Performance Optimization of Conventional Lathes in the Shipbuilding Industry Integrating OEE and TPM

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***Abstract*— PT DPKB manufactures ship components such as M19 nuts and M20 bolts using conventional lathes. In its operations, the company faces challenges such as high downtime, rapid wear of cutting tools, coolant clogs, chip buildup, and unstable machine performance, all of which prolong production time and hinder the achievement of targets. This study aims to measure the effectiveness of conventional lathes, identify the dominant factors contributing to performance decline, and formulate strategies for improvement. The method used is a quantitative descriptive approach that integrates Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE), the Six Big Losses, the Fishbone Diagram, and the 5W+1H analysis. The results show that the OEE for M19 nuts was 53.89% (Availability 76.40%, Performance Efficiency 77.97%, Quality 91.55%) and for M20 bolts was 19.30% (Availability 81.65%, Performance Efficiency 28.58%, Quality 82.58%), far below the Japan Institute of Plant Maintenance benchmark (85%). Operational efficiency is a key critical factor driven by speed-reduction losses and equipment failures resulting from a lack of preventive maintenance, clogged cooling channels, limited operator skills, and an unsupportive work environment. The novelty and contribution of this study lie in the formulation of a TPM framework tailored to heterogeneous shipyards, providing tactical guidance based on the 5W+1H action plan and the TPM pillars to optimize self-maintenance, periodic cleaning, and work standardization to improve the operational efficiency of shipyards.**

Keywords: Conventional Lathe, Overall Equipment Effectiveness, Shipyard, Six Big Losses, Total Productive Maintenance.

I INTRODUCTION

Increasingly fierce competition in the manufacturing industry requires companies to continuously improve productivity, product quality, and operational efficiency. In the modern manufacturing environment, the success of production processes is determined not only by production capacity but also by a company's ability to maintain the reliability of its machinery and production equipment. Machines operating at optimal performance can boost productivity, reduce downtime, and ensure consistent product quality. Conversely, a decline in machine performance can lead to production delays, increased operating costs, reduced product quality, and even the loss of market opportunities due to unmet production targets [1], [2].

Machine maintenance is a strategic factor that determines the sustainability of a production system. An effective system aims to keep machines operating at optimal conditions throughout their life cycle. As the field has evolved, the concept of maintenance has integrated corrective, preventive, and predictive approaches, culminating in the implementation of Total Productive Maintenance (TPM). The TPM approach involves all elements of the organization to improve equipment effectiveness, prevent breakdowns, reduce production losses, enhance operator skills, and foster a culture of continuous maintenance. The success of TPM is measured using the Overall Equipment Effectiveness (OEE) indicator, which evaluates three key components: Availability Rate, Performance Efficiency, and Quality Rate. According to the Japan Institute of Plant Maintenance (JIPM) , An ideal OEE of ≥85% is the standard for world-class manufacturing. Therefore, OEE serves as a key evaluation tool for identifying the sources of productivity losses and determining priorities for improving the production system [3], [4]

While Total Productive Maintenance (TPM) and Overall Equipment Effectiveness (OEE) frameworks have been extensively investigated in automated, high-volume manufacturing sectors [5], [6], a distinct research gap exists regarding its applicability to conventional lathes within shipbuilding workshops [7]. Unlike repetitive assembly lines, conventional lathes in shipyards operate in a highly customized job-shop environment characterized by non-repetitive setups, heavy workpiece alignment, variable processing allowances, and harsh ambient exposure. These distinct conditions lead to unique downtime patterns and speed losses that generic TPM models fail to capture, highlighting the need for a tailored empirical OEE–TPM investigation in shipyard maintenance environments.

PT DPKB is a company engaged in new shipbuilding, ship maintenance and repair (docking), and the maritime support industry. In the workshop, conventional lathes are used to produce ship support components such as M19 nuts and M20 bolts. These components play a critical role as fasteners in various ship structures and mechanical systems, so the continuity of the production process must be carefully maintained.

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Based on field observations, conventional lathes experience operational issues characterized by high downtime, relatively rapid wear of cutting tools, clogged coolant flow due to the accumulation of cutting chips, and unstable machine performance during the production process. These conditions result in longer production times, reduced productivity, and difficulties in meeting the production targets set by the company [8], [9]. In addition, to date, the company does not yet have an integrated system for measuring machine effectiveness, so machine efficiency and productivity levels cannot yet be evaluated quantitatively. Various previous studies have applied the TPM and OEE approaches to evaluate the effectiveness of production machinery. For example, a report shows that the OEE value for the Continuous Pickling Line was only 32.75%, primarily due to losses in the categories of Reduced Speed Losses and Equipment Failure Losses. These findings indicate that the integration of TPM [10], [11].

