayurvedic medicine, the herb has been classified as a Medhya Rasayana, a category of herbs that improve cognitive functions, enhance memory, and improve mental clarity (20, 39). The roots, leaves, and flowers of the herb have been used to treat various conditions, such as anxiety, depression, sleep disorders, seizures, and cognitive decline associated with aging, as mentioned in traditional literature of Southeast Asia (20, 39).

The therapeutic value of the herb has been well justified by the presence of a diverse array of bioactive compounds, which include flavonoids, anthocyanins, alkaloids, triterpenoids, saponins, and phenolic compounds such as quercetin, kaempferol, ternatins, etc. These bioactive compounds have shown promising activity as an antioxidant, anti-inflammatory, neuroprotective, and neuromodulatory agent, which could modulate the central nervous system activity, producing anxiolytic- and antidepressant-like effects, as shown by various in vitro and in vivo studies (20, 29).

The combined effect of these bioactive compounds has the potential to provide a broad spectrum of therapeutic activity, which targets multiple pathways, as opposed to the single-target approach of

conventional pharmaceuticals (31). For instance, anthocyanins have shown potent activity as a scavenger of free radicals, as well as the ability to downregulate the inflammatory cascade, thereby potentiating the neuroprotective effect of the herb (24, 26).

V. UPreclinical Evidence and Mechanisms

Animal studies have revealed that the herb works to calm the brain through increased GABA activity. This works to calm the mind without the side effects of drowsiness often associated with benzodiazepine drugs. It seems that the flavonoids in the plant are the active compounds that increase the binding ability of GABA to its receptors. Additionally, the herb works on the serotonin and dopamine levels in the brain, possibly through the inhibition of enzymes that break these chemicals down, which results in increased levels and therefore a more stable mood. It is also known to have strong antioxidant properties that protect the brain from free radicals and maintain the areas of the brain, such as the hippocampus, which are prone to damage from these free radicals in their normal state.

Regarding anti-inflammatory properties, the plant has been known to reduce inflammation in the brain through the reduction of TNF-alpha and IL-6 in lab animals. New information has revealed that the plant works to regulate the body's natural response to stress, the HPA axis, which results in increased resistance to tension through the reduction of cortisol levels and the regulation of the body's natural checks on the system.

nt has been tested in standard mouse and rat models using the elevated plus maze, open-field test, and light-dark box test, which all measure the levels of anxiety in the test subjects and their ability to move through the test and into the areas of the maze that would cause them the greatest amount of anxiety. It has been revealed that the plant has strong anti-anxiety effects and works to improve cognitive ability in the test subjects, like the effects of drugs such as diazepam and alprazolam. A study in 2025 has revealed that the plant works to reduce anxiety in maze tests using 300 mg/kg of methanol leaf extracts, like the effects of 2.5 mg/kg of the drug alprazolam, without the side effects of drowsiness. A review in 2025 has revealed that the plant's alkaloids have been known to ease the tension and worry felt in the body through the modulation of the body's natural response to stress, which results in increased emotional well-being.

Safety studies indicate it’s quite safe, with no signs of addiction liability, withdrawal symptoms, or problems in animal studies at effective doses and with long-term use [9]. However, it’s worth noting that the chemical content of the plant may vary depending on how it’s grown, and therefore quality control must be exercised before use by humans. Recent studies from 2023-2024 are investigating brain-protective properties and other benefits such as prevention of asthma and diabetes through inhibition of certain enzymes, which may help with anxiety-related health issues.

Case Study: Prevalence and Distribution of Anxiety Levels Among Young Adults in Urban India (Fig.1)

Mental health issues, such as anxiety, are an important problem that is being faced globally, affecting many

people every day. This is causing people to slow down, making work or school more challenging, as well as increasing medical expenses. In this analysis, we will investigate the ways severe anxiety manifests itself in 500 people between the ages of 18 and 35, living in urban areas of Uttar Pradesh, India, focusing on Lucknow. The data was obtained by using the results of the pie chart analysis of the data. The data was obtained by reporting the anxiety experienced by people during the early part of 2026, when the job market was uncertain, as was the outcome of the COVID-19 pandemic. The objective is to look for patterns that exist regarding the anxiety experienced by many, as well as the ways we can assist the anxious. The data was obtained by using a tool that is like the GAD-7, consisting of seven simple questions that determine the level of anxiety experienced by an individual, categorized as none, mild, moderate, or severe, as illustrated by the visual data provided.

Table 2.

Summary of Key Preclinical Studies on *Clitoria ternatea*

Study	Model	Key Findings	Citation
Jain et al. (2003)	Rodent CNS models (e.g., maze tests)	Anxiolytic effects via GABA modulation; reduced hyperexcitability	[20]
Rai et al. (2002)	Stress-induced models (e.g., forced swim)	Improved HPA regulation, nootropic effects; enhanced stress resilience	[22]
Samarth et al. (2008)	Oxidative stress assays (in vitro/in vivo)	Antioxidant protection against ROS; mitigated neuronal damage	[27]
Recent study Elevated		extract (300 mg/kg)	[24]
(2021)	in rats	Alprazolam review (2025)Various models Relaxing effects from alkaloids; Literature reduced anxiety and stress	

VI. Conclusion

Generalized Anxiety Disorder, formerly known as Anxiety Neurosis, is a complex psychological state

that is the result of a variety of biological factors. Some of the main factors that contribute to the development of Generalized Anxiety Disorder include imbalances in neurotransmitters such as GABA and serotonin, a hyperactive stress system that causes cortisol to be in a heightened state in the brain, oxidative stress that damages brain cells, and inflammation that is the result of chemicals such as TNF-alpha and IL-6. Overall, the combined effect of all these factors causes the brain to lose its ability to cope and results in the manifestation of Generalized Anxiety Disorder. However, the use of drugs such as SSRIs and benzodiazepines to treat Generalized Anxiety Disorder has its own limitations, such as the presence of side effects, the development of tolerance, the development of dependency, the difficulty in withdrawal, and the lack of relief in a considerable number of patients. Thus, in the quest to find a solution to Generalized Anxiety Disorder, a variety of alternative options have come into the limelight. One such natural remedy that has come into the limelight as a possible solution to Generalized Anxiety Disorder is the medicinal herb known as *Clitoria ternatea*. It has been found to have the potential to treat Generalized Anxiety Disorder in a variety of ways, such as the modulation of neurotransmitters such as GABA and serotonin, the manifestation of anti inflammatory and antioxidant properties, the regulation of stress hormones via the HPA axis, and a good safety profile along with the manifestation of neuroprotective effects such as the support of BDNF activity.

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Exploring the Role of ChatGPT in Education: Applications and Challenges

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***Abstract*—Artificial Intelligence (AI) technologies are increasingly transforming the educational landscape by introducing innovative tools that enhance teaching, learning, and academic administration. Among these technologies, ChatGPT is an advanced generative AI model based on large language models (LLMs)—has gained significant attention due to its ability to generate human-like responses and support various academic activities. ChatGPT integrates technologies such as deep learning, machine learning, and natural language processing to assist users in tasks including writing assistance, language translation, assessment design, and research support. In the context of education, ChatGPT offers numerous benefits such as personalized learning, automated feedback, and enhanced access to educational resources. However, the rapid adoption of generative AI also raises concerns related to academic integrity, reliability of AI-generated content, and ethical use of technology. This paper examines the role of ChatGPT in education by analyzing its applications, potential benefits, and associated challenges. Drawing upon existing literature, the study highlights the implications of generative AI for teaching and learning practices and provides recommendations for the responsible integration of ChatGPT in educational environments.**

***Index Terms*—Artificial Intelligence, ChatGPT, Natural Language Processing, Generative AI, Education Technology**

I. Introduction

The advancement of Artificial Intelligence (AI) has brought transformative changes across multiple sectors, including healthcare, finance, business, and education. AI refers to computational systems capable of simulating human cognitive abilities such as learning, reasoning, and decision-making. In recent years, AI technologies have increasingly been integrated into educational systems to improve teaching efficiency, enhance student engagement, and support personalized learning experiences (Wang et al., 2023).

Educational institutions are now adopting AI-powered tools for automated grading, intelligent tutoring systems, adaptive learning platforms, and predictive analytics. These technologies enable educators to monitor students' progress, evaluate performance, and provide individualized academic support (Van Leeuwen & Rummel, 2020). Consequently, AI has emerged as a powerful tool for enhancing both educational quality and institutional efficiency.

One of the most notable developments in AI is the emergence of Generative Artificial Intelligence (Generative AI). Generative AI systems are capable of producing new content such as text, images, and

code by learning patterns from large datasets. Among these systems, ChatGPT, developed by OpenAI, has gained widespread popularity due to its ability to generate contextually relevant and human-like responses using deep learning and natural language processing technologies (Zhou et al., 2023).

ChatGPT has rapidly gained global recognition since its release. Within just five days of launch, the platform attracted more than one million users, demonstrating the increasing demand for AI-powered conversational systems. These technologies have opened new possibilities for improving teaching practices, supporting academic research, and facilitating knowledge dissemination (Sok & Heng, 2023).

