CHAPTER 44

Implementation of Total Productive Maintenance (TPM) for Effective Equipment Management in Infrastructure Projects

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ABSTRACT

Efficient equipment management ensures infrastructure projects are delivered in time and at lower cost. However, frequent breakdowns, poor maintenance practices, and lack of performance monitoring often lead to productivity losses and increased project costs. This research aims to Automate Equipment Maintenance by using ERP systems for efficient equipment management in construction and infrastructure projects, by following various maintenance practices such as Total Productive Maintenance (TPM). The research work explores existing maintenance practices that have been adopted in the organization and identifies the deviation, then evaluates the impact of TPM on improving Overall Equipment Effectiveness (OEE). Data regarding various equipment operations in several construction projects are analysed, which includes Daily operations, Idle time, Breakdown time, Repair time, Maintenance scheduling, Actual maintenance carried out, Time taken for maintenance, and expert interviews to understand the loss areas. A TPM model is developed to improve reliability, preventive maintenance culture, and safety awareness among maintenance crew. The results are expected to demonstrate significant reductions in equipment downtime, increased utilization percentage, production quantity, thereby reducing the equipment cost for the project. The research highlights TPM as a practical and sustainable approach for modern infrastructure project management.

Keywords: Total Productive Maintenance, Overall Equipment Effectiveness, Preventive maintenance.

1.0 Introduction

Effective equipment management is an integral part of infrastructure project.

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Construction and infrastructure environment demands equipment which are reliable, always available for utilisation, and capable of keeping pace with construction project timelines and costs. Sudden failures in equipment, and ineffective maintenance activities leads to low equipment performance which causes losses and negatively affect in construction timeline and costs. To mitigate such issues, Total Productive Maintenance (TPM) can be adopted, as it involves and encourages various stakeholders to take preventive and continuous improvement measures to optimise equipment performance and production.

For instance, in infrastructure projects heavy construction equipment like Tunnel Boring Machine (TBM), Earthmovers, Cranes, Material Handling, Road Making Equipment etc. are used to execute the project in safe, fast, quality, and cost effective. The use of TPM and measuring performance by OEE provides a means of ensuring that such potential drawbacks or challenges associated with heavy machine usage in infrastructure development projects are addressed.

This paper gives an overall review of literature on TPM, a research methodology to analyse the application of TPM on infrastructure projects and concludes by identifying some areas for research on TPM in the future.

1.1 Present industry scenario

In infrastructure projects, effective equipment management begins with strategically deploying suitable construction equipment from various yards or project locations based on site demand and availability. This process involves selecting right equipment for right activity and coordinating with relevant stakeholders to fulfil the needs of project execution team.

Generally, infrastructure projects are spread across large areas, and simultaneously multiple activities are being performed on daily basis and to perform these activities safely and with quality, we need heavy construction equipment.

Construction equipment is bound to fail over a period of usage. To reduce these sudden failures, we need to perform periodic or preventive maintenance in a timely manner.

In construction projects most of this equipment are being handled and operated by operators. As a general practice, before starting the equipment operation operators are checking the conditions of equipment on daily basis and logs of daily usage are recorded in manual logbook, and later this data is being updated in the system by a data entry person, and subsequently being reviewed by the concerned manager, and necessary maintenance schedules are being prepared considering the anticipated operating hours.

Maintenance schedules are prepared in line with OEM recommendations. Maintenance tasks are performed according to schedule and actual operating hours; however, the entire process is manually controlled, numerous delays occur.

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On reviewing the maintenance tasks that are already performed, we could see few delays, like the operator is not communicating with the maintenance crew about the maintenance due, the nonavailability of spares in stock, and sudden changes in equipment deployment/engagement. There are a few repeated reasons that lead to delays in maintenance. On studying the data, we can derive and identify similar things that are impacting our maintenance tasks, and these delays can be controlled very well if they are done in a proper systematic way. To perform the maintenance task in an equipment, we need to closely interact with multiple stakeholders like the execution team for the spareability of equipment, the store in-charge for availability of spare parts and P&M in-charge for availability of the maintenance crew. The delay in preventive/ periodic maintenance results in sudden failures which are unplanned downtime, and frequent breakdowns. The unplanned downtime creates lot of pressure in the execution, maintenance and operation team. Once equipment fails, all the resources like man and machine which are allotted for the activity will be idle. This would lead to inefficient utilization of equipment as well as high equipment cost for the project.

