Industrial Review of TPM, Downtime Reduction, and Machine Reliability Improvement in Plastic Injection Molding Industries

[1]Mr. Mahesh Myanpawar, [2]Dr. S.K. Biradar, [3]Prof. RL Karwande, [4]Prof. VB Jadhav , [5]Md. Irfan

[1]PG Student, [2]Principal and Professor

[12345]Department of Mechanical Engineering

[12345]MSSCOE Jalna, Maharashtra

Abstract—**Plastic injection molding industries play a significant role in modern manufacturing by producing high-volume and high-precision components for automotive, packaging, electronics, medical, and consumer product applications. However, frequent machine breakdowns, excessive downtime, reduced equipment reliability, and maintenance-related losses adversely affect production efficiency and profitability. This review paper presents a comprehensive analysis of Total Productive Maintenance (TPM), downtime reduction techniques, and machine reliability improvement strategies adopted in plastic injection molding industries. The study critically reviews published literature related to TPM implementation, Overall Equipment Effectiveness (OEE), reliability assessment parameters such as MTBF and MTTR, preventive and predictive maintenance approaches, and industrial case studies. The findings indicate that TPM significantly improves equipment availability, productivity, product quality, and maintenance performance while reducing downtime and operational losses. Furthermore, recent advancements in Industry 4.0 technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), and Digital Twin systems, have enhanced maintenance decision-making and reliability management capabilities. The review also identifies existing research gaps and highlights future opportunities for developing intelligent and sustainable maintenance systems in injection molding industries. Overall, TPM remains a powerful strategy for achieving manufacturing excellence, reliability enhancement, and continuous productivity improvement.**

Index Terms—**Total Productive Maintenance (TPM), Injection Molding Industry, Overall Equipment Effectiveness (OEE), Machine Reliability, Downtime Reduction**

I. Introduction

1.1 Background of Plastic Injection Molding Industries

Plastic injection molding is one of the most widely adopted manufacturing processes for producing plastic components with high accuracy, repeatability, and productivity. The growth of automotive, medical, packaging, consumer goods, and electronics sectors has significantly increased the demand for injection molded products. Modern injection molding technology enables mass production with reduced cycle time and improved product quality, making machine productivity a key factor in industrial competitiveness and profitability [9], [10], [15].

1.2 Maintenance Challenges in Injection Molding Industries

Injection molding industries frequently face machine breakdowns, hydraulic failures, heater malfunctions, mold wear, and electrical faults that interrupt production activities. These failures lead to downtime losses, quality defects, increased maintenance costs, and reduced machine utilization. Effective maintenance management is therefore essential for ensuring continuous production and operational efficiency [11], [13], [21].

1.3 Importance of TPM in Manufacturing Industries

Total Productive Maintenance (TPM) is a maintenance philosophy that aims to maximize equipment effectiveness through employee involvement, preventive maintenance, and continuous improvement. TPM focuses on achieving zero breakdowns, zero defects, and zero accidents while improving equipment reliability, productivity, and quality performance. TPM has become a widely accepted strategy for manufacturing excellence across industries [1], [2], [23].

1.4 Need for Downtime Reduction

Downtime is one of the major contributors to productivity loss in manufacturing industries. Machine failures reduce production output, increase operating costs, and affect customer delivery commitments. Reducing downtime improves equipment availability, production continuity, and overall profitability. Several studies have reported significant productivity gains through systematic downtime reduction programs [13], [21], [28].

1.5 Need for Reliability Improvement

Machine reliability determines the ability of equipment to perform its intended function without failure. Higher reliability results in fewer breakdowns, improved production stability, and lower maintenance requirements. Reliability indicators such as MTBF and MTTR are commonly used to evaluate equipment performance and maintenance effectiveness in industries [4], [7], [8].