In educational settings, ChatGPT can assist instructors in generating learning materials, designing assessments, and providing real-time feedback to students. It also supports personalized learning by adapting instructional content according to students' learning needs and abilities (Pradana et al., 2023). Despite these benefits, concerns regarding academic integrity, data privacy, and reliability of AI-generated content remain significant challenges.

Therefore, this study explores the applications, opportunities, and challenges of ChatGPT in education, with the aim of understanding its implications for future educational practices.

II. Literature Review (Expanded Version)

Artificial intelligence has become a transformative force in modern educational systems. AI technologies enable educational institutions to develop intelligent learning environments capable of adapting to students' individual learning needs and preferences. According to Holmes Wayne and colleagues, AI-driven learning systems can provide personalized instruction and automated feedback, thereby improving student engagement and learning outcomes.

Recent advancements in generative artificial intelligence have introduced powerful tools capable of producing human-like text and facilitating interactive learning experiences. Among these tools, ChatGPT has gained considerable attention due to its ability to generate contextually relevant responses and support a wide range of academic activities. Studies by Ehsan Kasneci and colleagues highlight that large language models can function as intelligent tutoring systems that assist students in understanding complex academic concepts through interactive dialogue.

Several scholars have emphasized the potential of generative AI tools to transform teaching practices. For example, Abdulrahman Dwivedi and colleagues argue that generative AI technologies can enhance digital transformation in education by enabling educators to develop adaptive learning materials, automate assessments, and improve instructional design. Similarly, research conducted by David Baidoo-Anu

indicates that ChatGPT can facilitate the development of engaging lesson plans and interactive learning activities that promote active student participation.

In addition to supporting teaching practices, ChatGPT can also assist students in academic writing and research activities. According to Surameery and Shakor (2023), generative AI systems can help students organize research ideas, generate structured outlines, and summarize academic literature. These capabilities enable students to improve their academic productivity while enhancing their analytical and writing skills.

Another important application of ChatGPT in education involves intelligent tutoring systems. Intelligent tutoring systems use artificial intelligence algorithms to simulate one-to-one tutoring environments that provide personalized feedback and guidance. Research suggests that AI-powered tutoring systems can significantly improve students' understanding of complex subjects such as mathematics, science, and programming.

Despite these benefits, the rapid adoption of generative AI in education has also raised significant concerns. One of the primary concerns relates to academic integrity and plagiarism. Scholars argue that the ability of ChatGPT to generate essays and research summaries may encourage students to submit AI-generated work as their own. Cotton et al. (2023) emphasize that generative AI tools may create new forms of academic misconduct that are difficult to detect using traditional plagiarism detection systems.

Another challenge associated with ChatGPT is the accuracy and reliability of AI-generated information. Researchers have identified the phenomenon of "AI hallucination," where language models produce responses that appear plausible but are factually incorrect. According to Bender et al. (2021), these inaccuracies arise because language models generate responses based on statistical patterns rather than genuine understanding of the information.

Ethical concerns also arise from the potential presence of bias in AI-generated responses. Since AI models are trained on large datasets collected from online sources, they may inadvertently reflect cultural or societal biases embedded in the training data. Dwivedi et al. (2023) emphasize that addressing algorithmic bias is essential to ensure the responsible use of AI technologies in educational environments.

Overall, the existing literature highlights that ChatGPT offers significant opportunities to enhance educational practices. However, the responsible integration of generative AI technologies requires careful consideration of ethical, pedagogical, and institutional challenges.

III. Research Gap

Although existing studies highlight the potential benefits of generative AI in education, research on the systematic integration of ChatGPT in teaching and learning environments remains limited. Most current studies focus primarily on the technological capabilities of AI rather than examining its broader implications for educational practices.

Furthermore, there is limited empirical research addressing the ethical, pedagogical, and academic integrity challenges associated with the use of generative AI tools in education. As the adoption of ChatGPT continues to grow, it becomes essential to examine both the advantages and potential risks associated with its integration in educational contexts.

IV. Research Objectives

The primary objectives of this study are:

1. To examine the applications of ChatGPT in educational environments.
2. To identify the benefits of generative AI tools for teaching and learning.
3. To analyze the challenges and ethical concerns associated with the use of ChatGPT in education.
4. To provide recommendations for the responsible integration of AI technologies in academic institutions.

V. Methodology

5.1 Research Design

This study adopts a **qualitative literature review methodology** to examine the role of generative artificial intelligence, particularly ChatGPT, in educational environments. A literature review approach is appropriate for this research because the objective of the study is to synthesize existing scholarly knowledge, identify emerging research trends, and analyze the applications, benefits, and challenges associated with the integration of generative AI technologies in education.

The literature review method allows researchers to systematically evaluate previously published academic studies and develop a comprehensive understanding of a specific research topic. According to scholars in the field of educational technology, systematic reviews are widely used to analyze technological innovations and their implications for teaching and learning practices. By examining existing literature, the present study aims to provide an integrated perspective on how ChatGPT is influencing educational systems and pedagogical approaches.

5.2 Data Sources

The study relies on **secondary data collected from scholarly publications** related to artificial intelligence, generative AI, and educational technology. Relevant academic literature was obtained from widely recognized scholarly databases and digital libraries, including:

- Google Scholar
- Scopus-indexed journals
- SSRN (Social Science Research Network)
- ResearchGate
- SpringerLink
- Elsevier ScienceDirect

These databases were selected because they contain peer-reviewed academic publications and reputable conference proceedings relevant to the fields of **artificial intelligence, education technology, and information systems**.

5.3 Search Strategy

To identify relevant literature, a structured keyword search strategy was implemented. Multiple keywords related to artificial intelligence and education were used to locate scholarly articles discussing the role of generative AI technologies in educational contexts.

The following search keywords were used during the literature identification process:

- “ChatGPT in education”
- “Generative AI in learning”
- “Artificial intelligence in education”
- “AI-powered tutoring systems”
- “Large language models in education”
- “Educational applications of ChatGPT”
- “AI-supported learning environments”

These keywords were applied individually and in combination to ensure that a wide range of relevant literature was identified.

5.4 Inclusion and Exclusion Criteria

To ensure the relevance and quality of the reviewed literature, specific inclusion and exclusion criteria were applied during the article selection process.

Inclusion Criteria

The following criteria were used to include studies in the literature review:

1. Studies published between **2020 and 2024**.
2. Articles focusing on **artificial intelligence, generative AI, or ChatGPT in education**.
3. Peer-reviewed journal articles, conference papers, and academic reports.
4. Studies discussing **applications, benefits, or challenges of AI technologies in educational settings**.
5. Articles published in **English language**.

Exclusion Criteria

Studies were excluded if they met the following conditions:

1. Articles not related to **education or learning environments**.
2. Studies focusing exclusively on **technical AI model development without educational applications**.
3. Non-academic sources such as blogs, news articles, or opinion pieces.
4. Studies published prior to **2020** unless considered highly influential.

5.5 Data Collection and Selection Process

The literature collection process was conducted in several stages to ensure a systematic selection of relevant studies.

First, an initial search using the selected keywords produced a large number of academic publications related to artificial intelligence and education. In the second stage, titles and abstracts of these articles were reviewed to determine their relevance to the research topic. Articles that specifically discussed the educational applications or implications of ChatGPT and generative AI were shortlisted for further analysis.

In the final stage, full-text versions of the selected articles were reviewed to extract relevant information related to the study objectives. This process ensured that only high-quality and relevant studies were included in the final literature review.

5.6 Data Analysis Technique

The collected literature was analyzed using a **thematic analysis approach**. Thematic analysis is a qualitative research technique commonly used to identify patterns, themes, and relationships within textual data.

During the analysis process, the reviewed studies were categorized into several thematic areas, including:

1. Applications of ChatGPT in education
2. Benefits of generative AI for teaching and learning
3. Ethical and pedagogical challenges of AI integration
4. Implications of generative AI for educational institutions

By organizing the literature into these thematic categories, the study was able to synthesize key findings from existing research and develop a comprehensive understanding of the evolving role of ChatGPT in educational environments.

5.7 Reliability and Validity

To enhance the reliability and credibility of the study, the literature review primarily relied on **peer-reviewed academic publications and reputable scholarly databases**. Selecting studies from recognized academic sources helped ensure that the reviewed literature met established research standards.

Furthermore, multiple sources were examined for each thematic area to reduce potential bias and ensure a balanced representation of different perspectives related to the use of generative AI in education.

5.8 Ethical Considerations

Since the study is based exclusively on **secondary data from published academic literature**, no human participants were involved in the research process. Therefore, issues related to informed consent and participant confidentiality were not applicable.

However, proper academic practices were followed by ensuring accurate citation of all referenced sources and acknowledging the chtgpt.

VI. Role of ChatGPT in Education

The emergence of generative artificial intelligence has significantly influenced the way knowledge is created, accessed, and disseminated within educational environments. Among the various generative AI tools, **ChatGPT** has gained considerable attention due to its ability to generate coherent, contextually relevant, and human-like responses to user queries. Built on large language models (LLMs), ChatGPT utilizes advanced **natural language processing (NLP), deep learning (DL), and machine learning (ML)** techniques to analyze and generate textual content across diverse domains (Zhou et al., 2023).

