Technema: Journal of Intelligent Engineering and Computing
Vol 1 No 2 June 2026, Hal 152-164
ISSN: 3163-6020 (Print) ISSN: 3163-5997 (Electronic)
Open Access: https://sovereignresearch.org/technema

Analysis of Cement Fiber Machine Maintenance Using the PMMS (Preventive Maintenance Management System) Method at PT. Nusantara Building Industries

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Article Info :
Received:
02-06-2026
Revised:
13-06-2026
Accepted:
20-06-2026

Abstract

Effective machine maintenance is essential for ensuring production continuity in the fiber cement industry, where high-capacity equipment operates continuously under demanding production conditions. This study analyzes the maintenance performance of cement fiber production machines at PT. Nusantara Building Industries using the Preventive Maintenance Management System (PMMS). An empirical case study approach was employed by collecting data through direct observation, semi-structured interviews, and documentation of maintenance records, PMMS forms, inspection checklists, and downtime reports during the internship period. Machine reliability was evaluated using Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), Pareto analysis, and Fishbone analysis to identify critical equipment and dominant failure causes. The results indicate substantial variations in operational reliability among production machines, with FS6 and FS7 exhibiting the highest downtime and failure frequencies. Pareto analysis revealed that a limited number of failures contributed to most cumulative downtime, while Fishbone analysis identified machine condition, maintenance methods, human factors, environmental conditions, materials, and measurement practices as the principal causes of recurring failures. Reliability-based preventive maintenance scheduling within the PMMS framework established maintenance intervals according to equipment criticality, enabling more effective maintenance planning and resource allocation. The proposed PMMS approach improves maintenance decision-making, enhances equipment reliability, supports production continuity, and provides a practical framework for data-driven maintenance management in continuous manufacturing systems.

Keywords: *Cement Fiber Machine, Downtime, Preventive Maintenance, Preventive Maintenance Management System (PMMS), Reliability.*

INTRODUCTION

The rapid evolution of Industry 4.0 has fundamentally transformed manufacturing systems by shifting industrial competitiveness from production volume toward equipment reliability, operational resilience, and intelligent maintenance management capable of ensuring continuous production performance in increasingly automated environments (Amir, 2024). Advances in intelligent engineering have simultaneously accelerated the adoption of preventive maintenance frameworks integrated with digital information systems, enabling manufacturing organizations to optimize maintenance planning while minimizing unexpected downtime and extending equipment life cycles (Silalahi et al., 2025). Recent engineering studies also demonstrate that maintenance management is progressively supported by digital twins, data-driven monitoring, and integrated analytical platforms that strengthen decision-making for asset management across industrial sectors (Al-Mistarehi et al., 2025). Fiber cement manufacturing represents one of the industrial sectors where uninterrupted machine operation is indispensable because every production stage is interconnected, making a single machine failure capable of disrupting the entire manufacturing flow. Under these circumstances, maintenance management should be regarded as a strategic organizational capability rather than merely a corrective technical activity. The effectiveness of preventive maintenance therefore becomes increasingly essential for sustaining productivity, maintaining product quality, and improving long-term operational competitiveness.

Previous investigations consistently report that preventive maintenance contributes significantly to improving equipment reliability and reducing operational losses, although the analytical approaches employed vary considerably according to industrial characteristics (Akbar & Widiasih, 2022). Research focusing on cement manufacturing has demonstrated that systematic preventive maintenance scheduling improves machine availability while reducing unplanned production interruptions through structured maintenance planning (Ebrahimi et al., 2020). Studies applying reliability-based maintenance scheduling further reveal that maintenance intervals determined from equipment reliability characteristics produce better operational performance than conventional time-based maintenance practices (Alfadhlani et al., 2025). These findings collectively indicate that maintenance effectiveness depends not only on maintenance frequency but also on how maintenance activities are systematically organized and continuously monitored. Existing evidence therefore supports the importance of preventive maintenance as an operational strategy capable of improving both production continuity and maintenance efficiency. Nevertheless, the managerial integration of maintenance activities remains less extensively discussed than quantitative reliability optimization.