The lack of a data-driven and proactive maintenance culture is also a challenge to safety, reliability, and timely decision-making, thus the need to address the weakness of manual maintenance of equipment through approaches like TPM and ERP System.

2.0 Literature review

2.1 Total Productive Maintenance (TPM) concepts and pillars

Total productive maintenance (TPM) is an Overall concept of equipment maintenance and equipment assets management with an aim to optimize equipment efficiency. This is achieved through the overall staff and equipment engagement and minimizing losses in overall equipment life cycles. This paper reveals that TPM is a strategic process incorporating preventive, predictive, and autonomous maintenance techniques to optimize equipment reliability, productivity, and quality outcomes within manufacturing processes.(Ahuja & Khamba, 2008)

As stated by the study paper, the implementation of TPM works on the foundation of 8 pillars: Focused Improvement, Autonomous Maintenance, Planned Maintenance, Education and Training, Earley Equipment Management, Quality Maintenance, Office TPM, Safety, Health & Environment. These pillars control the overall 6 big losses, which include breakdowns, set up losses, idle time losses, losses due to speed, defects, and start-up losses.(Meca Vital & Camello Lima, 2020)

TPM stands to be a cultural shift rather than a maintenance method as it involves operates, maintenance personnel, as well as management in improvement activities. The focused improvement and plant maintenance pillars have been found to be the most effective

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in overcoming downtimes as well as improvement in reliability in a diverse range of industries such as automobile, textile, chemical as well as food processing industries.(Meca Vital & Camello Lima, 2020; Mwanza & Mbohwa, 2015)

2.2 Overall Equipment Effectiveness (OEE) as a performance measure

Overall Equipment Effectiveness (OEE) – It is a key statistical measurement used to assess the effectiveness of TPM implementation. (Corrales et al., 2020)It enhances the overall efficiency of equipment by accounting for the secondary losses resulting from the 6 major losses, enabling a comparison with world class manufacturing standards where an OEE above 85% is considered excellent. It gives the overall effect by multiplying the other two, which is the effect of the 6 big losses. (Okoro, Gospel Onyebuchi, 2024) This paper examines the unequal effectiveness of different pillars of Total Productive Maintenance (TPM) in improving OEE performance. Through a survey conducted on Brazilian manufacturing companies it was found that focused improvement and plant maintenance generated improvement in OEE ranging from 12.5% to 33.3% by reducing breakdown losses, Mean Time To Repair (MTTR), and quality defects.(Meca Vital & Camello Lima, 2020) Extending these findings to another industry, automotive case studies further affirm the evidence that implementing TPM results in marked enhancements in availability, performance efficiency, and quality rates. OEE values increase between 6% and 10% after a systematic implementation of the AM and QM pillars of TPM(Kumar Das et al., n.d.)

2.3 Impact of TPM pillars on manufacturing performance

The diverse impact of various TPM pillars is highlighted by empirical data from multiple studies. Because of operator involvement, autonomous maintenance improves basic conditions by decreasing minor stoppage and increasing fault detection speed.(Adesta et al., 2018). Unplanned downtime is decreased and scheduling efficiency is increased with plant maintenance. Quality maintenance integrates maintenance with process quality control systems to achieve zero defect pollution.(Meca Vital & Camello Lima, 2020)

Studies in the pharmaceutical and automotive industries shows that bpm adoption increases machine availability by 15 to 25%, slower corrective maintenance by over 50%, and boost OEE by roughly 20% with structured pillar implementation and ongoing monitoring.(Kumar Das et al., n.d.)