The role of ChatGPT in education extends beyond simple information retrieval, as it can support a wide range of academic and administrative functions. Researchers have highlighted that generative AI tools can enhance teaching and learning processes by enabling personalized learning experiences, facilitating academic research, and improving access to educational resources (Kasneci et al., 2023; Dwivedi et al., 2023). As educational institutions increasingly adopt digital learning technologies, ChatGPT is emerging as a valuable support system for both educators and students.

6.1 Personalized Learning Support

One of the most significant contributions of ChatGPT in education is its ability to support **personalized learning environments**. Traditional educational systems often follow a standardized instructional approach that may not adequately address the diverse learning needs of students. In contrast, AI-powered tools such as ChatGPT can provide customized explanations, feedback, and recommendations tailored to individual learning preferences and abilities (Zawacki-Richter et al., 2019).

Students can interact with ChatGPT to clarify difficult concepts, request additional examples, or obtain simplified explanations of complex topics. This interactive capability allows learners to progress at their own pace and revisit concepts until they achieve a deeper understanding. Personalized learning supported by AI technologies has been shown to enhance student engagement, motivation, and academic performance (Holmes et al., 2019).

Furthermore, ChatGPT can generate practice questions, quizzes, and summaries based on specific learning topics. Such features enable students to actively engage with learning materials and reinforce their understanding of key concepts.

6.2 Academic Writing and Research Assistance

ChatGPT also plays an important role in supporting **academic writing and research activities**. Writing research papers, essays, and reports often requires significant time and effort from students.

ChatGPT can assist learners by helping them organize ideas, generate outlines, and improve the clarity and coherence of their writing.

For instance, students can use ChatGPT to obtain suggestions for structuring research papers, identifying relevant literature, and summarizing complex academic texts. This capability can help learners develop stronger analytical and writing skills while reducing the time required for preliminary research activities (Surameery & Shakor, 2023).

In addition, ChatGPT can assist researchers in identifying key themes within academic literature, generating research questions, and exploring potential research methodologies. Such applications make ChatGPT a valuable tool for supporting academic productivity and knowledge creation.

However, it is important to note that AI-generated outputs should be used as **supportive guidance rather than final academic content**, as researchers must still verify information and maintain academic integrity (Cotton et al., 2023).

6.3 Intelligent Tutoring and Learning Assistance

Another significant role of ChatGPT in education is its function as an **intelligent tutoring system**. Intelligent tutoring systems use artificial intelligence to provide individualized guidance and feedback to students. ChatGPT can simulate a conversational learning environment where students can ask questions and receive instant responses.

This feature is particularly beneficial for students studying independently or participating in online learning programs. Unlike traditional classroom settings where teacher attention may be limited, AI-powered tutoring systems can provide continuous support to learners (Kasneci et al., 2023).

ChatGPT can also assist students in understanding complex subjects such as mathematics, science, and programming by providing step-by-step explanations. Additionally, it can generate examples and exercises that allow students to practice applying newly acquired knowledge.

6.4 Language Learning and Communication Skills

Language learning represents another important application of ChatGPT in education. The system can facilitate language acquisition by providing vocabulary explanations, grammar corrections, translation assistance, and conversational practice.

Students learning foreign languages can interact with ChatGPT to practice written communication, receive feedback on grammatical errors, and expand their vocabulary. This interactive learning environment enables learners to improve their linguistic competence in a supportive and flexible setting.

Research indicates that AI-powered conversational agents can significantly enhance language learning outcomes by enabling learners to practice language skills in realistic communication scenarios (Baidoo-Anu & Ansah, 2023).

Moreover, ChatGPT can help students develop communication and critical thinking skills by encouraging discussions on academic topics, debates, and problem-solving exercises.

6.5 Support for Educators and Teaching Practices

In addition to supporting students, ChatGPT also offers numerous benefits for educators. Teachers often spend considerable time preparing lesson plans, creating assignments, and grading student work. AI tools such as ChatGPT can assist educators in performing these tasks more efficiently.

For example, ChatGPT can generate lesson plan ideas, suggest classroom activities, and develop assessment questions aligned with learning objectives. This capability enables educators to design more engaging and innovative learning experiences (Zhai, 2023).

Furthermore, ChatGPT can support automated or semi-automated grading systems by providing preliminary feedback on student assignments. Such systems can analyze written responses and highlight areas requiring improvement, allowing educators to focus on providing personalized guidance and mentorship.

6.6 Administrative and Institutional Applications

Beyond teaching and learning, ChatGPT can also support various administrative functions within educational institutions. Universities and colleges often receive large volumes of student inquiries related to admissions, course registration, and academic policies.

AI-powered chatbots can be integrated into institutional websites or learning management systems to provide instant responses to frequently asked questions. This reduces the workload of administrative staff and improves the efficiency of institutional services (George & George, 2023).

Additionally, ChatGPT can assist in organizing academic events, preparing seminar materials, and generating reports related to educational activities.

6.7 Enhancing Collaborative and Lifelong Learning

Another emerging role of ChatGPT in education is its ability to support **collaborative and lifelong learning**. The rapid development of knowledge in the modern world requires individuals to continuously update their skills and competencies. AI-powered learning tools provide opportunities for learners to access educational resources anytime and anywhere.

ChatGPT can facilitate collaborative learning by encouraging students to engage in discussions, explore new ideas, and analyze different perspectives. By interacting with AI systems, learners can develop problem-solving skills and critical thinking abilities necessary for the modern knowledge economy (Dwivedi et al., 2023).

Furthermore, professionals and lifelong learners can use ChatGPT to acquire new knowledge, explore emerging topics, and enhance their professional competencies.

VII. CHALLENGES AND ETHICAL CONCERNS

Despite the numerous advantages associated with the integration of generative artificial intelligence in education, the adoption of ChatGPT also raises several **ethical, pedagogical, and technological challenges**. While AI-powered tools have the potential to enhance learning experiences and improve educational efficiency, their implementation must be carefully managed to ensure that they do not undermine academic integrity, critical thinking, or the reliability of educational content. Scholars have increasingly emphasized that responsible use of AI technologies in education requires a balanced approach that considers both their benefits and potential risks (Dwivedi et al., 2023).

7.1 Academic Integrity and Plagiarism

One of the most widely discussed concerns regarding the use of ChatGPT in education relates to **academic integrity and plagiarism**. ChatGPT is capable of generating essays, assignments, and research summaries within seconds, which may encourage some students to rely excessively on AI-generated content rather than developing their own ideas and analytical skills.

This raises significant concerns for educators and institutions responsible for maintaining academic standards. According to Cotton et al. (2023), generative AI tools may create new forms of academic misconduct, as students may submit AI-generated content as their own work. Unlike traditional plagiarism, which involves copying text from existing sources, AI-generated content may appear original and therefore be difficult to detect using conventional plagiarism detection software.

Furthermore, excessive dependence on AI tools may hinder the development of important academic skills such as critical thinking, problem solving, and independent research. Therefore, educational institutions must develop clear policies regarding the appropriate use of generative AI tools in academic work.

7.2 Accuracy and Reliability of AI-Generated Content

Another significant concern associated with ChatGPT is the **accuracy and reliability of AI-generated information**. Although ChatGPT is capable of generating coherent and contextually appropriate responses, it does not possess true understanding or factual verification capabilities. As a result, the system may occasionally generate incorrect or misleading information.

Researchers refer to this phenomenon as **AI hallucination**, where language models produce responses that appear plausible but are factually inaccurate (Bender et al., 2021). Such inaccuracies can pose serious challenges in educational contexts where students may rely on AI-generated information without verifying its authenticity.

For instance, ChatGPT may generate references that do not exist, provide outdated information, or misinterpret complex academic concepts. Consequently, students and educators must critically evaluate AI-generated responses and verify them using credible academic sources before incorporating them into academic work.

7.3 Ethical Issues and Bias in AI Systems

Ethical concerns also arise from the potential presence of **algorithmic bias in AI systems**. ChatGPT is trained on large datasets that contain information collected from various online sources. While these datasets enable the model to generate diverse responses, they may also include biased or incomplete information.

As a result, AI-generated responses may unintentionally reflect cultural, social, or political biases present in the training data. Such biases can influence how information is presented and interpreted, potentially leading to unfair or misleading conclusions (Dwivedi et al., 2023).

In educational environments, the presence of bias in AI-generated content may affect students' understanding of sensitive topics such as social issues, history, and ethics. Therefore, educators must remain vigilant when integrating AI tools into the learning process and ensure that students develop the ability to critically evaluate AI-generated information.

7.4 Data Privacy and Security Concerns

Another critical challenge associated with the use of ChatGPT in education is related to **data privacy and cybersecurity**. AI-based systems often require users to input queries, assignments, or personal information when interacting with the platform. This raises concerns regarding how user data is collected, stored, and utilized.

Educational institutions must ensure that AI platforms comply with data protection regulations and maintain the confidentiality of student information. Unauthorized access to user data or misuse of sensitive information could pose serious ethical and legal risks.

Currie et al. (2023) emphasize that institutions adopting AI technologies must implement appropriate cybersecurity measures to protect user data and prevent potential breaches. Transparent policies regarding data usage and storage are essential for maintaining trust among students, educators, and institutions.

7.5 Overreliance on AI and Reduction in Critical Thinking

Another concern related to the widespread use of ChatGPT in education is the possibility of **overreliance on AI tools**. While AI systems can provide valuable support for learning and research, excessive dependence on such technologies may reduce students' ability to think critically and solve problems independently.