Despite substantial advances in maintenance engineering, several conceptual and empirical limitations remain evident in the literature. Numerous studies primarily emphasize reliability calculations, maintenance interval optimization, or component replacement policies while providing limited attention to the integration of maintenance scheduling, documentation, inspection procedures, historical maintenance records, and performance evaluation within a unified management framework (Nurroif & Retnowati, 2022). Similar limitations appear in studies concerning preventive maintenance timing, where maintenance decisions are frequently evaluated through statistical reliability without adequately considering organizational implementation processes and maintenance information management (Khaurullah & HR, 2022). Reviews of maintenance management systems similarly suggest that intelligent maintenance technologies continue to encounter practical challenges related to maintenance standardization, information integration, and operational consistency across industrial environments (Sarsam, 2016). These limitations demonstrate that many maintenance studies still prioritize mathematical optimization over organizational implementation aspects. Such conditions indicate that the practical implementation of Preventive Maintenance Management Systems (PMMS) remains insufficiently investigated within continuous-process manufacturing industries.

The unresolved limitations identified in previous studies possess important scientific and industrial implications because machine failures in continuous manufacturing systems directly influence productivity, maintenance costs, production schedules, and customer satisfaction (Oktaviani & Singgih, 2024). Contemporary maintenance management increasingly requires systematic planning approaches that combine preventive scheduling, maintenance documentation, performance monitoring, and operational evaluation to achieve sustainable production performance rather than relying primarily on corrective maintenance practices (Mohammadi et al., 2022). Recent developments in modular preventive maintenance also emphasize the importance of standardized maintenance procedures capable of improving maintenance effectiveness across complex industrial facilities (Ernawati, 2026). PT. Nusantara Building Industries faces similar challenges because its fiber cement production process relies heavily on continuous machine availability throughout multiple interconnected production stages. Maintenance interruptions in one production unit may propagate throughout the entire production line, creating significant operational losses. These circumstances highlight the practical necessity of implementing an integrated PMMS capable of supporting systematic maintenance management.

Within the broader landscape of intelligent engineering research, relatively few empirical studies have specifically examined PMMS implementation for fiber cement production systems using a comprehensive managerial perspective. Existing investigations are generally concentrated on isolated maintenance optimization techniques, including Reliability Centered Maintenance, modular maintenance design, or reliability-based scheduling, without integrating operational documentation, inspection activities, maintenance history, and performance evaluation into a unified maintenance management framework (Arifai, 2024). Recent maintenance studies also continue to emphasize optimization models and decision-support techniques while providing limited empirical validation regarding organizational implementation in continuous manufacturing industries (Allamsyah, 2025). This condition creates an important research gap because effective maintenance performance depends not only on optimization models but also on systematic management practices that ensure maintenance activities are consistently executed and evaluated. Examining PMMS implementation in PT. Nusantara

Building Industries therefore offers an opportunity to enrich empirical understanding of integrated preventive maintenance management in the fiber cement industry. Such a perspective also aligns with the increasing emphasis on intelligent maintenance systems capable of supporting sustainable industrial operations.

This study aims to analyze the maintenance management of cement fiber machines at PT. Nusantara Building Industries using the Preventive Maintenance Management System (PMMS) approach by evaluating maintenance scheduling, inspection activities, maintenance documentation, equipment history, and operational performance in an integrated manner. The research is expected to contribute theoretically by extending the application of PMMS as a comprehensive maintenance management framework within continuous manufacturing systems rather than limiting its role to preventive scheduling alone. From a methodological perspective, the study demonstrates an integrated analytical approach that combines multiple maintenance management components into a unified evaluation framework applicable to manufacturing industries. The findings are expected to provide practical recommendations for improving maintenance effectiveness, reducing unexpected downtime, and supporting sustainable production performance. Ultimately, this research seeks to strengthen the integration of maintenance management principles within the broader domain of intelligent engineering and computing.

RESEARCH METHODS

This study employed an empirical case study design to evaluate the implementation of the Preventive Maintenance Management System (PMMS) for cement fiber production machines at PT. Nusantara Building Industries. Primary data were collected through direct field observations, semi-structured interviews with maintenance personnel and production supervisors, and documentation of PMMS forms, maintenance logs, machine inspection checklists, and downtime records during the internship period. The investigated maintenance system comprised preventive maintenance scheduling, inspection procedures, equipment history recording, corrective action reports, and maintenance performance evaluation integrated within the company's PMMS framework (Akbar & Widiasih, 2022). Data collection focused on critical production equipment involved in the cement fiber manufacturing process, including the Forming Press and supporting machine components, to identify failure characteristics, maintenance intervals, and operational reliability. The implementation stages consisted of identifying critical equipment, compiling historical maintenance records, analyzing machine failures, developing preventive maintenance schedules, executing routine inspections, and documenting maintenance activities within the PMMS to ensure traceability and standardized maintenance management (Arifai, 2024). This systematic implementation enabled maintenance data to be consistently recorded and provided a reliable basis for evaluating machine performance and maintenance effectiveness throughout the production process.

