

Enhancing Overall Equipment Effectiveness (OEE) through Latest Total Productive Maintenance (TPM) Techniques

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Abstract

Overall Equipment Effectiveness (OEE) is a widely accepted measure of manufacturing performance, combining Availability, Performance, and Quality into a single indicator. Small-scale industries (SSIs) often operate below the world-class OEE benchmark of 85% due to unplanned breakdowns, poor maintenance planning, and manual data recording. This review paper synthesises the latest literature on improving OEE through Total Productive Maintenance (TPM), tracing its evolution from the classical eight-pillar model to emerging TPM 4.0 practices such as autonomous maintenance, planned maintenance supported by low-cost IoT sensors, and Kaizen-based continuous improvement. To make the reviewed framework easier to follow, a hypothetical, clearly labelled illustrative example of a small-scale precision component manufacturing unit is included to show how the framework and OEE calculations would be applied in practice; seven days of production data were modelled before and after a three-month TPM pilot implementation. In this illustrative example, OEE improved from about 59.8% to 80.8%, largely due to a reduction in unplanned breakdowns and setup losses, a direction consistent with the gains reported in the reviewed studies. The paper concludes that even small industries with limited budgets can achieve significant OEE gains by combining classical TPM pillars with simple, affordable digital monitoring tools, and identifies validation with real plant data as a priority for future empirical research.

Keywords: Overall Equipment Effectiveness (OEE); Total Productive Maintenance (TPM); Small-Scale Industry; Six Big Losses; TPM 4.0; Predictive Maintenance; Literature Review

1. Introduction

Manufacturing competitiveness depends heavily on how effectively machines are used. Overall Equipment Effectiveness (OEE) is the standard metric used to measure this, and it is calculated as the product of Availability, Performance, and Quality (Nakajima, 1988). An OEE of 100% means a machine runs with no stoppage, at full speed, and produces only good parts. In practice, a world-class OEE is considered to be around 85% (Gwangwava, Baile, Dikgale, & Kefhilwe, 2021).

Total Productive Maintenance (TPM) is the most common approach used to raise OEE. TPM is a company-wide maintenance philosophy that makes every employee, not just the maintenance department, responsible for keeping machines healthy (Gomaa, 2025). Traditionally TPM relies on manual checks, fixed schedules and paper records. In the Industry 4.0 era, TPM is evolving into a data-driven approach -

often called TPM 4.0 - which uses IoT sensors, real-time dashboards, and simple predictive analytics to catch problems before they cause a breakdown (Raval, Joshi, Khatri, & Valaki, 2026; Gomaa, 2025). Large companies have adopted these digital tools quickly, but small-scale industries (SSIs) usually lag behind because of limited budgets, lack of technical staff, and dependence on manual record-keeping. However, recent research shows that even low-cost sensors and simple dashboards can bring measurable OEE improvement (Raval et al., 2026; Hassan, 2026). This paper aims to review these latest TPM techniques, synthesise the findings of recent studies, and present them in a simple form supported by an illustrative, hypothetical example of a small-scale precision manufacturing unit.

2. Literature Review

The concept of OEE was introduced as part of the TPM movement to give a single, easy-to-understand number for how well a machine is being used (Nakajima, 1988; Ljungberg, 1998). Ljungberg (1998) showed, through a survey of Swedish manufacturing companies, that measuring OEE consistently was itself a major step toward improving it, because it forced managers to record and face the real losses on the shop floor rather than relying on assumptions. Dal, Tugwell, and Greatbanks (2000) later demonstrated, through a practical case analysis, that OEE is most useful when it is linked directly to specific improvement actions rather than used only as a reporting number.