2.4 Digital TPM and Industry 4.0 integration

As industry 4.0 emerges, TPM becomes digital TPM (TPM 4.0), which integrates IoT and smart sensors with AI and TPM 4.0. This is clear from a systematic study by, which

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showed how digital technology rises OEE, MTBF, and MTR and enhances condition monitoring and predictive maintenance.(Mouhib et al., 2025)

According to their research there are 4 crucial elements that must be present for TPM 4.0 to be implemented successfully:

- Workforce integration and training
- Phased deployment strategy
- Modular technology architecture
- Standardised performance metrics OEE, MTBF, MT

The research on the unified digital TPM framework is crucial, particularly for scaled applications involving SMEs and infrastructure intensive industries.(Hussien Gomaa, 2025; Mouhib et al., 2025)

2.5 Data driven and lean 4.0 based TPM frameworks

Recent literature shows how traditional total product in maintenance (TPM) will change due to data driven and digital maintenance systems in the context of industry 4.0 and lean 4.0. This paper suggests a complete data drilling framework for TPM, combining Association Rule Mining and Network Analysis to support strategic decision-making for improving Overall Equipment Effectiveness (OEE).(Lucantoni et al., 2025)

This four-layer model include data acquisition, processing, analytics, and decision support. This setup allows for real-time identification of key loss factors affecting availability, performance, and quality. The research demonstrate that advanced analytics can reveal hidden connections among production variable and TPM pillars. The results from an industrial case study showed a 14% increase in OEE and successful implementation of seven out of eight TPM pillars confirm in the effectiveness Lean 4.0-enabled TPM.

This digital shift addresses the limitation of traditional TPM, which depends on manual data collection and reactive tools like Pareto charts and Ishikawa diagram. The integration of IoT-based data acquisition systems, computerised maintenance management system (CMSS), Manufacturing Execution Systems (MES), and data warehouses allows for continuous monitoring of equipment health, failure trends, and performance, enhancing predictive and proactive maintenance capabilities. Research evidence shows that digital TPM frameworks significantly enhance the accuracy of OEE calculation and early detection of chronic losses due to speed and quality defects that the traditional maintenance dashboards generally fail to detect.

2.6 TPM implementation practices and organizational readiness

The article gives a critical classification of TPM implementation methods for large industries and SMEs and has emphasized that the success of TPM greatly realizes on

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organisational maturity, skills, and management commitment (Jain et al., 2014) . An analysis of 148 studies shows that TPM boost equipment availability, cuts maintenance costs, increases operator involvement and enhance OEE. However, it also identifies challenges such as resistance to change, insufficient training, lack of standard maintenance data, and weak collaboration between production and maintenance teams.

The authors stress the importance of autonomous maintenance and planned maintenance as vital foundation in SMEs, as they empower operators and establish equipment conditions. Focused Improvement and Quality Maintenance further enhance overall equipment effectiveness by addressing losses and root causes of defects. Particularly highlights the value of integrating TPM with Reliability-Centered Maintenance (RCM) and CMMS.

This paper will further confirm these findings by synthesizing global literature on TPM's success implementation (Ngoy & Israel, n.d.). It emphasizes that TPM provides immediate benefits, such as reduction of breakdowns by 65% to 78% detect reduction by 65% to 80% and OEE improvement of 14% and 45% along with indirect benefits like enhanced safety culture, employee motivation, knowledge sharing, and better workplace organization these study reaffirms that TPM's effectiveness relies on teamwork among departments, ongoing training and strong leadership, which aligns with social-technical view of maintenance excellence.

2.7 Eight-Piller TPM and performance outcome

The eight-pillar TPM model-Autonomous Maintenance, Focused Improvement, Planned Maintenance, Quality Maintenance, Education and Training, Office TPM, Early Equipment Management, and Safety, Health and Environment-remains central to both traditional and digital TPM systems. (Aditya Sari, 2015) Confirms this framework while executing TPM deployment in water treatment facility using Likert-scale-based on maturity assessment across all pillars.

The results indicated that implementation levels were 84.8% for Planned Maintenance, 87.5% for Quality Maintenance and 82.3% for Autonomous Maintenance. Such brought noticeable change for the better in equipment reliability, process, and customer satisfaction.