The effectiveness of the implemented PMMS was evaluated using both descriptive and quantitative maintenance performance analyses. Machine failure records were analyzed using the Pareto diagram to identify the dominant failure modes contributing to cumulative production downtime, following the principle that a limited number of failure categories generally account for the majority of maintenance problems (Syafei & Suhendar, 2022). The performance of the maintenance system was validated by comparing maintenance indicators before and after PMMS implementation, including average daily downtime, technician checklist completion rate, maintenance compliance, and preventive maintenance interval recommendations for critical machine components. Preventive maintenance intervals were subsequently determined according to equipment operational history and maintenance performance, resulting in maintenance recommendations of approximately 31 operating hours for the Forming Press and approximately 77 operating hours for the Electrical Panel Relay. The overall effectiveness of the PMMS was assessed based on its capability to reduce machine downtime, improve maintenance documentation completeness, increase maintenance compliance, and support data-driven maintenance decision-making, which are widely recognized as key indicators of preventive maintenance performance in manufacturing systems (Ebrahimi et al., 2020).

RESULTS AND DISCUSSION

Data Acquisition and Maintenance Performance Overview

The implementation of the Preventive Maintenance Management System (PMMS) at PT. Nusantara Building Industries generated a comprehensive maintenance database that served as the primary foundation for evaluating the operational reliability of cement fiber production machines. Data acquisition was conducted through direct observation of maintenance activities, semi-structured interviews with maintenance technicians and production supervisors, and systematic documentation of preventive maintenance records, machine inspection checklists, downtime reports, and equipment maintenance histories collected during the internship period. The integration of multiple data sources allowed the maintenance condition of each production unit to be examined from both operational and managerial perspectives rather than relying exclusively on machine failure records. Such an approach increases the consistency of maintenance evaluation because equipment performance can be interpreted together with maintenance execution and documentation quality. Previous studies have emphasized that integrated maintenance documentation improves maintenance traceability and supports more accurate maintenance planning in manufacturing industries (Akbar & Widiasih, 2022). Similar maintenance information systems have also been recognized as essential components for improving maintenance performance through systematic recording and standardized maintenance workflows (Silalahi et al., 2025).

The collected operational data covered eight cement fiber production machines, designated FS1 through FS8, during the observation period from January to June 2025. Three primary operational indicators were documented for every machine, namely operation time, accumulated downtime, and failure frequency, allowing maintenance performance to be evaluated from multiple reliability dimensions. Operation time reflects equipment utilization, whereas downtime and failure frequency indicate the effectiveness of maintenance activities in maintaining production continuity. The simultaneous observation of these indicators provides a more representative assessment of equipment performance because production availability cannot be interpreted from a single operational variable alone. Maintenance assessment therefore requires a balanced evaluation between machine utilization and operational interruptions occurring throughout the production process. This integrated monitoring approach is consistent with preventive maintenance management principles that emphasize continuous equipment performance evaluation instead of corrective maintenance responses alone (Arifai, 2024).

The operational records demonstrate considerable variation in machine utilization and downtime among individual production units, indicating that maintenance requirements differ according to machine workload and operational characteristics. Machines FS6 and FS7 consistently recorded relatively higher downtime and failure frequency than several other production units despite operating under comparable production environments. This observation suggests that equipment criticality should not be determined solely by production capacity but also by the frequency and duration of operational interruptions experienced throughout the production cycle. Before conducting reliability calculations, the operational characteristics of each machine must first be understood because maintenance priorities depend largely on historical equipment behavior. The summarized operational data used in this study are presented in Table 1.