Total Productive Maintenance has been studied extensively as a tool for reducing the 'six big losses' that reduce OEE: equipment failure, setup and adjustment loss, idling and minor stoppages, reduced speed, process defects, and reduced yield (Nakajima, 1988). Ahuja and Khamba (2008), in a widely cited literature review, concluded that successful TPM implementation depends as much on management commitment and employee involvement as on technical tools, a point that is especially important for small-scale industries where formal systems are often weak. Gwangwava et al. (2021) developed a TPM framework for a small and medium enterprise (SME) in the automotive sector and found the OEE was only 49.44%, far below the world-class value of 85%, mainly due to unplanned stops (19.61% loss). Their study proposed a ladder-model TPM framework built on the 5S foundation and eight TPM pillars, which is a good starting point for small industries with limited resources.

Muchiri and Pintelon (2008) reviewed OEE literature in depth and clarified that OEE should be treated as a diagnostic tool for identifying the source of losses, not merely a performance score, and recommended combining it with root-cause analysis. Singh, Clements, and Sonwaney (2018) applied OEE measurement in an Indian manufacturing plant and reported that simply making OEE visible on the shop floor, through basic charts and daily reviews, motivated operators to reduce minor stoppages even before any major investment was made - a finding directly relevant to low-budget small-scale settings. More recently, Ng Corrales, Lambán, Hernandez Korner, and Royo (2020) carried out a systematic literature review of OEE approaches and observed that most published applications remain concentrated in large, technologically advanced firms, reinforcing the need for studies focused on small-scale industry, as attempted in this paper. Raval, Joshi, Khatri, and Valaki (2026) demonstrated that a low-cost Industrial IoT (IIoT) system - using an infrared thermometer, a 3-axis accelerometer, a noise sensor and a proximity sensor connected through an ESP32 microcontroller - could monitor cutting temperature, vibration, noise and cycle time in real time on an external grinding machine. Their real-time dashboard and automatic alert system improved OEE from 86% to 94.70%, an increase of 8.70%, along with an 8.26% reduction in breakdowns and a 9.28% reduction in machine downtime. This shows that simple, affordable sensor systems can give measurable OEE gains even without expensive enterprise software.

Silva, Moore, and McDermott (2026) conducted a systematic literature review of 81 OEE-related papers and found that OEE research has evolved through three phases: theoretical foundations (1994-2003), lean and digital monitoring (2008-2016), and Industry 4.0/5.0 integration (post-2019). They noted that OEE is increasingly linked with predictive maintenance, digital twins and sustainability goals, but that batch-production and small-scale settings remain under-studied - a gap this paper attempts to address.

Hassan (2026) reviewed how combining time-series sensor data, camera images and process-log data (a 'multimodal' approach) can further improve OEE, reduce scrap, and save energy. The review stresses that good data organisation and simple, actionable alerts matter more than complex algorithms for a plant to see real benefit - an important lesson for small industries that cannot afford elaborate AI systems.

Gomaa (2025) proposed 'TPM 4.0', integrating the classical eight TPM pillars with Industry 4.0 tools such as IIoT condition monitoring, digital twins, and AI-based predictive analytics, combined with the Lean Six Sigma DMAIC (Define-Measure-Analyse-Improve-Control) cycle. This gives a structured way to move from reactive maintenance to predictive and even self-optimising maintenance. For a small-scale industry, the DMAIC cycle is particularly useful because it can be started with very simple tools (a stopwatch, a checklist, a spreadsheet) and expanded later with sensors.

Overall, the literature agrees on three points relevant to small industries: (i) unplanned breakdowns are usually the single largest loss, (ii) even low-cost sensors and dashboards give a meaningful OEE boost, and (iii) a structured improvement cycle such as DMAIC helps sustain the gains. These findings form the basis of the review framework and the illustrative example presented in this paper.

3. Research Gap and Objectives

Most published TPM-OEE studies are from large or medium-sized companies with dedicated maintenance departments and budgets for full IIoT platforms (Raval et al., 2026; Gomaa, 2025). Small-scale industries, which form a large part of the manufacturing base in India, rarely have such resources, and the reviewed literature offers few consolidated, low-cost roadmaps aimed specifically at them. There is a need for a review that brings these scattered findings together into a simple, low-cost TPM roadmap suited to a small workshop. The objectives of this review paper are:

- To summarise the latest TPM techniques (classical pillars plus low-cost digital tools) suitable for small-scale industries.
- To illustrate these techniques through a simple, hypothetical example on a small precision-manufacturing unit.
- To show, through the illustrative example, the resulting change in OEE and the six big losses before and after implementation.