1.6 Scope and Objectives of the Review Paper

This review paper focuses on TPM implementation, downtime reduction techniques, and machine reliability improvement practices in plastic injection molding industries. The objective is to review existing literature, identify research trends, compare industrial findings, and highlight future opportunities for productivity enhancement through advanced maintenance systems.

Table 1.1 Summary of Challenges in Injection Molding Industries

Sr. No.	Challenge	Impact
1	Machine Breakdowns	Production Loss
2	Hydraulic Failures	Downtime Increase
3	Mold Failures	Product Defects
4	Quality Issues	Customer Complaints
5	High Maintenance Cost	Reduced Profitability
6	Low Equipment Availability	Reduced Productivity

Major operational and maintenance challenges encountered in plastic injection molding industries. These challenges directly influence productivity, quality, and equipment effectiveness.

Plastic Injection Molding Manufacturing Framework (HD)

Figure 1.1: Overall manufacturing framework of plastic injection molding industries showing the transformation of raw materials into finished products through molding operations.

II. OVERVIEW OF INJECTION MOLDING MACHINES AND MAINTENANCE SYSTEMS

2.1 Injection Molding Process

Injection molding is a manufacturing process in which molten plastic material is injected into a mold cavity, cooled, and ejected as a finished product. The process involves feeding, melting, injection, packing, cooling, and ejection stages. Process parameters such as injection pressure, melt temperature, mold temperature, and cooling time significantly affect product quality [9], [10].

2.2 Injection Molding Machine Components

The machine consists of an injection unit, clamping unit, hydraulic system, mold assembly, and control system. Each subsystem contributes to the overall performance and productivity of the molding process [9], [10].

2.3 Common Failure Modes in Injection Molding Machines

Common failures include hydraulic leakage, heater band failures, mold wear, cooling system blockage, sensor malfunction, and electrical faults. These failures contribute significantly to machine downtime and reduced productivity [11], [13], [30].

2.4 Evolution of Maintenance Systems

Maintenance systems have evolved from breakdown maintenance to preventive maintenance, predictive maintenance, condition-based maintenance, and reliability-centered maintenance. Modern maintenance strategies focus on preventing failures before they occur and improving equipment reliability [4], [18], [19].

2.5 Maintenance Performance Indicators

Key indicators used for evaluating maintenance effectiveness include downtime, availability, MTBF, MTTR, reliability, and maintainability. These metrics provide quantitative information regarding machine performance and maintenance quality [7], [8], [20].

Table 2.1 Maintenance Performance Indicators

Indicator	Purpose
Downtime	Measure production loss
Availability	Equipment readiness
MTBF	Reliability evaluation
MTTR	Repair efficiency
Reliability	Failure-free operation
Maintainability	Ease of maintenance

Maintenance performance indicators commonly used for evaluating equipment effectiveness and maintenance performance in manufacturing industries.

Injection Molding Machine System (HD)

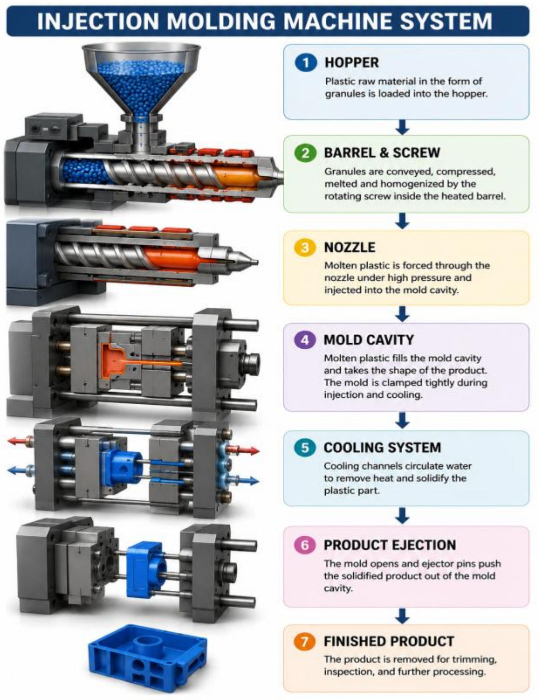

Figure 2.1: Basic injection molding machine architecture showing material flow from feeding