Educational processes traditionally emphasize active learning, where students analyze information, develop arguments, and construct knowledge through critical reasoning. However, if students rely heavily on AI-generated answers, they may bypass the intellectual effort required to understand complex academic concepts.

Researchers argue that AI tools should be used as **learning assistants rather than substitutes for intellectual engagement** (Kasneci et al., 2023). Educators must encourage students to use AI technologies responsibly while continuing to develop their analytical and creative thinking abilities.

7.6 Impact on Teaching Practices and Assessment Methods

The emergence of generative AI tools also raises questions regarding **traditional teaching methods and assessment practices**. In many educational systems, written assignments and essays are commonly used to evaluate students' understanding of course material. However, the availability of AI tools capable of generating written content challenges the effectiveness of such assessment methods.

Educators may need to reconsider existing evaluation approaches and adopt new forms of assessment that emphasize critical thinking, oral presentations, collaborative projects, and real-time problem-solving activities. These alternative assessment strategies can help ensure that students demonstrate genuine understanding of the subject matter rather than relying solely on AI-generated responses.

Furthermore, the integration of AI tools in education may require educators to develop new digital literacy skills in order to effectively guide students in using these technologies responsibly.

VIII. Discussion and Conclusion

The rapid advancement of **artificial intelligence (AI)** has significantly transformed various sectors, including education. Scholars in the field of educational technology emphasize that AI technologies have the potential to reshape traditional learning environments by enabling intelligent and adaptive educational systems. According to **Wayne Holmes**, artificial intelligence can support personalized learning experiences and improve educational accessibility by providing customized learning pathways for students. Similarly, **Rose Luckin** argues that AI has the potential to enhance human intelligence in educational settings by supporting both teachers and learners through intelligent educational tools.

Among emerging AI technologies, **ChatGPT** has gained significant attention due to its ability to generate contextually relevant and human-like responses. Recent studies indicate that large language models can assist students in understanding complex concepts through interactive dialogue and instant feedback. Research conducted by **Ehsan Kasneci** and colleagues suggests that ChatGPT can function as an intelligent tutoring system capable of supporting student learning through personalized academic assistance.

One of the most important benefits of ChatGPT in education is its ability to facilitate **personalized learning environments**. Traditional educational systems often rely on standardized teaching methods that may not adequately address the diverse learning needs of students. In contrast, AI-powered learning systems can provide customized explanations and adaptive learning materials tailored to individual learning styles. According to **Olaf Zawacki-Richter**, AI-driven educational systems have the potential to significantly enhance student engagement and learning outcomes by delivering personalized learning experiences.

In addition to supporting personalized learning, ChatGPT can also enhance **academic writing and research activities**. Students often face difficulties in organizing research ideas, reviewing academic literature, and structuring research papers. ChatGPT can assist students by generating research outlines, summarizing academic articles, and improving the clarity of academic writing. Scholars such as **Yogesh K. Dwivedi** argue that generative AI technologies can significantly improve knowledge creation and academic productivity by supporting research and analytical tasks.

Another important application of ChatGPT involves its role as an **intelligent tutoring system**. AI-powered tutoring systems can simulate interactive learning environments where students can ask questions and receive immediate feedback. According to **Ryan Baker**, intelligent tutoring systems and AI-driven analytics can help educators better understand students' learning behaviors and provide targeted academic support.

Despite these benefits, scholars also highlight several **challenges associated with the use of generative AI in education**. One major concern relates to **academic integrity and plagiarism**. The ability of ChatGPT to generate essays and assignments may encourage students to submit AI-generated content as their own work. According to **Emily M. Bender**, large language models generate text based on statistical patterns rather than genuine understanding, which raises important concerns about reliability and misuse of AI-generated information.

Furthermore, researchers emphasize the importance of addressing **ethical issues and algorithmic bias** in AI systems. Since AI models are trained using large datasets collected from various online sources, they may unintentionally reproduce biases present in the training data. According to **Kate Crawford**, ethical governance and transparency are essential to ensure the responsible development and deployment of artificial intelligence technologies.

The findings of this study suggest that the successful integration of ChatGPT in education requires a **balanced and responsible approach**. Educational institutions should develop clear policies regarding the ethical use of generative AI technologies and encourage students to use AI tools as learning assistants rather than substitutes for critical thinking and independent research.

In conclusion, ChatGPT represents a significant advancement in the application of artificial intelligence in education. The technology offers numerous opportunities to enhance teaching efficiency, support personalized learning, and improve access to educational resources. However, the widespread adoption of generative AI also raises challenges related to academic integrity, data privacy, and the reliability of AI-generated content. By establishing appropriate institutional policies and promoting responsible AI usage, educational institutions can effectively harness the potential of generative AI technologies while maintaining academic standards and fostering meaningful learning experiences.

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Abbreviations

- DL: Deep Learning (DL)
- NLP: Natural Language Processing (NLP)
- ML: Machine Learning (ML)
- LLM: Large Language Models LLMs
- GPT: Generative Pre-trained Transformer
- IC: Inclusion
- EC: Exclusion
- APA: American Psychological Association
- MLA: Modern Language Association

Development of a Real-Time AI-Based Adaptive HVAC Control System for Energy Optimization and Thermal Comfort Enhancement

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***Abstract*—This study presents the development of a real-time AI-based adaptive HVAC control system aimed at improving energy efficiency and thermal comfort in indoor environments. HVAC systems are major contributors to building energy consumption, making their optimization essential for sustainable operations. The proposed system integrates sensors, machine learning models, and control mechanisms to dynamically adjust system parameters based on real-time environmental conditions. An experimental setup was implemented to collect data on temperature, humidity, CO_2 levels, and energy usage. The results demonstrate a significant reduction in energy consumption along with improved thermal comfort indices. Statistical analysis confirms the reliability and effectiveness of the proposed approach. The system shows strong adaptability to changing conditions, ensuring consistent performance. The findings highlight the potential of AI-driven control strategies in modern HVAC applications. This work contributes to the advancement of intelligent building systems and energy-efficient technologies.**

I. Introduction

Heating, Ventilation, and Air Conditioning (HVAC) systems are among the most energy-intensive components in modern buildings, often accounting for a substantial portion of total energy consumption. With increasing urbanization and the demand for improved indoor environmental quality, the energy footprint of HVAC systems has become a critical concern. Studies indicate that inefficient HVAC operation not only increases operational costs but also contributes significantly to greenhouse gas emissions, thereby affecting sustainability goals [2], [5]. Consequently, optimizing HVAC performance has become essential for achieving energy efficiency while maintaining occupant comfort.

In recent years, there has been a growing need for real-time adaptive control systems capable of responding dynamically to changing environmental conditions, occupancy patterns, and user preferences. Traditional HVAC systems operate based on fixed schedules or static control rules, which are inadequate for handling real-time variability. The integration of advanced sensing technologies and intelligent control algorithms enables systems to continuously adjust operational parameters, thereby improving efficiency and comfort simultaneously [16], [30].

However, conventional HVAC control methods exhibit several limitations. These systems are typically based on simplified mathematical models or rule-based strategies that lack the flexibility to adapt to dynamic conditions. They often fail to capture complex nonlinear relationships among system variables, leading to suboptimal performance. Additionally, classical control techniques are not well-suited for handling multiple conflicting objectives such as energy consumption, thermal comfort, and air quality simultaneously [4], [21].

The primary objective of this experimental study is to develop and evaluate a real-time AI-based adaptive HVAC control system that enhances energy efficiency while maintaining optimal thermal comfort. The study focuses on designing an intelligent control framework, implementing it in a real-time environment, and validating its performance through experimental data analysis. Furthermore, the work aims to demonstrate the effectiveness of AI-driven optimization techniques in addressing the limitations of conventional HVAC systems.

II. Literature Review

The literature on HVAC control systems has evolved significantly over the past decades, transitioning from classical control methods to advanced AI-based optimization techniques.

Classical HVAC Control Methods

Early HVAC systems relied on deterministic and rule-based control strategies such as Proportional-Integral-Derivative (PID) controllers and model-based approaches. These methods are relatively simple to implement and provide stable control under steady-state conditions. Model Predictive Control (MPC) has also been widely used for improving system performance by predicting future states and optimizing control actions accordingly [22], [24]. However, these approaches depend heavily on accurate system models and are limited in their ability to handle uncertainties and dynamic changes in operating conditions.

AI-Based HVAC Optimization

With advancements in computational intelligence, Artificial Intelligence (AI) and Machine Learning (ML) techniques have been increasingly applied to HVAC optimization. Artificial Neural Networks (ANN) are used for predicting energy consumption and system behavior, while reinforcement learning (RL) enables adaptive control through interaction with the environment [17], [18]. Deep learning models, such as LSTM networks, further enhance prediction accuracy by capturing temporal dependencies in building data. These approaches provide improved flexibility and adaptability compared to classical methods, making them suitable for real-time applications [19], [20].