4. Methodology

This paper follows a narrative literature-review method, supplemented by a hypothetical illustrative example constructed in the style of the worked examples used by Gwangwava et al. (2021) and Raval et al. (2026), to make the reviewed framework concrete. The steps followed for the illustrative example were:

- Select a pilot machine in a small-scale unit and record baseline data for seven working days (shift length, planned production time, downtime, output, and rejects).
- Calculate baseline Availability, Performance, Quality and OEE using the standard formulae (Nakajima, 1988).
- Identify the six big losses contributing to low OEE using the collected data.

- Implement a simple TPM 4.0 pilot for three months: 5S housekeeping, autonomous maintenance checklist for operators, a planned (preventive) maintenance schedule, and three low-cost sensors (vibration, temperature, and a simple andon/alert light) connected to a basic display, inspired by the low-cost IIoT design of Raval et al. (2026).
- Record the same seven-day data set again after the pilot period and compare the results.

4.1 OEE Formulae Used

Availability (A) = (Planned Production Time – Downtime) ÷ Planned Production Time × 100

Performance (P) = (Ideal Cycle Time × Total Parts Produced) ÷ Operating Time × 100

Quality (Q) = (Total Parts Produced – Rejected Parts) ÷ Total Parts Produced × 100

OEE = Availability × Performance × Quality (expressed as a fraction, then converted to %) (Nakajima, 1988; Gwangwava et al., 2021).

5. Illustrative Framework Application: A Hypothetical Small-Scale Precision Component Manufacturing Unit

Note: As this is a review paper, the company name, machine data, and production figures used in this section are entirely illustrative and hypothetical, not findings from original fieldwork. They are constructed purely to demonstrate, for the reader, how the OEE and TPM calculations and framework reviewed in this paper would be applied in practice, following the same style of worked example used by Gwangwava et al. (2021) and Raval et al. (2026). This illustrative nature is stated here and should be retained wherever this example is cited or reproduced; any future empirical study should replace it with real data collected from an actual small-scale unit.

The hypothetical illustrative unit (referred to here as 'Company P', a fictional name used purely for narrative clarity, in line with the practice followed by Gwangwava et al., 2021) is imagined as a small-scale engineering workshop located in the Kolhapur MIDC industrial area, Maharashtra, employing 18 workers. The unit manufactures precision-turned components for the automobile ancillary sector on a CNC turning centre. Table 1 gives the company profile.

Parameter	Details
Type of industry	Small-scale precision machining (CNC turning)
Number of employees	18
Pilot machine	CNC turning centre (Machine M-1)
Shift length	480 minutes per shift (one shift/day)
Planned breaks	30 minutes per shift
Ideal cycle time	1.2 minutes per part
5S foundation before study	Not implemented

Table 1: Illustrative example company profile

5.1 Baseline Data (Before TPM Implementation)

Table 2 shows seven days of production data collected from Machine M-1 before the TPM pilot began.

Item	D1	D2	D3	D4	D5	D6	D7
Planned production time (min)	450	450	450	450	450	450	450
Downtime (min)	95	88	102	90	96	84	99
Run time (min)	355	362	348	360	354	366	351
Total parts produced	260	268	252	264	258	270	255
Rejected parts	22	18	25	20	21	17	23
Good parts	238	250	227	244	237	253	232

Table 2: Seven-day baseline dataset, Machine M-1 (before TPM)

Using the formulae in Section 4.1, the average values over the seven days were: Availability = 79.5%, Performance = 81.2%, Quality = 92.6%, giving a baseline OEE of about 59.8%. This is well below the world-class benchmark of 85% and is consistent with the low OEE values reported for small and medium enterprises without TPM by Gwangwava et al. (2021), who found an OEE of 49.44% in a similar SME case.