Table 1. Summary of Operation Time, Downtime, and Failure Frequency of Cement Fiber Production Machines (January–June 2025)

Machine	Operation Time (min)	Downtime (min)	Failure Count	Initial Observation
FS1	156,330	15,119	710	Stable performance
FS2	49,140	10,040	307	Moderate utilization
FS3	49,325	9,671	426	Moderate reliability
FS4	37,140	8,901	221	Limited observation period
FS5	179,075	18,510	898	High utilization
FS6	215,895	36,954	2,241	Highest downtime and failure frequency
FS7	153,090	20,796	1,635	Critical maintenance priority
FS8	126,175	9,227	480	Relatively stable

Source: Maintenance records of PT. Nusantara Building Industries, January–June 2025

The information presented in Table 1 indicates that production equipment operated under substantially different maintenance conditions despite belonging to the same manufacturing system. Machines exhibiting high operation time were not necessarily associated with lower downtime, suggesting that production intensity alone cannot adequately explain maintenance performance. FS6 repeatedly experienced high downtime together with frequent failures across multiple observation periods, indicating a persistent maintenance concern requiring more detailed reliability analysis. In contrast, several machines maintained relatively stable operational performance despite comparable production demands, reflecting differences in equipment condition, maintenance quality, or operating environment. These findings reinforce the importance of continuously monitoring maintenance indicators because recurring failures frequently originate from underlying maintenance management deficiencies rather than isolated technical problems. Similar observations have been reported in preventive maintenance studies where historical operational records constitute the principal basis for identifying critical production equipment requiring maintenance prioritization (Rais et al., 2020).

To further identify the dominant maintenance problems affecting production continuity, the operational data were subsequently analyzed using the Pareto principle, which classifies maintenance problems according to their cumulative contribution to total downtime. The Pareto approach enables maintenance managers to prioritize corrective actions toward failure categories responsible for the greatest operational losses instead of distributing maintenance resources uniformly across all equipment. This prioritization strategy is particularly valuable in continuous manufacturing environments because maintenance resources are generally limited while production reliability must remain consistently high. The resulting Pareto analysis revealed that a relatively small number of machine failures contributed disproportionately to cumulative production downtime. Such findings indicate that maintenance optimization can be achieved more effectively through focused preventive actions directed toward critical equipment categories. The corresponding Pareto distribution is illustrated in Figure 1, which visually identifies the dominant contributors to downtime throughout the observation period.

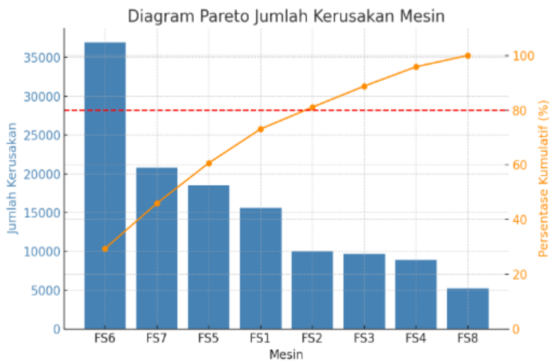

Figure 1. Pareto Chart of Cement Fiber Machine Downtime (January–June 2025)

The combined results obtained from operational records and Pareto analysis demonstrate that the implementation of PMMS provides a structured foundation for identifying maintenance priorities before reliability-based maintenance scheduling is performed. Rather than functioning solely as a maintenance documentation system, PMMS facilitates systematic integration between operational monitoring, historical maintenance records, and maintenance decision-making processes. The availability of comprehensive maintenance data enables engineers to distinguish between routine operational variation and recurring equipment failures requiring preventive intervention. Such analytical capability becomes increasingly important in intelligent maintenance management because maintenance decisions are expected to be supported by objective operational evidence rather than subjective experience alone. These findings establish the empirical basis for the subsequent reliability analysis using MTTR and MTBF, where maintenance effectiveness is quantitatively evaluated according to equipment operational behavior over the six-month observation period. Similar maintenance management frameworks have been recognized as effective approaches for improving maintenance planning through systematic data utilization and evidence-based decision support (Amir, 2024).

Reliability Analysis Using MTTR and MTBF

The reliability performance of cement fiber production machines was evaluated using the Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) indicators, which are widely recognized as fundamental metrics for assessing equipment availability and maintenance effectiveness in industrial manufacturing systems. MTBF reflects the average operating duration between consecutive failures, whereas MTTR measures the average time required to restore equipment after a failure has occurred. The combination of these two indicators provides a comprehensive assessment because equipment reliability depends not only on the frequency of failures but also on the efficiency of maintenance interventions. Within the PMMS framework, these reliability parameters serve as quantitative evidence for establishing preventive maintenance priorities and determining appropriate maintenance intervals. Reliability-centered maintenance studies consistently demonstrate that simultaneous evaluation of MTBF and MTTR produces more accurate maintenance planning than assessments based solely on failure frequency (Nurroif & Retnowati, 2022). Similar approaches have been successfully implemented in cement manufacturing industries to improve production continuity through systematic maintenance scheduling (Ebrahimi et al., 2020).