Given that empirical data in this study were collected from a single shipyard facility across two specific component production lines (M19 lead screw nuts and M20 bolts), the proposed integrated OEE–TPM model is framed as a single-case empirical baseline rather than a fully generalized framework for all heterogeneous shipyards [12], [13], [14]. Nevertheless, this baseline provides a practical diagnostic foundation and a structured methodological reference for maintenance management in similar heavy engineering job-shop settings.

This study aims to (1) measure the actual values of Availability, Performance, Quality, and OEE in the processing of M19 nuts and M20 bolts; (2) identify the percentage of dominant waste based on the Six Major Losses categorization; (3) analyze the root causes of machine inefficiency using a Fishbone Diagram. (4) formulate recommendations for improvement strategies based on TPM using the 5W+1H approach.

II METHODOLOGY

A. Research Design, Location, and Time

A quantitative descriptive method combined with direct field observations. This study describes conventional lathes based on production and machine operation data. The objective is to understand the actual condition of the machines, the workflow, and the factors affecting the decline in machine effectiveness. This study was conducted at PT DPKB on a conventional lathe production line that manufactures M19 nuts and M20 bolts. Primary operational data and machine stoppage records were systematically collected over a three-month observation period from January 2026 to March 2026 during active shipyard production shifts. Specifying this explicit timeframe ensures temporal context and reproducibility in accordance with industrial data-collection standards [15], [16]

B. Data Collection Methods

The data used in this study consists of primary and secondary data. Primary data was obtained from direct measurements of installation time, observations of the physical condition of the machines, coolant flow rates, and machine cleanliness, as well as interviews with operators and maintenance technicians. Secondary data was obtained from summaries of production reports and machine allocation logbooks, load time, downtime, total production, and number of defective products. Overall equipment effectiveness (OEE), which includes availability, performance, quality, and efficiency, is calculated using this data [2], [17]

C. Data Analysis Procedures

The Total Productive Maintenance (TPM) framework, utilizing Overall Equipment Effectiveness (OEE) as the quantitative indicator, was applied to analyze equipment performance. The analytical steps comprise a structured three-step quantitative procedure [18], [19]. (1) calculating individual OEE component metrics; (2) categorizing downtime losses using the Six Big Losses framework; (3) conducting root-cause analysis using a 5M/1E Fishbone Diagram; and (4) formulating targeted improvement strategies using the 5W+1H approach [20].

1) *Calculation of OEE components*

a) The availability rate measures the percentage of time during which the machine is ready for operation, minus downtime.

$$Operating = Loading\ Time - Downtime \quad (1)$$

with :

$$Availability = \frac{Operation\ Time}{Loading\ Time} x100\% \quad (2)$$

The higher the availability score, the less time is wasted when the machine is not operating [17], [21].

b) The efficiency of a machine's ability to produce output at its ideal speed during actual operating time [12].

$$Performa = \frac{Processed\ amount\ x\ ideal\ cycle\ time}{Loading\ Time}\ x\ 100\% \quad (3)$$

c) Poor performance indicates that the engine is not operating at optimal speed or that there are obstacles during operation [21], [22].

$$Quality\ = \frac{Processed\ Amount - Defect\ Amount}{Processed\ Amount}\ x\ 100\% \quad (4)$$

d) The higher the quality score, the fewer defective products are produced during the manufacturing process [9], [17].

e) Overall Equipment Effectiveness (OEE)

To establish a rigorous operational baseline, Overall Equipment Effectiveness (OEE) was computed as the product of Availability (A), Performance Rate (P), and Quality Rate (Q):

$$OEE\ =\ \text{Availability x Performance x Quality} \quad (5)$$

According to authoritative world-class standards established by the Japan Institute of Plant Maintenance [13], [23], [24]. *a world-class manufacturing facility is expected to achieve an overall OEE threshold of at least 85.0%. Individual component benchmarks are defined as follows:*

(1). Availability Rate (≥ 90.0%): Measures scheduled operating uptime against breakdown downtime and setup losses.