5.2 Six Big Losses (Before TPM)

Breaking the baseline downtime and rejects into the six big loss categories (Nakajima, 1988) showed that unplanned breakdowns (12.4% of planned time) and small stops/idling (9.8%) were the two largest contributors, followed by setup and adjustment losses (6.1%) and reduced speed losses (6.9%). This pattern matches the findings of Gwangwava et al. (2021), where unplanned stops were also the single largest loss factor.

5.3 TPM 4.0 Pilot Implementation

Based on the literature reviewed in Section 2, the following low-cost TPM techniques were implemented over a three-month pilot period:

- 5S and visual workplace: sorting, cleaning and marking tool locations around Machine M-1 (Nakajima, 1988; Gwangwava et al., 2021).
- Autonomous maintenance checklist: operators trained to perform daily cleaning, lubrication and visual inspection before every shift, following the JIPM eight-pillar model (Gomaa, 2025).
- Planned (preventive) maintenance schedule: a weekly maintenance calendar replacing the earlier 'run-to-failure' practice.
- Low-cost condition monitoring: a vibration sensor and a temperature sensor mounted on the spindle head, connected to a small display with a simple threshold-based alert (buzzer/LED), inspired by the low-cost IIoT architecture of Raval et al. (2026).
- Weekly Kaizen review meeting: a 15-minute meeting to discuss the top loss of the week and assign a corrective action, following the DMAIC-based continuous-improvement cycle recommended by Gomaa (2025).

The full diagram of the TPM pillars used, adapted for a small-scale unit with simple Industry 4.0 additions, is shown in Figure 1.