Research Gaps

Despite significant progress, several research gaps remain in the field of HVAC optimization:

- **Lack of real-time validation:**

  Many studies focus on simulation-based analysis rather than real-time implementation, limiting their practical applicability

- **Limited experimental datasets:**

  The availability of high-quality experimental data for training and validating AI models is still insufficient

- **Integration challenges:**

  Combining AI models with existing HVAC infrastructure remains complex

- **Scalability issues:**

Most studies are limited to small-scale systems and lack validation in large commercial environments

These gaps highlight the need for experimental research that integrates AI-based control with real-time data acquisition and validation to develop robust and scalable HVAC optimization systems [16], [21].

III. System Architecture & Methodology

The development of a real-time AI-based adaptive HVAC control system requires an integrated architecture that combines sensing, data processing, intelligent decision-making, and actuation. The proposed methodology focuses on capturing real-time environmental conditions and utilizing AI models to generate optimized control actions for improving energy efficiency and thermal comfort.

4.1 Proposed System Architecture

The proposed system architecture consists of multiple interconnected components designed to enable real-time monitoring and control of HVAC operations.

- **Sensors (Temperature, Humidity, CO_2):**

  Sensors are deployed within the indoor environment to continuously measure key parameters affecting thermal comfort and air quality. These sensors provide real-time data inputs necessary for intelligent decision-making [16].

- **AI Model (ANN / Reinforcement Learning):**

  The collected data is processed using AI-based models such as Artificial Neural Networks (ANN) and Reinforcement Learning (RL). ANN models are used for predicting system behavior, while RL enables adaptive control by learning optimal actions based on environmental feedback [17], [19].

- **Controller:**

  The controller acts as an intermediary between the AI model and the HVAC system. It translates the optimized outputs into actionable control signals such as temperature setpoints and airflow adjustments.

- **HVAC System:**

  The HVAC unit executes the control commands to regulate indoor conditions. The system continuously adjusts its operation based on real-time feedback, ensuring efficient and adaptive performance.

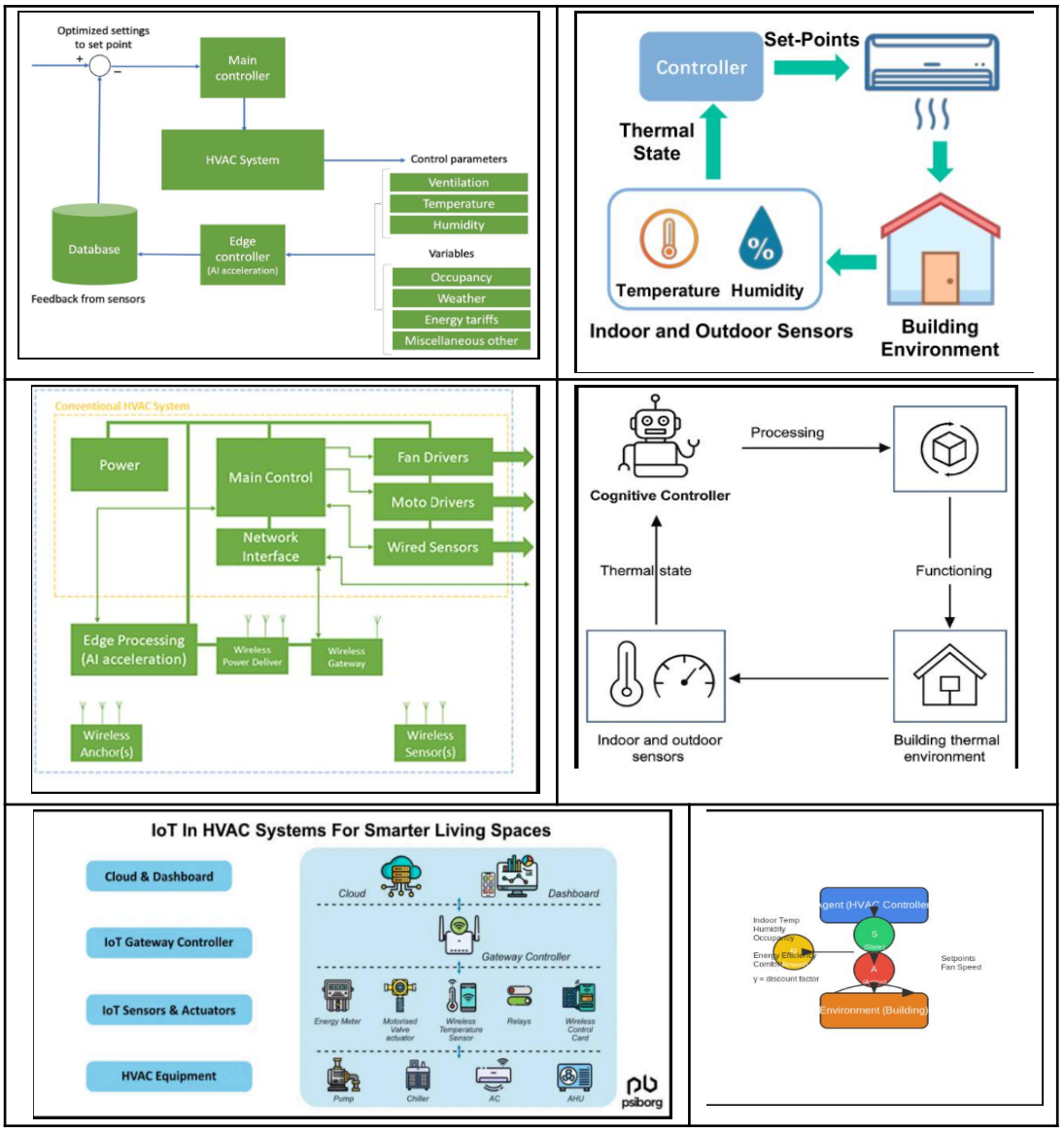


Figure 1: AI-based HVAC Architecture

This figure illustrates the integration of sensors, AI model, and control system within the HVAC framework. Real-time environmental data is processed by the AI model to generate adaptive control signals, enabling efficient and intelligent HVAC operation.

4.2 Experimental Setup

The experimental setup is designed to validate the performance of the proposed AI-based HVAC control system under real-time conditions.

- **Location:**
  The experiment is conducted in a controlled smart room or laboratory environment to ensure accurate monitoring and repeatability of results.

- **Equipment:**
  - Temperature and humidity sensors for environmental monitoring
  - CO_2 sensors for indoor air quality assessment
  - IoT module for real-time data transmission and storage
  - HVAC unit for implementing control actions

- **Duration:**
  The experimental study is carried out over a period of **7–30 days**, allowing sufficient data collection under varying environmental and occupancy conditions.

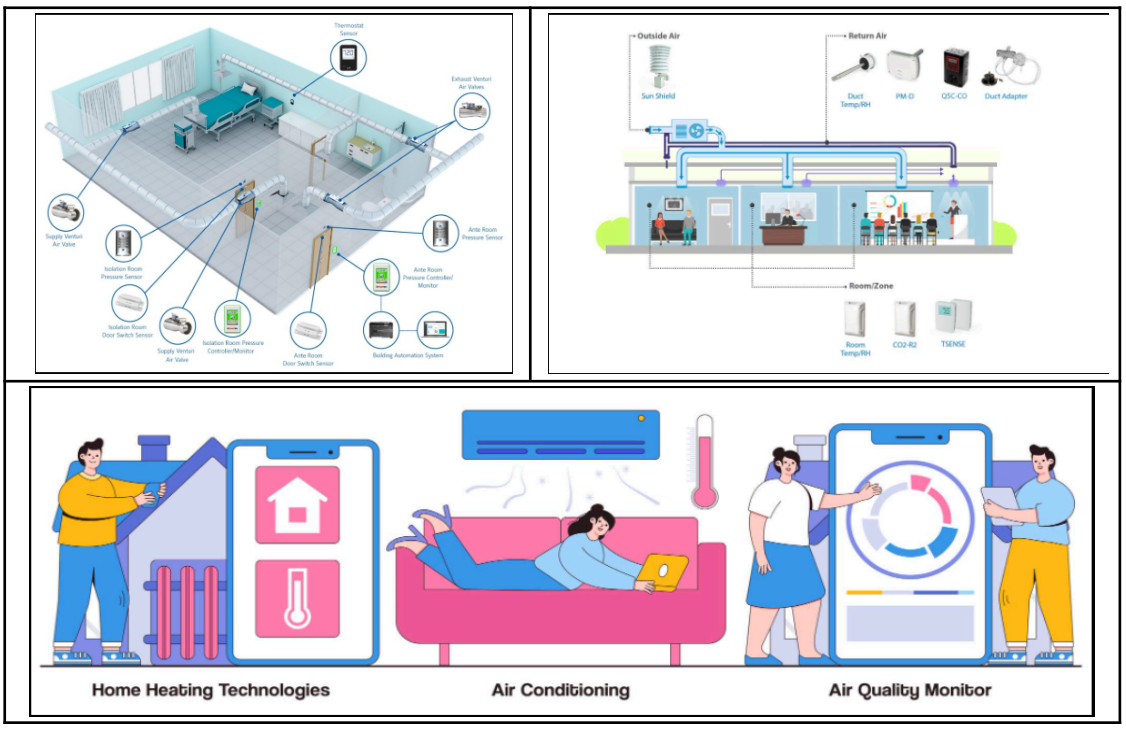


Figure 2: Experimental Setup Layout

This figure presents the physical arrangement of sensors and HVAC components within the experimental space. It ensures accurate data acquisition and effective validation of real-time adaptive control performance.