(2). Performance Rate (≥ 95.0%): Evaluates operating speed efficiency relative to ideal cycle time, capturing minor stoppages and speed reduction.

(3). Quality Rate (≥ 99.0%): Quantifies the percentage of defect-free finished parts relative to total

production.

Mathematically, the 85.0% world-class threshold is derived directly from the cumulative product of these individual component benchmarks (90.0% × 95.0% × 99.0% = 84.645% ≈ 85.0%) [25], [26].

f) *To determine whether a machine has achieved the expected level of effectiveness, OEE metrics are used. These values are then compared to the global OEE standard of 85%* [27], [28]*:*

2) *Six Big Losses Analysis*

To evaluate root operational inefficiencies, downtime records were categorized under the Six Big Losses Analysis framework [5], [20], comprising breakdown losses, setup/adjustment losses, idling/minor stoppage losses, reduced speed losses, quality defects, and yield losses.

3) *Improvement using an approach 5W+1H*

The primary causes of OEE components and losses were identified, and an analysis of the causes of low machine effectiveness was conducted using a fishbone diagram. To systematically identify root causes of equipment losses, Cause-and-Effect Analysis (Ishikawa diagram) was conducted across five standardized categories [25], [29], [30], [31]: Manpower (People), Machinery, Methods, Environment, and Materials (5M/1E framework**)**.

4) *Improvement using the 5W+1H approach*

Based on the results of the fishbone diagram analysis, improvement proposals were formulated using the 5W+1H approach, which includes:

a) What corrective actions should be taken.
b) Why improvements need to be made..
c) Where the targeted location or area for improvement is.
d) When the implementation will take place.
e) Who is responsible.
f) How the improvement will be implemented, including the methods or steps to be taken.

This approach is used to make the improvement proposal clearer, more practical, and easier for the company to implement in its efforts to improve the effectiveness of conventional lathes [32], [33].

III Results and Discussion

A. Collection and Compilation of Operational Data

This study was conducted at PT DPKB, a company engaged in shipbuilding, ship maintenance, and ship repair activities that support the maritime industry. PT DPKB manufactures supporting components, including M19 nuts and M20 bolts. These components are produced using conventional lathes. This study focuses on the conventional lathes used for nuts and bolts. The production process is showing signs of declining machine performance, high downtime, and suboptimal output. These conditions are leading to longer processing times and difficulties in meeting daily production targets. This analysis uses the Total Productive Maintenance (TPM) approach, with Overall Equipment Effectiveness (OEE) as the primary indicator. The calculation is based on four components: availability, performance, quality, and OEE [9], [22]. Furthermore, a summary of the calculation results is used as the basis for analyzing the causes of low machine efficiency and to formulate proposals for improvement, as summarized in Table I.

TABLE I . SUMMARY OF OPERATIONAL DATA FOR CONVENTIONAL LATHES

Operational Parameters	M19 Nuts	M20 Bolt	Unit
Loading Time	7,140	7,140	Minutes
Total Downtime	1,685	1,310	Minutes
Operating Time	5,455	5,830	Minutes
Total Processed	686	333	Units
Total Defects	58	58	Units
Total Good Units	628	275	Units
Ideal Cycle Time	6.2	5.00	Minutes/Unit

Note: All time-based variables, including Loading Time, Operating Time, and Planned Downtime, are explicitly standardized in minutes (min). Number formatting has been corrected to standard IEEE decimal representation to ensure full mathematical reproducibility of Availability, Performance Rate, Quality Rate, and overall OEE values (ISO 80000-1, 2009; IEEE, 2021).

The ideal cycle times used for Performance Rate calculations, specifically 6.20 minutes per unit for lathe M19 and 5.00 minutes per unit for lathe M20, were established through direct time study observations using stopwatch measurement methods across multiple standard operating cycles, validated against the manufacturer's technical design speed specifications [34].

B. OEE Measurement Results and Evaluation of JIPM Standards

The results of the calculations for Availability, Performance, Quality, and OEE are shown in Table II.