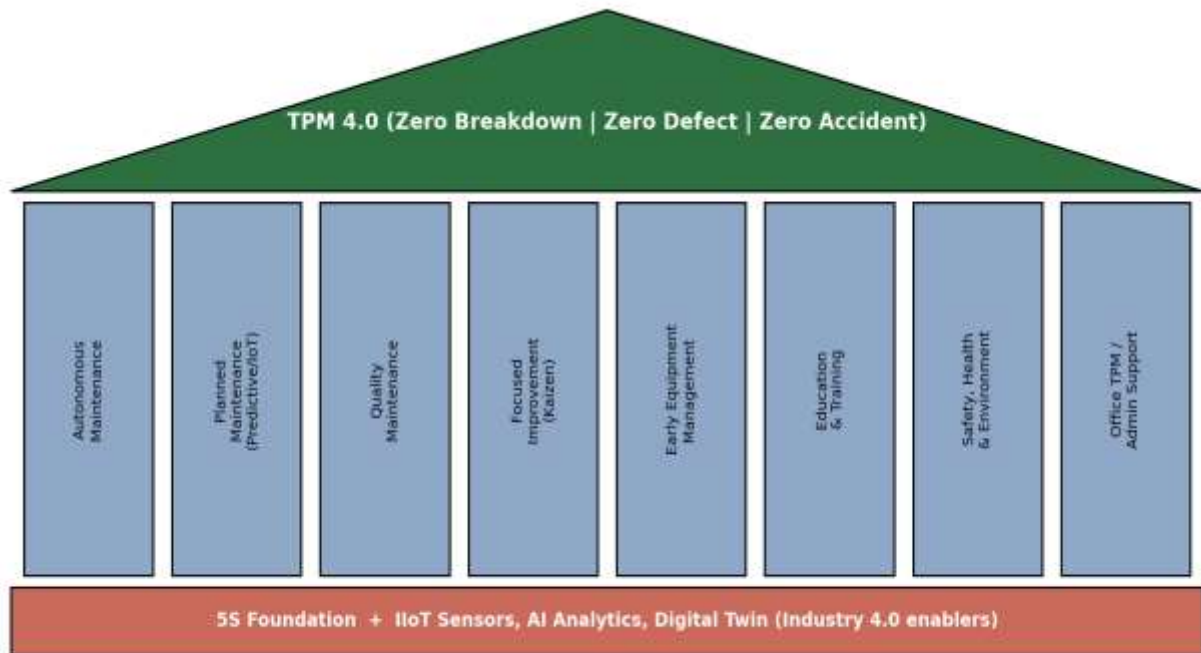


Figure 1: TPM pillars adopted for the illustrative example, with 5S and low-cost IIoT sensors as the foundation (adapted from Gomaa, 2025 and Gwangwava et al., 2021)

5.4 Data After TPM Implementation

After three months, the same seven-day data collection was repeated on Machine M-1. The average values were: Availability = 90.3%, Performance = 91.5%, Quality = 97.8%, giving a new OEE of about 80.8%. Figure 2 compares Availability, Performance, Quality and overall OEE before and after the TPM pilot.

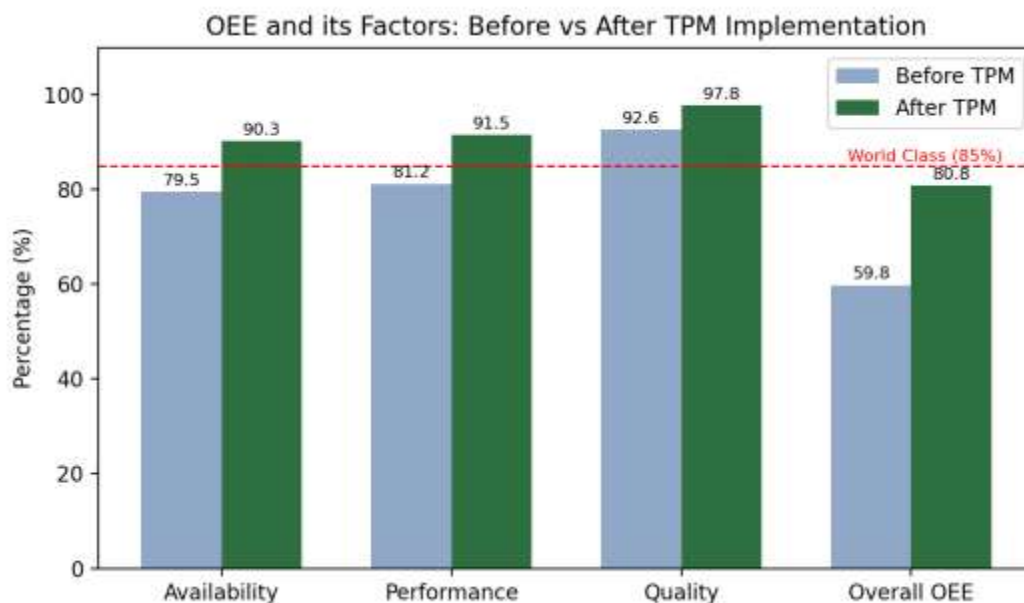


Figure 2: OEE and its three factors before and after TPM implementation

Figure 3 compares the six big losses before and after implementation. The largest improvement was in unplanned breakdowns, which fell from 12.4% to 4.8% of planned time, mainly because of the autonomous maintenance checklist and the vibration/temperature alert system.