III. REVIEW OF TOTAL PRODUCTIVE MAINTENANCE (TPM)

3.1 Historical Development of TPM

TPM originated in Japan during the 1970s and was pioneered by Seiichi Nakajima. It evolved from preventive maintenance concepts and became a globally recognized methodology for achieving manufacturing excellence and equipment effectiveness [1], [2], [16].

3.2 TPM Concepts and Principles

TPM emphasizes total employee participation, continuous improvement, proactive maintenance, and equipment ownership. The philosophy encourages operators and maintenance personnel to work together to eliminate equipment losses and improve productivity [3], [23], [24].

3.3 TPM Pillars

The TPM framework consists of eight pillars:

- Autonomous Maintenance
- Planned Maintenance
- Focused Improvement
- Quality Maintenance
- Education and Training
- Safety, Health and Environment
- Early Equipment Management
- Office TPM

These pillars collectively support equipment reliability and manufacturing performance improvement [1], [2].

3.4 TPM Implementation Methodologies

Successful TPM implementation involves management commitment, employee training, equipment evaluation, autonomous maintenance development, preventive maintenance planning, and continuous improvement activities. Challenges include resistance to change, training requirements, and data management issues [23], [24], [25].

3.5 Review of TPM Applications in Manufacturing Industries

Several studies in automotive, plastic, food processing, and manufacturing industries have demonstrated significant improvements in OEE, reliability, productivity, and downtime reduction through TPM implementation. Reported improvements confirm TPM as an effective maintenance and productivity enhancement strategy [11], [12], [13], [21], [26], [30].

TPM Framework (HD)

Figure 3.1: TPM framework illustrating the relationship between TPM objectives and productivity improvement. TPM aims to eliminate losses and maximize equipment effectiveness through continuous improvement activities.

IV. REVIEW OF DOWNTIME REDUCTION TECHNIQUES AND OEE IMPROVEMENT

4.1 Concept of Industrial Downtime

Industrial downtime refers to the period during which equipment is unable to perform production activities. Downtime can be classified as planned downtime, including scheduled maintenance and setup activities, and unplanned downtime caused by machine failures and operational disruptions. Excessive downtime negatively affects productivity, profitability, and customer satisfaction [5], [18], [20].

4.2 Downtime Analysis Techniques

Various analytical techniques are used to identify and reduce downtime losses. Pareto Analysis helps identify critical failure causes, Fishbone Diagrams determine root causes, Root Cause Analysis (RCA) investigates failure mechanisms, and Failure Mode and Effects Analysis (FMEA) prioritizes maintenance actions based on risk assessment [4], [7], [8].

4.3 Six Big Losses in TPM

TPM identifies six major equipment losses: breakdown losses, setup and adjustment losses, minor stoppages, reduced speed losses, quality defects, and startup losses. These losses significantly reduce machine effectiveness and manufacturing productivity [1], [2], [3].

4.4 Overall Equipment Effectiveness (OEE)

OEE is a key performance indicator used to evaluate equipment productivity. It consists of Availability, Performance Efficiency, and Quality Rate. OEE provides a comprehensive measure of machine utilization and is widely used to assess TPM effectiveness [11], [12], [26].

4.5 Literature Review of OEE Improvement Studies

Several industrial studies have reported OEE improvements through TPM implementation, preventive maintenance, and continuous improvement initiatives. Reported OEE enhancements typically range from 10% to 25%, resulting in higher productivity and reduced downtime [11], [12], [25], [29], [30].