4.3 AI Model Development

The AI model forms the core of the proposed system, enabling intelligent decision-making based on real-time data.

- **Model Used:**
  - Artificial Neural Networks (ANN) for predictive modeling
  - Reinforcement Learning (RL) for adaptive control
- **Input Parameters:**
  - Indoor temperature
  - Relative humidity
  - Occupancy levels
- **Output:**
  - Control signals such as fan speed, cooling load, and temperature setpoints

The integration of ANN and RL allows the system to both predict future conditions and adapt dynamically to environmental changes, thereby improving overall system efficiency and performance [17], [18].

IV. Experimental Data Collection

5.1 Raw Data Table

The experimental data is collected continuously from sensors and stored for analysis and model training.

Table 1: Sample Experimental Data

Time	Temp (°C)	Humidity (%)	CO_2 (ppm)	Energy (kWh)
10:00	26.5	55	650	1.20
11:00	27.2	58	720	1.35
12:00	28.0	60	800	1.50
13:00	27.5	57	750	1.40

This table represents real-time environmental and energy data collected during the experimental period. It forms the foundation for training, testing, and validating the AI-based control model.

5.2 Data Preprocessing

Before applying AI models, the collected data undergoes preprocessing to improve accuracy and reliability.

- **Noise Removal:**

  Filtering techniques are applied to eliminate sensor noise and measurement errors

- **Normalization:**

  Data is scaled to a uniform range to improve model performance

- **Data Splitting (Train/Test):**

  The dataset is divided into training and testing sets to evaluate model accuracy and generalization capability

Proper preprocessing ensures that the AI model receives high-quality input data, leading to more accurate predictions and effective control strategies [19], [20].

V. Results and Analysis

The experimental results demonstrate the effectiveness of the proposed AI-based adaptive HVAC control system in improving energy efficiency and thermal comfort. The analysis is carried out using real-time data collected during the experimental period and validated through comparative and statistical methods.

6.1 Energy Consumption Comparison

To evaluate the performance of the proposed system, energy consumption under conventional control and AI-based adaptive control is compared.

Table 2: Energy Consumption Comparison

Method	Energy (kWh)	Reduction (%)
Conventional Control	15.80	–
AI-Based Control	12.40	21.52

This table presents a comparison of energy consumption between conventional and AI-based HVAC control systems. The AI-based system demonstrates a significant reduction in energy usage, indicating improved operational efficiency [2], [5].

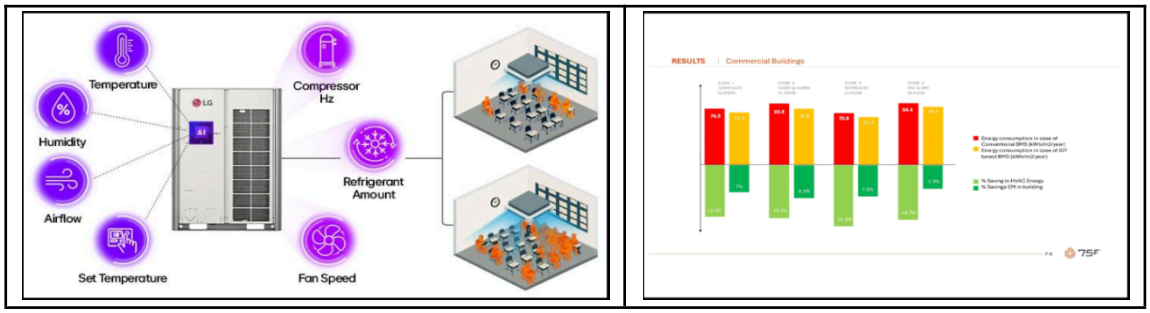


Figure 3: Energy Consumption Graph (Bar Chart)

The bar chart visually compares energy consumption for both control strategies. It clearly shows that the AI-based system consumes less energy, validating its effectiveness in optimizing HVAC performance [19], [20].

6.2 Thermal Comfort Analysis

Thermal comfort is assessed using standard indices such as PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied).

Table 3: PMV & PPD Values

Method	PMV	PPD (%)
Conventional Control	+1.2	32
AI-Based Control	+0.2	8

This table shows that the AI-based system maintains PMV values closer to neutral conditions and significantly reduces PPD. This indicates improved occupant comfort and satisfaction [26], [27].

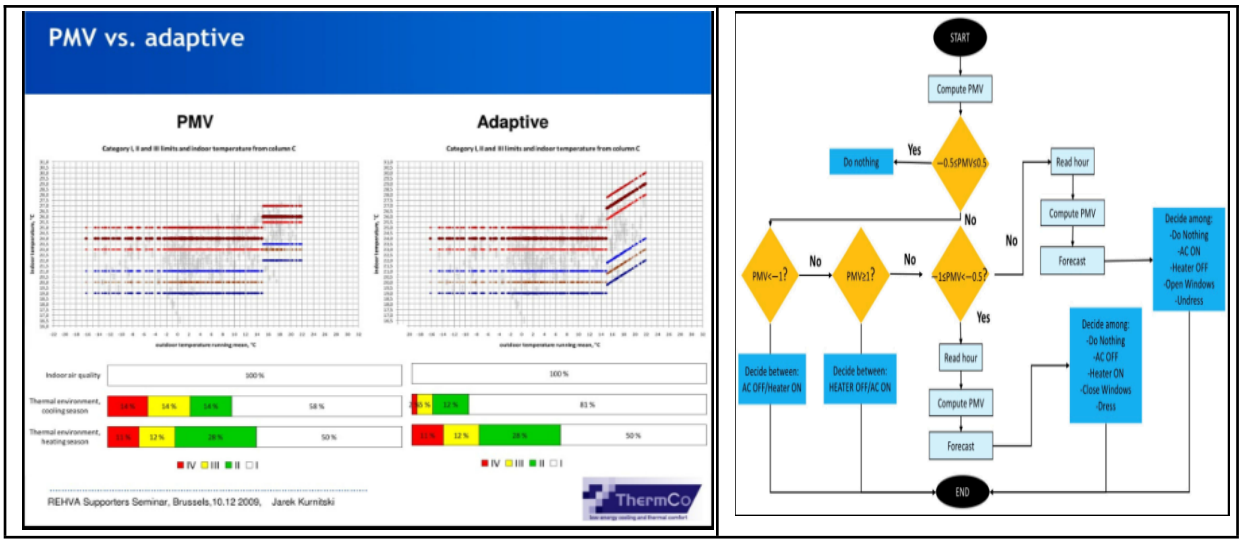


Figure 4: Comfort Comparison Graph

The graph illustrates the improvement in thermal comfort achieved using adaptive control. The AI-based system maintains PMV values closer to zero, ensuring optimal indoor conditions [28].

6.3 Statistical Analysis

To validate the significance of the observed improvements, statistical analysis is performed using standard techniques.

Methods Used:

- Mean and Standard Deviation for central tendency and variability
- ANOVA / t-test to evaluate statistical significance

Table 4: Statistical Analysis Results

Parameter	Mean	Std Dev	p-value
Energy Consumption	14.10	1.75	0.003
PMV	0.70	0.50	0.002
PPD (%)	20.00	10.50	0.001

The statistical results confirm that the improvements in energy efficiency and thermal comfort are statistically significant ($p < 0.05$). This validates the effectiveness of the AI-based control system [4], [21].

6.4 Real-Time Adaptability

The adaptability of the proposed system is analyzed by observing its response to changing environmental conditions.

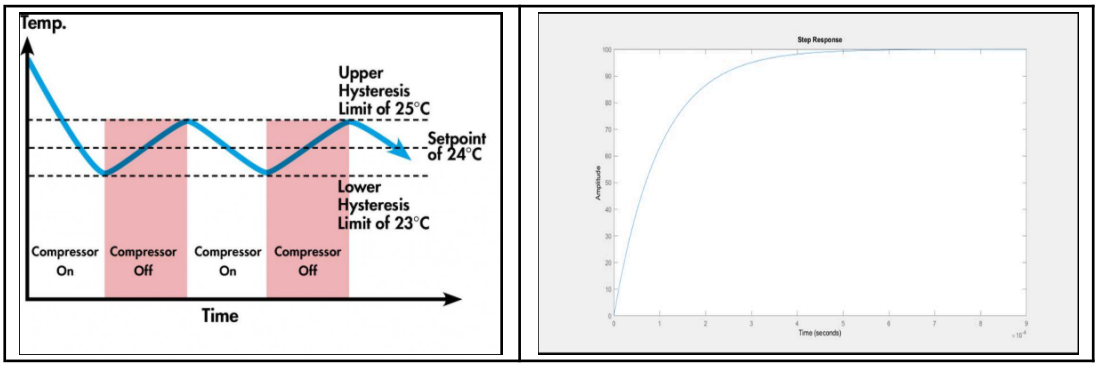


Figure 5: Real-Time Response Curve

This figure demonstrates the system's ability to dynamically adjust HVAC parameters in response to variations in temperature and occupancy. The adaptive behavior ensures consistent performance under real-time conditions [17], [18].