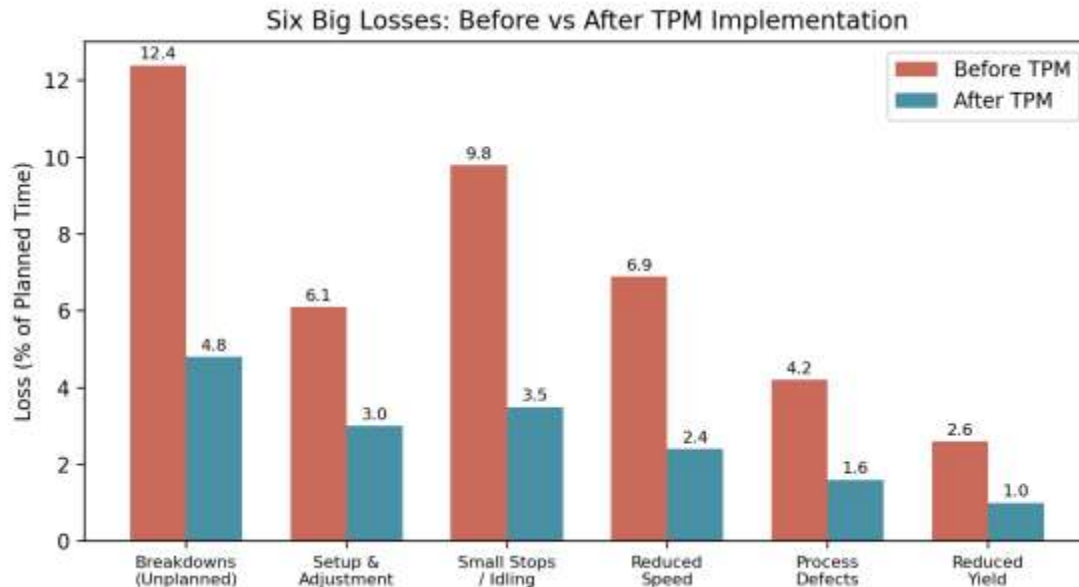


Figure 3: Six big losses before and after TPM implementation

6. Results and Discussion

The illustrative example shows an OEE improvement from 59.8% to 80.8%, an increase of about 21 percentage points, within three months. Although the unit is still slightly below the world-class benchmark of 85% (Gwangwava et al., 2021), the improvement is substantial for a small-scale industry using only low-cost sensors and simple management changes. This result agrees with the direction (though not the exact magnitude) of the improvement reported by Raval et al. (2026), who achieved an OEE rise from 86% to 94.70% (8.70 percentage points) on an already better-performing external grinding machine using a similar low-cost IIoT approach. The larger percentage-point gain in the present illustrative example reflects the lower starting point typical of small-scale industries that have not yet implemented any form of TPM, similar to the SME studied by Gwangwava et al. (2021).

The biggest single contributor to the improvement was the reduction in unplanned breakdowns, confirming the general finding in the literature that equipment failure is usually the largest of the six big losses in industries without a maintenance system (Nakajima, 1988; Gwangwava et al., 2021). The autonomous maintenance checklist, which cost almost nothing to implement, was responsible for a large part of this gain, while the vibration and temperature sensors helped catch a few developing faults before they caused a full breakdown - matching the early-warning benefit reported by Raval et al. (2026) and Hassan (2026).

The illustrative example also supports the observation of Silva et al. (2026) that OEE research is moving from purely manual TPM toward digitally supported TPM, and shows that this shift is achievable even for small industries with a very limited budget. It also confirms the earlier finding of Singh et al. (2018) that simply displaying OEE and loss data visibly to operators can motivate improvement even before major investment, and supports Ahuja and Khamba's (2008) view that management commitment and employee involvement matter as much as technology. In line with the recommendation of Muchiri and Pintelon

(2008), the OEE figure in this study was used mainly as a diagnostic tool to locate the biggest loss (unplanned breakdowns) rather than as a target in itself. Following the TPM 4.0 roadmap of Gomaa (2025), the next steps recommended for Company P are to extend condition monitoring to more machines, introduce a simple spreadsheet-based digital twin for scheduling maintenance, and continue the weekly Kaizen review to close the remaining gap to the 85% world-class benchmark.