TABLE II. EVALUATION OF OEE COMPONENTS OF CONVENTIONAL LATHES AGAINST JIPM WORLD-CLASS STANDARDS

OEE Components	JIPM Standard (%)	M19 Nuts (%)	M19 Gap (%)	M20 Bolt (20%)	M20 Gap (%)	Description
Availability	≥ 90.00	76.40	-13.60	81.65	-8.35	Below standard (due to high downtime)
Performance Efficiency	≥ 95.00	77.97	-17.03	28.58	-66.42	Below standard (due to high downtime)
Quality Rate	≥ 99.00	91.55	-7.45	82.58	-16.42	Below standard (due to high downtime)
Overall Equipment Effectiveness (OEE)	≥ 85.00	53.89	-31.11	19.3	-65.70	Very low (needs major improvement)

The calculation results show that the M19 nuts production process achieved an Availability Rate of 76.40%, a Performance Efficiency of 77.97%, a Quality Rate of 91.55%, and an OEE of 53.89% based on these four components. This indicates that the effectiveness of conventional lathes in the M19 nuts production process still falls short of JIPM standards, primarily due to downtime and suboptimal machine operating speeds. One of the main causes of decreased machine effectiveness is component availability. Meanwhile, the results of the M20 bolt production process

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show an Availability Rate of 81.65%, Performance Efficiency of 28.58%, Quality Rate of 82.58%, and OEE of 19.30%. The low OEE value for M20 bolts is primarily due to low performance, which indicates that the machine is not yet operating optimally. This suggests that, although the machine has been running for a sufficient amount of time, its actual rotational speed is much slower than the ideal cycle time. This is caused by frequent tool adjustments, machine vibrations, and frequent brief stops, known as micro-stops [29], [35].

Previous empirical studies in automotive and general machinery manufacturing report baseline OEE values between 65.0% and 78.0% [36], [37]. In contrast, lathes M19 and M20 exhibited OEE performance substantially below both general industry averages and the JIPM 85.0% benchmark. This disparity is attributable to shipyard-specific operational dynamics: unlike standardized mass production, shipyard lathe machining involves custom job-shop orders, prolonged setup times for heavy metal workpieces, and frequent manual adjustments [38].

Several limitations must be acknowledged when interpreting these findings. First, empirical data collection was conducted within a single shipyard facility across two conventional lathe production lines, which constrains direct statistical generalizability to fully automated or multi-site shipyard operations [12]. Second, the observation period captured active production shifts under specific operational demands, which may not account for long-term seasonal fluctuations or demand shifts. Third, the descriptive nature of the loss analysis establishes baseline diagnostics but requires longitudinal follow-up to measure post-TPM implementation gains. Future research should evaluate multi-site shipyard deployments, longitudinal TPM tracking, and automated condition-monitoring integration [36].

C. Waste Identification (The Six Major Drawbacks)

The results of the analysis of the proportion of operational waste show that the greatest losses in conventional lathes fall into two main categories.

1) Speed Reduction: This is the primary factor contributing to a decrease in performance efficiency, especially during the machining of M20 bolts, because the lathe's cutting tools wear out quickly and overheat due to irregular coolant flow
2) Equipment Failures and Downtime: 1,685 minutes of downtime during the machining of M19 nuts directly affected the Availability Rate. This was caused by mechanical failures and a failure to perform daily preventive maintenance activities.

D. Root Cause Analysis Using a Fishbone Diagram

An analysis of the causes of low OEE (Overall Equipment Effectiveness) was conducted by tracing the root causes using a fishbone diagram. Fig. 1. A Fishbone Diagram Illustrating The Main Causes Of Low OEE in Conventional Lathesshows the results of the analysis of low machine effectiveness, which is influenced by four main factors: human resources, machinery, methods, and the environment, as explained below [7], [20].