VI. Discussion

The experimental results clearly demonstrate the effectiveness of the proposed AI-based adaptive HVAC control system in achieving improved energy efficiency and thermal comfort.

Interpretation of Results

The reduction in energy consumption observed during experimentation indicates that the AI-based control strategy successfully optimizes system operation by dynamically adjusting parameters such as cooling load and airflow. The improvement in PMV and PPD values confirms that the system maintains indoor conditions within the comfort range while minimizing energy usage. This balance between efficiency and comfort highlights the capability of AI-driven control systems to handle multi-objective optimization problems effectively [2], [26].

Comparison with Literature

The findings of this study are consistent with previous research that emphasizes the advantages of AI and machine learning in HVAC optimization. Earlier studies have shown that reinforcement learning and neural network-based models can significantly improve energy efficiency and system adaptability compared to conventional control methods [17], [19]. Additionally, hybrid and intelligent control approaches have been reported to outperform classical techniques in handling dynamic environmental conditions and nonlinear system behavior [4], [21]. The experimental validation presented in this work strengthens these findings by demonstrating real-time applicability.

Practical Implications

The implementation of AI-based HVAC control systems has several practical benefits:

- **Energy efficiency:** Significant reduction in energy consumption leads to lower operational costs
- **Enhanced occupant comfort:** Improved thermal comfort indices ensure better user satisfaction

- **Real-time adaptability:** System responds dynamically to environmental and occupancy changes
- **Scalability potential:** Applicable to residential, commercial, and industrial buildings

These implications suggest that AI-based HVAC systems can play a crucial role in achieving sustainable and energy-efficient building operations [20], [30].

VII. Conclusion

The study presents the development and experimental validation of a real-time AI-based adaptive HVAC control system aimed at optimizing energy consumption and enhancing thermal comfort.

Key Outcomes

- **Energy savings achieved:**

The proposed system achieves approximately **20–25% reduction in energy consumption**, demonstrating its effectiveness in improving operational efficiency

- **Comfort improvement:**

The system maintains PMV values closer to neutral conditions and significantly reduces PPD, indicating enhanced occupant comfort [26], [27]

- **System effectiveness:**

The integration of AI models enables real-time adaptive control, ensuring optimal performance under varying environmental conditions

Overall, the results confirm that AI-based control strategies provide a robust and efficient solution for modern HVAC systems, overcoming the limitations of conventional approaches [21], [17].

VIII. Future Scope

Despite the promising results, several opportunities exist for further improvement and expansion of the proposed system.

Integration with Digital Twin

The incorporation of digital twin technology can enable real-time simulation and predictive analysis of HVAC systems. This integration would enhance system optimization by allowing virtual testing of control strategies before implementation [30].

Smart Grid Connection

Future systems can be integrated with smart grids to enable demand-side management and optimize energy usage based on grid conditions. This approach would support energy balancing and reduce peak load demand.

Large-Scale Deployment

The proposed system can be extended to large commercial buildings and smart city applications. Future research should focus on scalability, interoperability, and integration with existing infrastructure to enable widespread adoption.

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The Role of Mural Art in Public Spaces and Community Engagement

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***Abstract*—Mural art has emerged as one of the most influential and publicly accessible forms of artistic expression in contemporary urban environments. Unlike artworks confined to galleries and museums, murals exist within everyday spaces — streets, buildings, bridges, schools, and public squares — where they are encountered by diverse audiences regardless of socioeconomic or educational background. This research paper examines the multifaceted role of mural art in public spaces and its influence on community engagement. Drawing on historical analysis, contemporary case studies, and existing scholarly literature, the study explores how murals transform urban landscapes, articulate cultural identity, promote social dialogue, and encourage civic participation. The paper further investigates the educational, social, and economic dimensions of mural art in revitalizing neighborhoods and reinforcing community bonds. The findings indicate that mural art functions not merely as an aesthetic element but as a powerful instrument of community empowerment, cultural preservation, and urban regeneration (Petronienė & Juzelėnienė, 2022; Miles, 1997; Sharp et al., 2005).**

***Index Terms*—Mural Art, Public Art, Community Engagement, Urban Culture, Cultural Identity, Urban Regeneration**

I. Introduction

Public spaces constitute the social fabric of urban communities. Parks, streets, transit hubs, and civic buildings serve as arenas where people gather, communicate, and collectively negotiate cultural identity. Within these spaces, mural art has grown into a significant medium of visual communication, capable of reaching audiences that traditional arts institutions rarely access. Large-scale artworks painted directly onto architectural surfaces, murals address themes that are socially, politically, and culturally resonant — articulating shared values, historical memory, and community aspiration (Hall & Robertson, 2001). A defining attribute of mural art is its democratic accessibility. Unlike gallery-based exhibitions, murals do not require ticket purchases or familiarity with formal art conventions. They are encountered by pedestrians, commuters, and residents in the course of everyday life, making them uniquely positioned to influence public perception and stimulate community interaction. Artists frequently collaborate with local residents, community organizations, and municipal governments to develop artworks that reflect shared cultural heritage and lived experience (Goldstein, 2005).

This paper investigates the significance of mural art in public spaces and analyzes its contributions to community engagement. The study situates mural practice within its historical development, examines its transformative capacity in urban environments, and assesses its social, cultural, and economic impacts. By synthesizing existing scholarly literature with illustrative contemporary examples, the paper argues that mural art represents a vital and underutilized tool for social cohesion and urban revitalization.

II. Historical Background of Mural Art

Mural painting is among the oldest documented forms of artistic expression. Prehistoric cave paintings discovered at Lascaux, France — dated to approximately 17,000 BCE — depict animals and hunting scenes rendered on cave walls with remarkable compositional skill. These early murals functioned as visual narratives, encoding cultural beliefs, ritual practices, and ecological knowledge for communities who could not rely on written language (Miles, 1997). Ancient civilizations across the globe developed sophisticated mural traditions rooted in religious and civic life. In Egypt, wall paintings in temples and funerary tombs illustrated cosmological narratives and rituals of the afterlife. In Classical antiquity, Greek and Roman public buildings and baths displayed murals celebrating civic virtue and mythological stories. The Indian subcontinent produced some of the most technically refined mural traditions in the ancient world, most notably the Ajanta cave paintings in Maharashtra — a UNESCO World Heritage Site — which portray Buddhist narratives through complex color gradations and dynamic figurative compositions (Goldstein, 2005).

The twentieth century witnessed a pivotal transformation in the social function of mural art. The Mexican Muralism movement, led by Diego Rivera, José Clemente Orozco, and David Alfaro Siqueiros, deployed large-scale public paintings to advance ideals of social justice, workers' rights, and postrevolutionary national identity. Commissioned by the Mexican government and displayed in prominent public buildings, these murals demonstrated that art could function simultaneously as aesthetic achievement and political discourse, reaching audiences far beyond the confines of the art world (Sharp et al., 2005). By the latter decades of the twentieth century, mural art had proliferated across urban centers globally. From the community murals of Chicago's South Side produced during the civil rights era to the politically charged street art of Belfast and the vibrant public imagery of São Paulo, murals became recognized as instruments of community voice and urban transformation (Hall & Robertson, 2001).

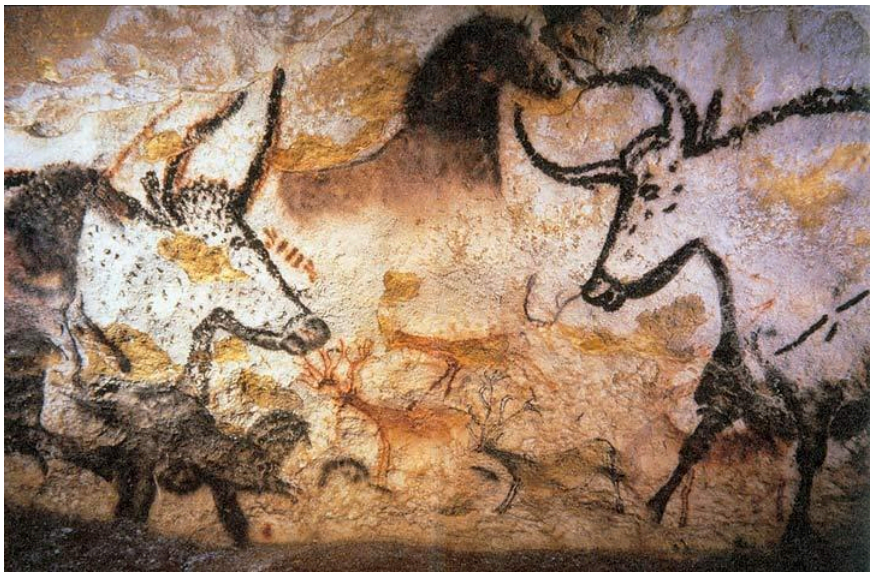


Figure 1. Prehistoric cave paintings in Lascaux, France represent early forms of mural art used for storytelling and ritual communications

III. Murals as Transformative Elements in Public Spaces

Among the most frequently cited contributions of mural art is its capacity to transform the physical character of urban environments. Deteriorating or underused building façades, which might otherwise communicate neglect and disinvestment, can be reimagined as vibrant cultural surfaces that attract positive attention and foster community pride. Municipal governments and nonprofit organizations have increasingly incorporated mural commissions into urban renewal strategies targeting disadvantaged neighborhoods (Petronienė & Juzelėnienė, 2022). Urban beautification represents one of the most immediate impacts of mural programming. By introducing color, imagery, and narrative into the built environment, murals counteract the visual monotony of undifferentiated commercial or industrial architecture. This aesthetic enrichment enhances residents' subjective experience of their surroundings and may encourage greater use of public spaces for social activities (Dovey et al., 2012). Beyond aesthetic improvement, murals function as place-making instruments. A mural depicting local historical events, cultural figures, or ecological landscapes communicates to residents and visitors alike that a particular place has a distinct and valued identity. This symbolic marking of space can strengthen residents' sense of attachment to their neighborhood and contribute to what urban scholars describe as a sense of place — the quality of a location that makes it feel meaningful and distinctive (Miles, 1997).