4.6 Review of Downtime Reduction Strategies

Modern downtime reduction strategies include preventive maintenance, predictive maintenance, TPM implementation, lean maintenance practices, and Industry 4.0-enabled maintenance systems. These approaches improve equipment availability, reduce failures, and enhance manufacturing performance [19], [20], [23], [30].

Table 4.1 Downtime Reduction Techniques

Technique	Primary Objective
Preventive Maintenance	Failure Prevention
Predictive Maintenance	Early Fault Detection
TPM	Productivity Improvement
Lean Maintenance	Waste Elimination
Industry 4.0 Maintenance	Smart Monitoring

Common downtime reduction techniques adopted in manufacturing industries for improving equipment availability and reducing production losses.

Reduction Framework (HD)

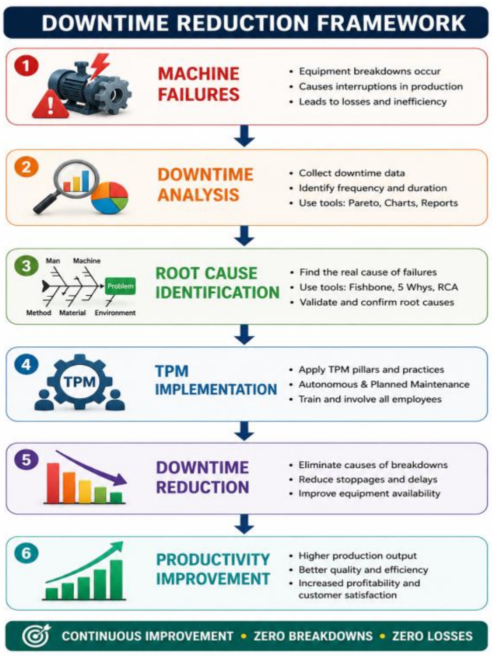

Figure 4.1: Framework illustrating the systematic process of identifying downtime causes and implementing TPM-based solutions for productivity improvement.

V. REVIEW OF MACHINE RELIABILITY IMPROVEMENT STRATEGIES

5.1 Fundamentals of Reliability Engineering

Reliability engineering focuses on ensuring that equipment performs its intended function without failure under specified operating conditions. Reliability improvement is essential for maintaining continuous production and reducing maintenance costs [4], [5], [8].

5.2 Reliability Assessment Parameters

Machine reliability is commonly evaluated using Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), Failure Rate, Availability, and Reliability Index. These parameters provide quantitative measures of equipment performance and maintenance effectiveness [7], [8], [18].

5.3 Reliability Improvement Approaches

Reliability improvement can be achieved through Reliability-Centered Maintenance (RCM), preventive maintenance, predictive maintenance, and TPM-based maintenance systems. These approaches reduce failure frequency and increase equipment availability [4], [18], [20], [27].

5.4 Literature Review of Reliability Improvement Studies

Published industrial studies indicate significant reliability improvements through TPM implementation. Applications in manufacturing, process industries, and injection molding operations have demonstrated increased MTBF, reduced MTTR, and improved machine availability [13], [21], [24], [30].

5.5 Smart Reliability Management Systems

Smart reliability management systems utilize IoT sensors, wireless monitoring devices, and condition monitoring technologies to continuously assess machine health and support predictive maintenance activities [19], [20].

5.6 AI and Machine Learning Applications

Artificial Intelligence (AI) and Machine Learning (ML) technologies are increasingly used for predictive analytics, failure prediction, condition monitoring, and intelligent maintenance planning. These technologies support proactive maintenance decision-making and improved reliability management [15], [19].

Table 5.1 Reliability Improvement Approaches

Approach	Benefit
RCM	Reliability Enhancement
Preventive Maintenance	Failure Reduction
Predictive Maintenance	Early Fault Detection
TPM	Equipment Effectiveness
AI-Based Maintenance	Intelligent Prediction

Reliability improvement methodologies commonly adopted in manufacturing industries to improve equipment performance and operational stability.