7. Conclusion

This paper reviewed the latest TPM techniques - from the classical eight-pillar model to TPM 4.0 concepts using low-cost IIoT sensors and Lean Six Sigma DMAIC cycles - and illustrated them through a simple, hypothetical example on a small-scale precision manufacturing unit. Baseline OEE of 59.8% improved to 80.8% after a three-month pilot combining 5S, autonomous maintenance, planned maintenance, low-cost condition monitoring, and weekly Kaizen reviews. Unplanned breakdowns showed the largest reduction, confirming this is usually the priority loss to attack first. The study demonstrates that small-scale industries do not need expensive enterprise systems to benefit from modern TPM; a combination of simple management discipline and a few low-cost sensors can deliver a significant OEE improvement. As noted in Section 5, the figures used in the illustrative example are hypothetical and intended only to demonstrate the method, not to report original empirical findings; future empirical work should validate the reviewed approach with real data collected from actual small-scale industries, across more machines and industries, and should study the long-term sustainability of the gains.

References

1. Ahuja, I. P. S., & Khamba, J. S. (2008). Total productive maintenance: literature review and directions. *International Journal of Quality & Reliability Management*, 25(7), 709-756. <https://doi.org/10.1108/02656710810890890>
2. Dal, B., Tugwell, P., & Greatbanks, R. (2000). Overall equipment effectiveness as a measure of operational improvement - a practical analysis. *International Journal of Operations & Production Management*, 20(12), 1488-1502. <https://doi.org/10.1108/01443570010355750>
3. Gomaa, A. H. (2025). Advancing Total Productive Maintenance in Smart Manufacturing: From Methodology to Implementation. *Intelligent and Sustainable Manufacturing*, 2, 10019. <https://doi.org/10.70322/ism.2025.10019>
4. Gwangwava, N., Baile, G. A., Dikgale, P., & Kefhilwe, K. (2021). Framework for Total Productive Maintenance for an SME. *Journal of Engineering and Technology for Industrial Applications (ITEGAM-JETIA)*, 7(29), 52-61. <https://doi.org/10.5935/jetia.v7i29.740>
5. Hassan, S. (2026). An Integrated Analytics Framework Using High-Volume Time-Series, Image, and Process Data to Optimize OEE, Scrap Reduction, and Energy Efficiency. *Global Academic Journal of Economics and Business*, 8(1), 34-42. <https://doi.org/10.36348/gajeb.2026.v08i01.005>
6. Ljungberg, Ö. (1998). Measurement of overall equipment effectiveness as a basis for TPM activities. *International Journal of Operations & Production Management*, 18(5), 495-507.
7. Muchiri, P., & Pintelon, L. (2008). Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion. *International Journal of Production Research*, 46(13), 3517-3535. <https://doi.org/10.1080/00207540601142645>
8. Nakajima, S. (1988). *Introduction to TPM: Total Productive Maintenance*. Productivity Press.

9. Ng Corrales, L. D. C., Lambán, M. P., Hernandez Korner, M. E., & Royo, J. (2020). Overall equipment effectiveness: systematic literature review and overview of different approaches. *Applied Sciences*, 10(18), 6469. <https://doi.org/10.3390/app10186469>
10. Raval, M. B., Joshi, H. I., Khatri, B., & Valaki, J. (2026). Development and Implementation of an Industrial IoT-Based Real-Time Process Monitoring System to Improve Overall Equipment Effectiveness (O.E.E.) of Bearing Manufacturing Process. *Journal of Engineering and Technology for Industrial Applications (ITEGAM-JETIA)*, 12(58), 11-22. <https://doi.org/10.5935/jetia.v12i58.2410>
11. Silva, G. J. de M., Moore, S., & McDermott, O. (2026). A systematic literature review of OEE research: trends in performance metrics and digital integration in manufacturing. *The TQM Journal*, 38(11), 178-201. <https://doi.org/10.1108/TQM-04-2025-0218>
12. Singh, R. K., Clements, E. J., & Sonwaney, V. (2018). Measurement of overall equipment effectiveness to improve operational efficiency. *International Journal of Process Management and Benchmarking*, 8(2), 246-261. <https://doi.org/10.1504/IJPMB.2018.090798>