The reliability analysis was performed using operational time, accumulated downtime, and machine failure records collected during the six-month observation period. MTBF was calculated by dividing total operating time by the number of recorded failures, while MTTR was obtained from the ratio between cumulative downtime and failure frequency. These calculations provide an objective measurement of machine reliability under actual production conditions rather than laboratory simulations. The resulting values allow maintenance engineers to compare the operational behavior of individual production units despite differences in production intensity. Machines with high MTBF and low MTTR are generally considered more reliable because they operate longer before failure and require shorter repair durations. The calculated reliability values for each production machine are summarized in Table 2.

Table 2. Average MTTR and MTBF of Cement Fiber Production Machines (January–June 2025)

Machine	Average MTTR (min)	Average MTBF (min)	Reliability Assessment
FS1	22.10	219.78	High
FS2	29.10	154.83	Moderate
FS3	23.53	114.40	Moderate
FS4	36.25	177.85	Moderate
FS5	20.20	200.23	High
FS6	16.85	102.98	Low
FS7	14.62	72.83	Very Low
FS8	19.23	260.75	Very High

Source: Calculated from maintenance records of PT. Nusantara Building Industries

The results presented in Table 2 indicate considerable differences in reliability among the production machines. FS8 achieved the highest average MTBF of 260.75 minutes, indicating the longest operating duration before failure, while FS7 exhibited the lowest MTBF of only 72.83 minutes, reflecting frequent operational interruptions. Although FS7 recorded the shortest MTTR, this condition does not necessarily indicate superior maintenance performance because the machine continued to experience failures more frequently than other production units. Conversely, FS1 and FS5 maintained relatively high MTBF values together with moderate repair durations, suggesting a more balanced maintenance condition. These findings emphasize that reliability assessment should simultaneously consider both MTBF and MTTR because isolated interpretation of either indicator may lead to inaccurate maintenance priorities. Similar observations have been reported in reliability-based preventive maintenance studies where equipment experiencing frequent failures remained critical despite relatively rapid repair times (Alfadhlani et al., 2025).

To examine reliability variation over time, the MTTR and MTBF values were subsequently aggregated according to monthly operational performance. Monthly analysis provides additional insight into maintenance consistency because equipment reliability may fluctuate as production intensity, operating conditions, and maintenance implementation change throughout the observation period. Monitoring temporal reliability trends is particularly important for validating the effectiveness of PMMS implementation because preventive maintenance should progressively improve equipment stability rather than produce isolated maintenance improvements. The monthly reliability averages are presented in Table 3.

Table 3. Monthly Average MTTR and MTBF During the Observation Period

Month	Average MTTR (min)	Average MTBF (min)	Reliability Trend
January	24.58	121.50	Initial condition
February	23.48	163.00	Improving
March	20.77	146.27	Stable
April	17.52	177.62	Improved
May	17.43	183.90	Best performance
June	21.53	163.16	Slight decline

Source: Calculated from maintenance records of PT. Nusantara Building Industries

The monthly reliability evaluation demonstrates a gradual improvement in maintenance performance from January to May, characterized by decreasing MTTR and increasing MTBF values. This trend suggests that maintenance interventions became progressively more effective as PMMS procedures were consistently implemented and maintenance documentation became more complete. The slight reduction in MTBF observed during June may indicate increasing production demand or the emergence of recurring failures requiring additional preventive actions rather than representing deterioration of the maintenance system itself. Such temporal fluctuations are common in continuous manufacturing environments where production schedules and equipment utilization continuously evolve. Reliability monitoring therefore should be conducted continuously instead of relying on isolated maintenance evaluations. Studies concerning maintenance planning similarly emphasize that continuous monitoring of MTBF and MTTR enables organizations to identify deteriorating equipment conditions before critical failures occur (Khaurullah & HR, 2022).