Reliability Improvement Framework (HD)

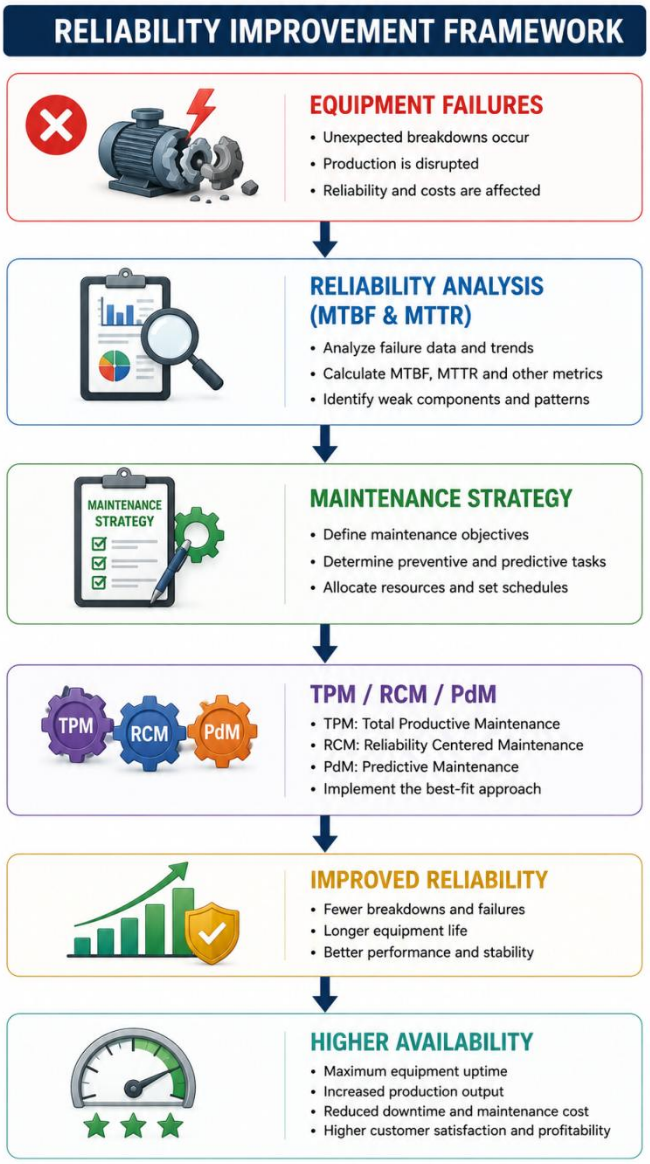

Figure 5.1: Reliability improvement methodology showing the relationship between maintenance strategies and equipment availability enhancement.

VI. DISCUSSION, RESEARCH GAPS, CONCLUSION AND FUTURE DIRECTIONS

6.1 Comparative Analysis of Literature

The reviewed literature indicates that TPM implementation consistently improves OEE, machine reliability, and downtime performance across different industrial sectors. Most studies report reductions in breakdown frequency and improvements in equipment effectiveness through structured maintenance programs [21], [23], [24], [25].

6.2 Research Gaps Identified

Although extensive TPM research exists, limited studies specifically address plastic injection molding industries. Few researchers have integrated TPM, OEE improvement, reliability analysis, and Industry 4.0 technologies into a unified framework. AI-assisted TPM implementation remains relatively unexplored [13], [15], [30].

6.3 Discussion of Findings

The literature confirms that TPM is an effective methodology for improving productivity, equipment reliability, and maintenance performance. Successful implementation depends on management commitment, employee involvement, training programs, and continuous improvement culture [23], [24], [25].

6.4 Future Research Directions

Future research should focus on Industry 4.0 integration, AI-based predictive maintenance, Digital Twin technology, smart TPM systems, and real-time monitoring platforms. These technologies offer significant opportunities for intelligent maintenance management and productivity enhancement [15], [19], [20].