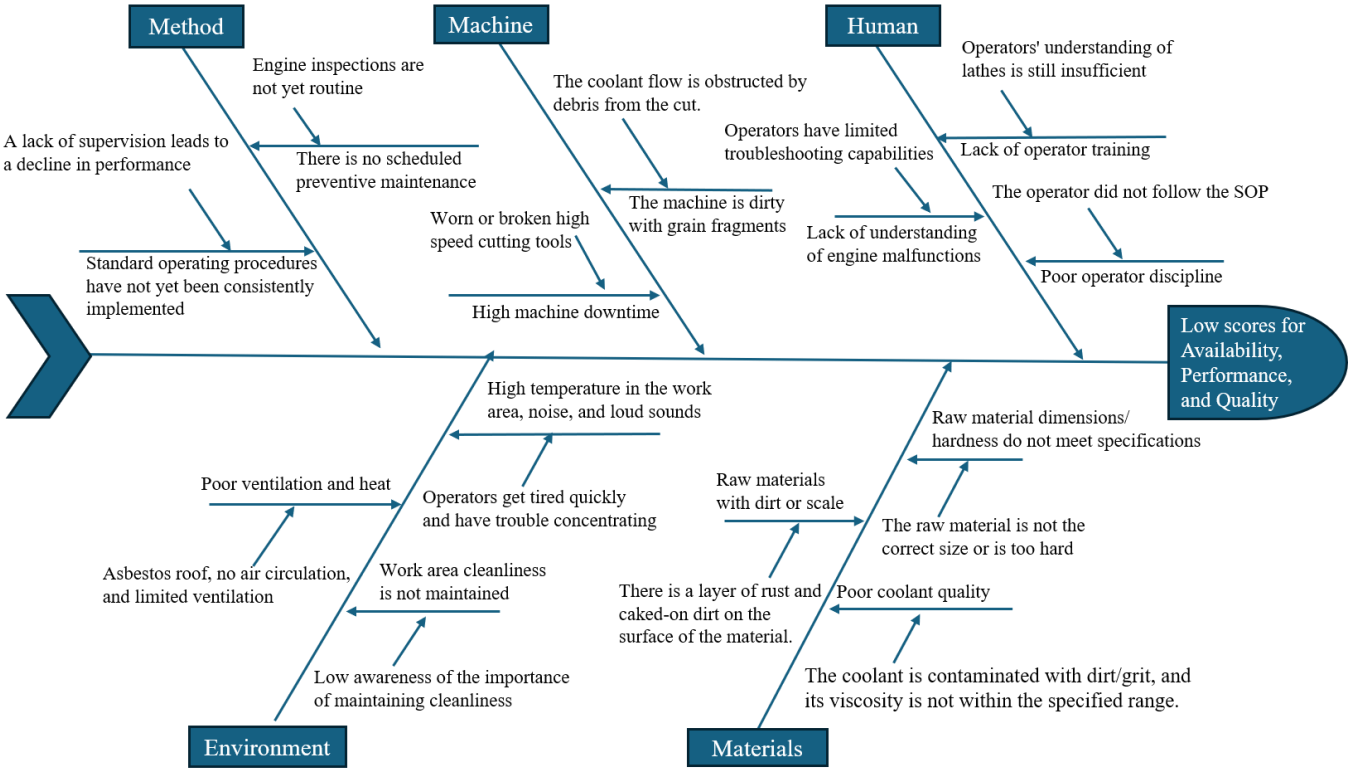


Fig. 1. A Fishbone Diagram Illustrating The Main Causes Of Low OEE in Conventional Lathes

According to the analysis in Fig. 1, four main factors-method, People, Environment, And Machine contribute to low OEE on conventional lathes. Regarding the "method" factor, the main causes are inadequate work supervision, inconsistent implementation of SOPs, unscheduled preventive maintenance, and infrequent machine inspections [39], [40].

1) Human factors: insufficient operator training, inadequate operational skills, poor problem-solving abilities, failure to follow SOPs, and a lack of operator discipline.
2) Machine-related factors reduce availability and performance, such as high downtime, clogged coolant flow, accumulated chips, and rapid wear of cutting tools and drill bits [33], [41], [42]
3) Method: There are no official documents or schedules for Preventive Maintenance (PM). Maintenance activities are reactive in nature (Corrective Maintenance).
4) A hot, dusty, noisy, and poorly ventilated work environment, combined with a lack of 5S practices, leads to premature fatigue and reduced operator concentration. Overall, these factors result in a low OEE score for conventional lathes.
5) Raw material dimensions or hardness failing to meet required specifications (materials being oversized or excessively hard), raw materials contaminated with surface dirt, rust, or scale, and poor coolant quality resulting from grit contamination and improper viscosity levels.

E. Proposed TPM-Based Improvement Strategy Using the 5W+1H Approach

Based on the results of the improvement analysis to address the root causes identified in the fishbone diagram based on the TPM pillars [43], [44], as shown in Table III.