The combined evaluation of machine-based and monthly reliability indicators demonstrates that PMMS provides a structured analytical foundation for maintenance decision-making by integrating operational history with quantitative reliability measurements. The identification of FS6 and FS7 as critical machines indicates that maintenance resources should be prioritized according to reliability performance rather than uniformly distributed across all production equipment. Such prioritization enables preventive maintenance activities to focus on equipment with the greatest potential impact on production continuity while avoiding unnecessary maintenance interventions on relatively reliable machines. Integrating MTBF and MTTR into the PMMS framework also supports evidence-based maintenance scheduling because maintenance intervals are determined according to actual equipment behavior instead of fixed operational calendars. This reliability assessment therefore establishes the analytical basis for the subsequent root cause analysis, where the dominant factors contributing to machine failures are investigated in greater detail using Pareto and Fishbone analyses. Recent maintenance management research similarly recognizes reliability indicators as essential inputs for intelligent maintenance planning and data-driven maintenance optimization (Syafei & Suhendar, 2022).

Root Cause Analysis of Machine Failures

The reliability analysis presented in the previous subsection demonstrated that several cement fiber production machines exhibited substantially different operational characteristics despite operating within the same manufacturing environment. Machines FS6 and FS7 consistently recorded lower reliability levels than the remaining production units, indicating that frequent failures were not merely random operational events but reflected recurring maintenance problems requiring systematic investigation. Reliability indicators such as MTBF and MTTR effectively quantify equipment performance; however, they cannot fully explain the mechanisms responsible for repeated machine failures. A comprehensive understanding of maintenance effectiveness therefore requires the identification of underlying operational factors contributing to equipment deterioration. Intelligent maintenance management emphasizes that maintenance decisions should be supported by systematic diagnosis of failure mechanisms rather than relying exclusively on statistical reliability indicators (Syafei & Suhendar, 2022). This study consequently employed root cause analysis to investigate the dominant factors contributing to recurring failures within the cement fiber production process.

The identification of failure causes was performed using the Fishbone Diagram, also known as the Ishikawa Diagram, because this analytical approach enables maintenance problems to be classified according to their potential sources in a structured and systematic manner. The analysis grouped possible causes into six principal categories consisting of Man, Machine, Method, Material, Environment, and Measurement, allowing technical and managerial issues to be evaluated simultaneously. Such categorization facilitates a more comprehensive interpretation because equipment failures generally originate from the interaction of multiple operational factors rather than from a single mechanical defect. Within the PMMS framework, this analytical structure supports preventive maintenance planning by identifying organizational weaknesses that may reduce maintenance effectiveness. Previous studies have similarly emphasized that structured root cause analysis significantly improves maintenance planning because preventive actions can be directed toward eliminating the origins of recurring failures instead of repeatedly repairing their consequences (Rais et al., 2020). The analytical structure used in this study is illustrated in Figure 2.

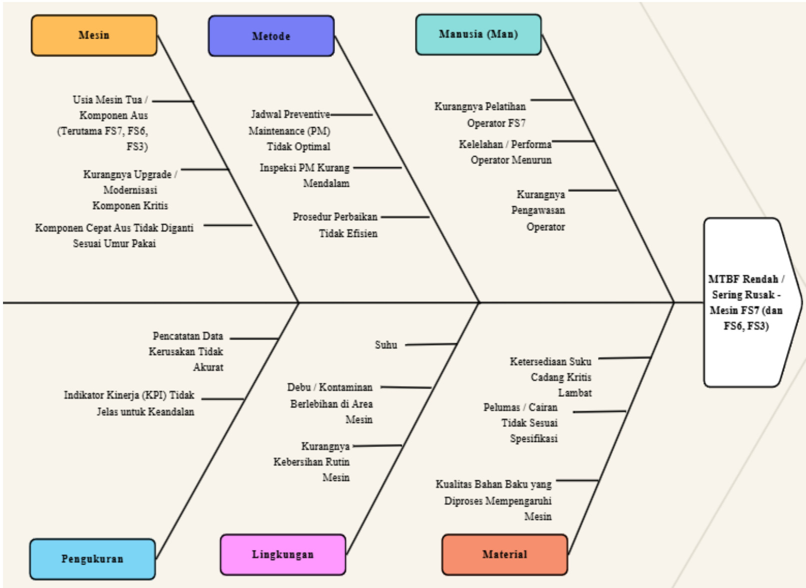

Figure 2. Fishbone Diagram of Cement Fiber Machine Failures

The Fishbone analysis indicates that machine-related factors represented the most dominant contributors to recurring production interruptions. Continuous machine operation accelerated component wear, particularly in mechanical parts operating under high production loads, resulting in increased failure frequency for several critical production units. Preventive lubrication and periodic component replacement were occasionally performed after performance degradation had already become apparent, reducing the effectiveness of maintenance interventions. Human-related factors also influenced maintenance consistency because inspection quality depended heavily on technician experience and adherence to maintenance procedures. Method-related issues were identified in maintenance scheduling practices that previously relied primarily on fixed operational routines instead of equipment reliability characteristics. Similar observations have been reported in maintenance planning studies where inappropriate maintenance strategies contribute directly to recurring equipment failures despite regular maintenance implementation (Arifai, 2024).