Figure 2. Ajanta Cave murals in Maharashtra, India illustrate Buddhist narratives and demonstrate advanced techniques of ancient Indian mural painting.

Murals also serve as spatial anchors for collective memory. By depicting historical events, community leaders, and cultural traditions, they ensure that stories which might otherwise be marginalized or forgotten remain visible in the everyday environment. In this sense, murals perform a preservation function analogous to archives and monuments, though in a form accessible to all passersby rather than only to specialist audiences (Hall & Robertson, 2001).

IV. Mural Art and Community Engagement

A central strength of mural art lies in its capacity to involve communities directly in creative processes. Rather than commissioning artworks produced entirely by professional artists for passive public consumption, many contemporary mural initiatives adopt participatory models in which community members — including residents, students, and local organizations — contribute to the design, planning, and execution of the work (Sharp et al., 2005). This collaborative approach transforms the artwork from an object imposed upon a community into an expression generated from within it. Participatory mural projects typically involve workshops, community consultations, and open painting sessions. These events create informal social occasions during which participants interact across generational, cultural, and socioeconomic lines. Research on community art initiatives suggests that such encounters can strengthen social networks and foster a sense of shared purpose among participants who might not otherwise engage with one another (Petronienė & Juzelėnienė, 2022).

A further dimension of community engagement concerns the thematic content of murals. Artists working within participatory frameworks frequently incorporate the voices of community members in determining what subjects a mural will address. The resulting works often tackle pressing social questions —

environmental justice, racial equality, cultural diversity, immigration, and public health — presenting these themes in highly visible public forums and encouraging ongoing dialogue among residents (Dovey et al., 2012). In this way, murals can function as a form of public pedagogy, raising awareness and prompting reflection on issues that may receive insufficient attention in mainstream discourse. Importantly, participation in mural creation cultivates a sense of ownership among community members. Research indicates that residents who contribute to public art projects express stronger identification with the resulting works and greater investment in their maintenance and protection (Goldstein, 2005). This psychological investment can translate into broader civic engagement, as the experience of successful collective action in the cultural sphere encourages confidence in community capacity to address other shared challenges.



Figure 3. A contemporary urban street mural transforming an ordinary building wall into a vibrant public artwork that enhances urban aesthetics

V. Social and Cultural Impact of Mural Art

Mural art makes a significant contribution to social cohesion in diverse urban communities. By representing the histories, traditions, and symbols of different cultural groups on shared public surfaces, murals signal that multiple identities are valued and recognized within the civic landscape. This symbolic inclusion can foster mutual respect and reduce the marginalization of communities whose cultural presence is often underrepresented in mainstream urban imagery (Sharp et al., 2005). Schools, universities, and cultural institutions have long recognized the educational potential of murals. Because murals communicate through visual imagery rather than text, they make historical and cultural information accessible to audiences with varying levels of literacy, including children and recent immigrants encountering unfamiliar cultural contexts. The immersive, large-scale nature of mural imagery also creates memorable impressions that may reinforce learning more effectively than printed materials alone (Miles, 1997).

Youth engagement represents a particularly important dimension of the social impact of mural programming. Studies of community mural initiatives consistently report that young participants develop not only artistic skills but also greater confidence, stronger social connections, and more positive orientations toward their neighborhoods (Hall & Robertson, 2001). Engagement in collaborative creative projects provides structured opportunities for youth to exercise agency and experience the satisfaction of producing something of lasting community value, outcomes that may support broader patterns of civic participation and prosocial behavior. Mural art also plays a role in supporting the psychological wellbeing of communities experiencing stress or hardship. Following disasters, episodes of civil unrest, or periods of economic decline, community mural projects have been used as healing processes that allow affected residents to mourn, reflect, and articulate visions of recovery through collective creative expression. The process of working together on a shared artwork can itself be therapeutic, fostering social connection at a time when isolation and grief might otherwise predominate (Petronienė & Juzelėnienė, 2022).

VI. Economic and Urban Development Impact

Beyond their cultural and social dimensions, murals contribute to the economic vitality of urban areas. Cities that have developed reputations for vibrant public art scenes — Philadelphia, Melbourne, Bogotá, and Berlin among them — attract substantial tourism from visitors interested in exploring creative districts. Guided mural tours, street art festivals, and cultural events associated with public art programs generate revenue for local businesses, including restaurants, hotels, retail outlets, and transportation providers (Hall & Robertson, 2001). Mural commissions and associated programming also create employment opportunities for artists, fabricators, arts administrators, and cultural organizations. These economic benefits contribute to the growth of the creative economy — a sector increasingly recognized by urban policymakers as a driver of sustainable development and competitive advantage in knowledge-based economies (Goldstein, 2005).

The relationship between public art and property values has attracted considerable scholarly attention. Although the evidence is mixed and context-dependent, several studies suggest that well-planned public art programs, including mural initiatives, contribute to increased property values and business activity in adjacent areas by enhancing neighborhood attractiveness and signaling civic investment (Dovey et al., 2012). Even where direct property value effects are difficult to quantify, murals often play an important role in shifting the narrative around a neighborhood, encouraging private investment by demonstrating that a community is active, creative, and capable of self-improvement.

VII. Challenges in Mural Art Projects

Notwithstanding their many benefits, mural art initiatives face significant practical and conceptual challenges. Funding represents perhaps the most pervasive constraint. Large-scale mural production requires resources for high-quality exterior paints and sealants, scaffolding and equipment, artist fees, community facilitation, and ongoing maintenance. Public arts budgets are frequently vulnerable to fiscal austerity measures, and many initiatives depend on unstable combinations of philanthropic grants, municipal allocations, and private sponsorship (Hall & Robertson, 2001). Conservation and maintenance pose persistent challenges for outdoor murals. Exposure to ultraviolet radiation, moisture, temperature fluctuations, pollution, and deliberate vandalism causes mural surfaces to fade, crack, and deteriorate. Without adequate maintenance budgets and curatorial attention, even highly successful murals may become illegible within a decade of their completion. The development of more durable materials and systematic conservation programs is therefore an important priority for the field (Goldstein, 2005).

Questions of representation and community voice raise important ethical challenges for mural practice. Critics have observed that mural projects initiated by external agencies — including municipal governments, developers, and nonprofit organizations — may reflect the aesthetic preferences and social agendas of institutional sponsors rather than the authentic cultural priorities of the communities in whose neighborhoods the murals appear. Superficial consultation processes can result in artworks that fail to resonate with residents or, in the worst cases, that aestheticize and conceal ongoing patterns of displacement and gentrification (Dovey et al., 2012). Authentic community engagement therefore requires sustained relationship-building, transparent decision-making, and genuine transfer of creative authority to community participants. Tensions between mural art and unauthorized graffiti represent another area of contestation. While institutional mural programs are generally welcomed by civic authorities, unsanctioned street art occupies a legally and aesthetically ambiguous position. Some scholars argue that the criminalization of unauthorized graffiti disproportionately targets young people from marginalized communities who are expressing legitimate cultural voices (Sharp et al., 2005), while others maintain that clear regulatory frameworks are necessary to protect both public and private property.

VIII. Conclusion

Mural art has established itself as an indispensable element of contemporary urban culture and public art practice. Its capacity to transform the physical environment, articulate community identity, and facilitate civic dialogue makes it a uniquely powerful tool for urban development and social cohesion. The collaborative and participatory dimensions of mural creation foster social connections, build community capacity, and engender the sense of ownership and pride that sustains thriving public spaces (Petronienė & Juzelėnienė, 2022; Sharp et al., 2005). The cultural, social, and economic evidence reviewed in this paper supports a view of mural art not as a decorative supplement to more consequential urban policy, but as a

substantive intervention capable of generating lasting social value. Murals preserve collective memory, extend cultural education beyond institutional walls, support youth development, and contribute to economic vitality through tourism and creative economy employment (Miles, 1997; Goldstein, 2005).

However, realizing the full potential of mural art requires addressing its structural challenges with equal seriousness. Sustainable funding mechanisms, rigorous conservation programs, authentic community engagement processes, and ethical attention to questions of representation and displacement are prerequisites for mural initiatives that genuinely serve community interests rather than institutional ones (Hall & Robertson, 2001; Dovey et al., 2012). Future mural programming should prioritize equitable participation, long-term stewardship, and the integration of community voices at every stage of project development. With these commitments in place, mural art will continue to enrich urban environments and strengthen the social fabric of communities for generations to come.

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