The outcome of the research reveals the importance of effective Planned Maintenance, aided by Vibration Analysis, Condition Monitoring, and Failure History, in minimizing the frequency of unplanned downtime and increasing availability. Effective Maintenance ensures no defects using Early Warning System, Poka-Yoke, and Standard Operating Procedures in the industry. The improvement teams apply problem-solving techniques and the 5S in the reduction of chronic losses in the workplace.

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These results validate previous studies conducted by Jain et al. (2014) and Ngoy et al. (2021), proving that TPM's overall efficiency has extended applications beyond just equipment efficiency alone. Furthermore, these results validate that OEE stands not only for a technological purpose but also for a level of maintenance process practices.

2.8 Integration of TPM, OEE, and advanced analytics

The integration of TPM with advanced analysis and Industry 4.0 technologies is considered a breakthrough in maintenance. (Lucantoni et al., 2025) observed that, though the potential offered by these approaches, seems enormous, most traditional studies in the area revolved around TPM pillars mostly relating to availability losses, in a restrictive manner, paying less attention to losses in performance and quality. Their ARM-NA framework was, however, a deviation from the norms because it maintained a balance in eliminating and accentuating the potential for best practice.

Literature also suggests that predictive models, network-based causal mapping, and real-time dashboards can enable dynamic prioritization of TPM initiatives, aligning maintenance strategy with operational risks, costs, and sustainability goals. However, fully integrated and long-term digital TPM implementations with empirical validation remain rare, and particularly in infrastructure and construction equipment management, where issues like asset mobility, environment changes, and fragmented data systems and complexity.

2.9 Research Gap

Even though TPM and OEE have been the subject of numerous published studies the majority have installed concentrated on case studies or industries not much has been done on:

- Integration of TPM with e digital transformation models for construction projects,
- integration of TPM with digital transformation models for construction projects,
- Comparative impact analysis of the TPM pillars on OEE using systematic review methods,
- Creation of TPM implementation models that are focused on performance in an industry 4.0 setting.

These research caps highlight the significant significance of conducting a systematic literature review to examine the available data regarding the connection between TPM and OEE and consequently, to develop the conceptual framework for digital equipment management system.

A synthesis of traditional TPM-OEE literature and modern digital TPM indicates that there are numerous research gaps in a Systematic Literature Review that seeks to fail.

- While the literature review indicates a positive relationship between the three pillars of TPM and improvement in OEE, much of the literature remains industry- and case-

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specific, thereby lacking broader applicability, especially in management of construction equipment.

- The literature focuses mostly on isolated TPM key pillars and OEE elements, considering mainly availability and breakdown losses, whereas there is a lack of studies that considered the whole eight pillars of TPM and three OEE limitations (availability performance and quality).
- There is no integrated, validated digital TPM framework despite the advances of Industry 4.0 and Lean 4.0 that integrate structured TPM deployment with real-time data gathering, advanced analytics, and decision-support system. Most digitalization efforts place much stronger emphasis on Predictive Maintenance or Condition Monitoring at the expense of much human-focused areas of improvement such as Autonomous Maintenance, Training Effectiveness, and Change Management.

Further, there is no standardization of performance measurement methodologies or harmonization of the formula for computation of OEE and empirical validation over a long period in many studies. These are some of the limitations to comparative studies and deployment of theory. Such knowledge gaps provide a stronger rationale for systematic synthesis of TPM-OEE literature to identify major themes, methodological trends, and success factors, and priorities for future research with implication for an integrated model of data-driven equipment management in complex project-based environments.

3.0 Research Methodology

3.1 Research design

In the current study, the design for the research is that of mixed methods, which aims to determine the effect of TPM implementation on infrastructure projects through both quantitative and qualitative analysis. Quantitative data will be collected regarding the number of running hours, unplanned downtime, number of breakdowns, repair time, and OEE values for the machinery, while Qualitative data will be gathered from expert interview with project managers, P&M in-charge, equipment operators, and maintenance crew.