Material quality and environmental conditions also contributed to equipment degradation throughout the production process. Fiber cement manufacturing continuously exposes production equipment to cement dust, moisture, vibration, and abrasive particles that gradually reduce the operational condition of mechanical components when preventive maintenance activities are insufficiently optimized. Environmental contamination may accelerate bearing wear, reduce lubrication effectiveness, and increase friction within moving components, ultimately shortening equipment operating life. Measurement-related issues further influenced maintenance performance because incomplete maintenance documentation occasionally limited the ability of maintenance personnel to recognize deterioration trends before machine failures occurred. Effective maintenance management therefore depends not only on technical repair activities but also on the quality and consistency of operational information collected throughout equipment operation. Recent preventive maintenance studies similarly emphasize that maintenance documentation and standardized inspection procedures are fundamental components supporting data-driven maintenance management systems (Allamsyah, 2025).

The interaction among the six Fishbone categories demonstrates that recurring failures resulted from cumulative organizational and technical factors rather than isolated mechanical defects. Equipment deterioration naturally increases with machine utilization; however, ineffective maintenance scheduling, inconsistent inspections, incomplete documentation, and unfavorable environmental conditions substantially accelerate failure occurrence. These relationships explain why certain production units continued to exhibit relatively low MTBF values despite achieving comparatively short repair durations. PMMS provides an important managerial advantage because maintenance decisions can be based on integrated operational evidence instead of reactive responses after equipment failures occur. Such an approach supports more efficient allocation of maintenance resources toward operational factors generating the greatest production impact. The analytical findings therefore reinforce the importance of integrating reliability indicators with structured root cause analysis when developing preventive maintenance strategies.

The results of the Fishbone analysis establish a comprehensive foundation for improving preventive maintenance management within the cement fiber production system. Rather than focusing exclusively on corrective maintenance after failures occur, maintenance improvement should prioritize systematic inspection procedures, standardized maintenance documentation, optimization of maintenance intervals, technician competency development, and continuous monitoring of critical machine components. The integration of these organizational and technical improvements enables PMMS to function as a decision-support framework capable of enhancing equipment reliability and production continuity. The identified root causes also provide practical guidance for determining preventive maintenance priorities according to equipment criticality and operational risk. These findings become the basis for establishing reliability-based preventive maintenance intervals discussed in the following subsection, where maintenance scheduling is developed according to the operational characteristics of each production machine.

Reliability-Based Preventive Maintenance Scheduling Using PMMS

The identification of machine reliability characteristics and root causes provides the foundation for establishing an effective preventive maintenance schedule within the Preventive Maintenance Management System (PMMS). Rather than applying identical maintenance intervals to all production equipment, PMMS emphasizes maintenance planning based on actual operational reliability and equipment criticality. This approach enables maintenance activities to be performed before significant performance degradation occurs, thereby reducing the probability of unexpected failures during production. Reliability-based scheduling also allows maintenance resources to be allocated more efficiently because machines with higher operational risks receive greater maintenance attention than relatively stable equipment. Recent studies have demonstrated that preventive maintenance scheduling based on equipment reliability significantly improves production continuity while reducing maintenance costs associated with unexpected breakdowns (Alfadhlani et al., 2025). Such an approach is particularly appropriate for continuous manufacturing environments where production interruptions immediately influence overall operational performance.

The preventive maintenance intervals in this study were determined using the average MTBF values obtained from the six-month operational analysis. A reliability factor of 0.80 was adopted, indicating that maintenance activities should be scheduled while the probability of equipment operating without failure remains at approximately eighty percent. This reliability threshold provides a balance between maintenance frequency and equipment utilization by preventing maintenance activities from being performed either too early or after excessive deterioration has occurred. Machines exhibiting lower MTBF values consequently receive shorter maintenance intervals because they experience failures more frequently under normal production conditions. The recommended preventive maintenance intervals calculated for each production machine are presented in Table 4.