6.5 Conclusion

The reviewed literature demonstrates that TPM significantly contributes to downtime reduction, reliability improvement, OEE enhancement, and manufacturing productivity. The integration of advanced digital technologies with TPM principles represents a promising direction for future smart manufacturing systems [1], [23], [30].

Figure 6.1 Future Smart Maintenance Framework (HD)

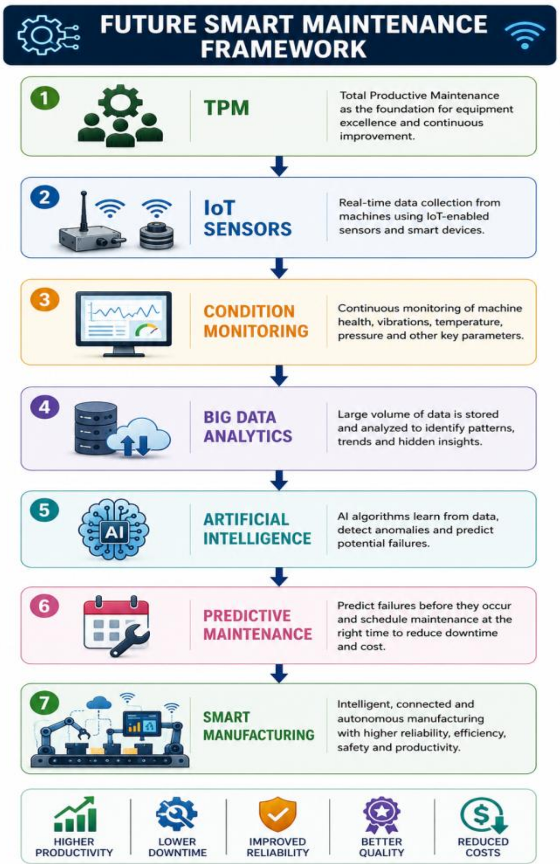

Figure 6.1: Future direction of maintenance systems integrating TPM with IoT, Artificial Intelligence, and predictive maintenance technologies to support Industry 4.0 manufacturing environments.

References

[1] S. Nakajima, Introduction to TPM: Total Productive Maintenance, Cambridge, MA, USA: Productivity Press, 1988.

[2] S. Nakajima, TPM Development Program: Implementing Total Productive Maintenance, Portland, OR, USA: Productivity Press, 1989.

[3] E. R. Wireman, Total Productive Maintenance, 2nd ed., New York, NY, USA: Industrial Press Inc., 2004.

[4] J. Moubray, Reliability-Centered Maintenance, 2nd ed., New York, NY, USA: Industrial Press, 1997.

[5] B. S. Dhillon, Engineering Maintenance: A Modern Approach, Boca Raton, FL, USA: CRC Press, 2002.

[6] A. Kelly, Maintenance Systems and Documentation, Oxford, U.K.: Butterworth-Heinemann, 2006.

[7] A. K. S. Jardine and A. H. C. Tsang, Maintenance, Replacement and Reliability: Theory and Applications, 2nd ed., Boca Raton, FL, USA: CRC Press, 2013.

[8] H. Wang and H. Pham, Reliability and Optimal Maintenance, London, U.K.: Springer, 2006.

[9] D. V. Rosato and M. G. Rosato, Injection Molding Handbook, 3rd ed., New York, NY, USA: Springer, 2000.

[10] T. A. Osswald and L. S. Turng, Injection Molding Handbook, Munich, Germany: Hanser Publishers, 2008.

[11] L. D. Gabahne, M. M. Gupta, and M. D. Zanwar, “Overall Equipment Effectiveness Improvement: A Case of Injection Molding Machine,” The International Journal of Engineering and Science (IJES), vol. 3, no. 8, pp. 1–10, 2014.