3.2 Data collection

The research study collects and utilises existing equipment operation and maintenance data of ongoing infrastructure project:

- Equipment Operational Records
- Repair and Breakdown History
- Maintenance Schedule
- ERP Modules Maintenance
- Interviews with Maintenance Engineers and Site Manager

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3.3 Detailed methodology to be used

- Downtime study of equipment failure
- Study on breakdown due to unavailability of consumables and spares
- Preventive maintenance plan - schedule vs actual
- Age of equipment and its impact on availability
- Study the need of skilled operator for operating critical P&M equipment
- Study of construction activity planning and scheduling on usage of machine
- Study of current process of monitoring the equipment parameter and its drawbacks

3.4 Expected contribution

- Projects can be executed at a faster pace as per project schedule by improving the availability of equipment
- Reduced labour deployment at project by enhancing P&M productivity
- Critical projects can be completed in less time with high P&M productivity using low resources like labour, equipment etc.
- Decide the frequency of preventive maintenance based on the age of equipment and/ or the repair cost.
- Reduce the cost of Maintenance/ Repair by identifying the equipment to be disposed.

4.0 Data Analysis

Operational data was analysed for machines. The OEE formula is as follows:

OEE = Availability x Performance Efficiency x Quality Rate

Where:

Availability measures actual operating time over planned operating time.
Performance Efficiency considers actual speed against ideal operating speed.
Quality Rate captures the ratio of acceptable output to the total outputs.

A framework for TPM has been developed based on 8 pillars of TPM

- Autonomous maintenance schedule
- Plant maintenance plan
- Focused improvement
- Quality in maintenance
- Education and Training
- Safety
- Early equipment management

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Comparative analysis was performed among pre-TPM state and the state after TPM regarding:

- Reduction in the breakdown hours
- Redefined response time in maintenance
- Increase in equipment utilization
- Reduction in ideal and waiting time because of the approvals and spares
- The root cause analysis used techniques such as pareto chart and fishbone diagram to determine the key loss causing factors.
- Reduction in man hours spent preparation of schedules and plan.

5.0 Findings/ Results

Industry research suggests that TPM implementation increase equipment effectiveness and productivity. Equipment efficiency improvements, reduce breakdowns, and culture of maintenance improvements identified by studies on TPM implementation. In the context of infrastructure using TPM might bring about various advantageous results such as:

1. Reduction in equipment downtime through identifying remedies factors leading to equipment failures and performing preventive maintenance, a reduction in downtime can easily be achieved in infrastructure projects.
2. Increased resource utilization this is because of increased OEE, more time is spent on productive activity, hence effective resource utilization. This directly reduces the overall project duration.
3. Enhanced safety and quality as preventive maintenance may minimise safety risk posed by equipment failure, resulting in improved safety and quality level at the workplace.

6.0 Conclusion

Total production maintenance can be viewed as a long-term approach aimed at improving equipment performance in infrastructure projects. Since its emphasis on maintaining equipment through prevention and continuous improvement, total productive maintenance can significantly minimize downtime, maximize equipment use, and eventually optimize project performance. Although most existing research works are based on manufacturing processes the philosophy of total productive maintenance can be applied across all other infrastructure projects since it has the potential to revolutionize the management of those projects. Future research should explore the application of total productive maintenance across all types of infrastructure projects based on innovative maintenance technologies.

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7.0 Recommendation

On the basis of findings in current studied and the expected findings in future studies, the following are proposed for managers in infrastructure projects:

1. Establish a Roadmap for TPM Deployment: Create a roadmap comprising assessment, TPM pilot implementation, operator training, and implementation in an organization.
2. Integration of TPM with Digital Technology: Application of the ERP system and maintenance management software for automatically gathering the equipment operating data and scheduling for maintenance task as well as tracking.
3. Invest in Training and Culture Change: Encourage our culture in which the maintenance efforts can, and most, be done together by the operators, supervisors, and maintenance personnel.
4. Monitor and Evaluate Continuously: Use OEE dashboards and performance reviews to monitor and adjust as necessary.

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