TABLE III. PROPOSED IMPROVEMENT MATRIX FOR THE EFFECTIVENESS OF CONVENTIONAL LATHES USING THE 5W+1H APPROACH

Factors	What (Action)	Why (Reason)	Where (Location)	When (Time)	Who (Person in Charge)	How & KPI Targets (Methods & Metrics)
People	Autonomous (AM) Operator & Maintenance Training Resources	Program to Improve Operator Skills, Reduce Setup Time and Errors	Training Area & Lathe Machine Line	Monthly and before each shift begins	Production Supervisors & HR Department	Conduct SOP briefings and autonomous maintenance modules. KPIs: 100% SOP compliance, Quality Rate ≥ 95.0%.
Machines	Standardization of cleaning procedures for coolants and tools	Coolant blockages cause tool wear and reduced speed	Conventional Lathe Unit	Daily (Start and End of Shift)	Machine Operators & Maintenance Technicians	Clean the coolant tank daily using standardized coolant flushing protocols. KPI: Performance Level ≥ 85.0%.
Method	Developing a Scheduled Preventive Maintenance (PM) Schedule	Prevent unplanned downtime and damage to key components	Maintenance & Workshop Department	Weekly & Monthly	Head of Maintenance	Develop periodic inspection checklists, maintenance calendars, and OEE control boards. Availability KPI ≥90%.
Environment	Organizing the work area through the 5S program and improving air circulation	A clean and cool environment helps operators maintain their concentration	Machining Shop Work Area	Weekly Evaluation (Clean Friday)	Area Supervisors & Operators	Add industrial blowers/fans; install organized cutting tool racks. 5S KPI Audit Score ≥85%.
Materials	Standardization of raw material quality control (QC) and cutting tool material specifications	Material hardness variations cause excessive tool wear, surface defects, and process delays	Raw Material Storage & Machine Shop Receiving Area	Upon raw material arrival & before machining	Quality Control (QC) Inspector & Material Handler	Implement hardness testing (Rockweel/Brinel) upon material arrival and mandate standard carbide cutting tool inserts for high-hardness forgings. KPI: Material Defect Rate ≤ 1%, Zero non-conforming material setups.

The target Key Performance Indicators (KPIs) proposed in the 5W+1H improvement matrix (Table III) are justified by establishing realistic, phased milestone targets that bridge the gap between actual baseline operational metrics and world-class standards defined by the Japan Institute of Plant Maintenance (JIPM).

1. Availability Rate KPI (≥ 90.0%): Directly aligned with the JIPM world-class availability benchmark (≥ 90.0%) [20] . Given the baseline availability of 76.40% for lathe M19 and 81.65% for lathe M20, reaching ≥ 90.0% is technically feasible by eliminating breakdown downtime and setup delays through scheduled preventive maintenance (PM).
2. Performance Level KPI (≥ 85.0%): Although the ideal JIPM world-class performance threshold is ≥ 95.0%, a pragmatic interim target of ≥ 85.0% was established to accommodate the customized, non-repetitive job-shop nature of shipyard conventional lathe operations [37]. Considering M20's severe baseline performance loss (28.56%), an 85.0% target represents an achievable first-phase improvement milestone.
3. Quality Rate KPI (≥ 95.0%): With baseline quality rates at 91.55% (M19) and 82.58% (M20), achieving ≥ 95.0% serves as an immediate operational target to mitigate defects caused by raw material hardness variations and tool chatter, systematically progressing toward the ultimate JIPM standard of ≥ 99.0% [26], [34].
4. Material Defect Rate KPI (≤ 1.0%): Established to strictly enforce receiving inspection protocols (Rockwell/Brinell hardness testing) and standardized carbide insert utilization, eliminating non-conforming raw stock setups before machining begins.
5. 5S Audit Score KPI (≥ 85.0%): Grounded in standard lean manufacturing implementation literature [36], where an 85.0% audit score is recognized as the formal baseline for sustained workplace organization, safety, and environmental cleanliness.

IV CONCLUSION

This study concluded that the effectiveness of conventional lathes at PT DPKB remains far below the JIPM world-class standard (85%), with an actual OEE of 53.89% for M19 nuts production and 19.30% for M20 bolt production.

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Performance Efficiency Components (particularly for M20 bolts at 28.58%) are critical factors contributing to the low effectiveness. Under the Six Big Losses framework, the dominant production losses are attributed to reduced speed losses, setup delays, and equipment failures. Root-cause analysis across the 5M/1E dimensions (People, Machinery, Methods, Materials, Environment) revealed that these losses stem from unstandardized operator practices, severe wear on the M19 lead screw nut, absence of setup SOPs, material hardness variations, and excessive ambient shop-floor dust. Framed as a single-case empirical baseline model, the proposed 5W+1H action plan offers a structured methodological reference for optimizing autonomous maintenance, preventive scheduling, and operational consistency in shipyard machining workshops.

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