[12] E. Sivaselvam and S. Gajendran, “Improvement of Overall Equipment Effectiveness in a Plastic Injection Moulding Industry,” IOSR Journal of Mechanical and Civil Engineering, vol. 11, no. 2, pp. 12–16, 2014.

[13] Y. Sulistyoadi, B. Hidajah, and H. H. Purba, “TPM Implementation to Reduce Downtime in Injection Molding Company,” Journal of Scientific and Engineering Research, vol. 3, no. 6, pp. 398–404, 2016.

[14] D. N. Gandhi and P. M. Gandhi, “A Review of TPM to Implement OEE Technique in Manufacturing Industry,” Industrial Engineering Journal, vol. 11, no. 6, pp. 36–46, 2018.

[15] S. E. Lino Moreno, R. F. Salas, and J. A. Flores, “Enhancement of Operational Efficiency in a Plastic Manufacturing Company through TPM, SMED and Machine Learning Integration,” Sustainability, vol. 17, no. 16, Art. no. 7445, 2025.

[16] K. Shirose, TPM for Operators, Portland, OR, USA: Productivity Press, 1996.

[17] K. Shirose, TPM for Workshop Leaders, Portland, OR, USA: Productivity Press, 1992.

[18] R. K. Mobley, Maintenance Fundamentals, 3rd ed., Burlington, MA, USA: Elsevier, 2011.

[19] R. K. Mobley, An Introduction to Predictive Maintenance, 2nd ed., Burlington, MA, USA: Elsevier, 2002.

[20] J. Campbell and A. K. S. Jardine, Maintenance Excellence: Optimizing Equipment Life-Cycle Decisions, 3rd ed., Boca Raton, FL, USA: CRC Press, 2016.

[21] A. Eti, S. O. T. Ogaji, and S. D. Probert, “Implementing Total Productive Maintenance in Nigerian Manufacturing Industries,” Applied Energy, vol. 79, no. 4, pp. 385–401, 2004.

[22] J. Bhadury, “Management of Productivity Through Total Productive Maintenance,” International Journal of Production Economics, vol. 95, no. 2, pp. 241–252, 2005.

[23] I. P. S. Ahuja and J. S. Khamba, “Total Productive Maintenance: Literature Review and Directions,” International Journal of Quality and Reliability Management, vol. 25, no. 7, pp. 709–756, 2008.

[24] I. P. S. Ahuja and J. S. Khamba, “Assessment of Contributions of Successful TPM Initiatives Towards Competitive Manufacturing,” Journal of Quality in Maintenance Engineering, vol. 14, no. 4, pp. 356–374, 2008.

[25] J. Singh, H. Singh, and G. Singh, “Productivity Improvement Through TPM in Manufacturing Industry,” Journal of Quality in Maintenance Engineering, vol. 19, no. 1, pp. 16–33, 2013.

[26] A. Gupta and R. Garg, “OEE Improvement by TPM Implementation: A Case Study,” International Journal of IT, Engineering and Applied Sciences Research, vol. 1, no. 1, pp. 115–124, 2012.

[27] V. S. Deshpande and J. P. Modak, “Application of RCM and TPM for Productivity Improvement in Manufacturing Industries,” International Journal of Productivity and Performance Management, vol. 51, no. 2, pp. 69–75, 2002.

[28] C. Tsarouhas, “Implementation of TPM in Food Manufacturing Industry: A Case Study,” Journal of Quality in Maintenance Engineering, vol. 13, no. 1, pp. 5–18, 2007.

[29] C. Tsarouhas, “Evaluation of Overall Equipment Effectiveness in the Beverage Industry,” International Journal of Production Research, vol. 51, no. 2, pp. 515–523, 2013.

[30] H. H. Purba, Y. Sulistyoadi, and B. Hidajah, “Implementation of TPM Concept to Improve Equipment Effectiveness in Plastic Manufacturing Industry,” International Journal of Technology, vol. 8, no. 7, pp. 1241–1250, 2017.