Table 4. Recommended Preventive Maintenance Interval Based on Reliability (R = 0.80)

Machine	Average MTBF (min)	Reliability Factor	Recommended PM Interval (min)	Recommended PM Interval (hour)
FS1	219.78	0.80	175.82	~3.0 h
FS2	154.83	0.80	123.86	~2.1 h
FS3	114.40	0.80	91.52	~1.5 h
FS4	177.85	0.80	142.28	~2.4 h
FS5	200.23	0.80	160.18	~2.7 h
FS6	102.98	0.80	82.38	~1.4 h
FS7	72.83	0.80	58.26	~1.0 h
FS8	260.75	0.80	208.60	~3.5 h

Source: Calculated from maintenance records of PT. Nusantara Building Industries

The scheduling results indicate considerable variation in maintenance requirements among the production machines. FS7 exhibits the shortest recommended maintenance interval of approximately one operating hour because it possesses the lowest average MTBF and the highest failure frequency observed during the study period. FS6 similarly requires frequent preventive maintenance due to its relatively low reliability despite maintaining shorter repair durations than several other production units. In contrast, FS8 demonstrates the highest reliability performance, allowing preventive maintenance activities to be scheduled at longer operating intervals without substantially increasing operational risk. These findings confirm that preventive maintenance should be determined according to equipment reliability characteristics rather than adopting uniform maintenance schedules for all production assets. Similar conclusions have been reported in reliability-centered maintenance studies where maintenance intervals based on MTBF produce more effective maintenance performance than conventional time-based scheduling approaches (Khaurullah & HR, 2022).

The implementation of reliability-based scheduling within PMMS provides several operational advantages beyond determining maintenance intervals alone. The availability of structured maintenance schedules enables maintenance personnel to prepare spare parts, allocate maintenance resources, coordinate technician workloads, and minimize conflicts between maintenance activities and production operations. Maintenance planning also becomes more transparent because maintenance priorities are supported by quantitative reliability evidence rather than subjective operational judgment. Such systematic planning strengthens production continuity by reducing emergency maintenance interventions that frequently generate unplanned downtime and additional operational costs. Digital maintenance management systems similarly emphasize that maintenance scheduling should be integrated with maintenance documentation and equipment history to support continuous performance improvement (Silalahi et al., 2025). PMMS therefore functions as an integrated maintenance management framework rather than simply a maintenance recording system.

The reliability-based maintenance strategy also supports continuous improvement because maintenance intervals can be periodically updated according to newly collected operational data. Machines exhibiting improving MTBF values after preventive maintenance implementation may gradually receive extended maintenance intervals, whereas equipment showing declining reliability can be scheduled more frequently before failures become critical. Such adaptive maintenance planning reflects the fundamental principle of intelligent maintenance management, where maintenance decisions continuously evolve according to equipment operating conditions and historical maintenance performance. This capability enables manufacturing companies to optimize maintenance costs while maintaining high production availability under changing operational conditions. Contemporary maintenance management research similarly recognizes adaptive scheduling as a key characteristic of intelligent preventive maintenance systems capable of supporting long-term operational sustainability (Amir, 2024).

The implementation of PMMS supported by reliability-based preventive maintenance scheduling demonstrates that maintenance management can evolve from conventional routine servicing toward evidence-based operational decision-making. The integration of operational data, reliability indicators, root cause analysis, and preventive maintenance scheduling establishes a comprehensive maintenance framework capable of improving equipment availability while reducing recurring production interruptions. The recommended maintenance intervals developed in this study provide practical guidance for prioritizing maintenance activities according to machine criticality and operational risk within the cement fiber production system. Such a framework not only improves maintenance effectiveness but also strengthens production stability by ensuring that maintenance interventions are performed before equipment reliability declines below acceptable operational levels. The proposed scheduling strategy therefore illustrates the practical contribution of PMMS as an intelligent maintenance management approach capable of supporting sustainable manufacturing performance in continuous production environments.

CONCLUSION

This study analyzed the maintenance performance of cement fiber production machines at PT. Nusantara Building Industries using the Preventive Maintenance Management System (PMMS) framework by integrating operational records, downtime history, reliability analysis, and root cause identification. The results indicate that the production machines experienced considerable variations in operation time, downtime, and failure frequency during the January–June 2025 observation period, demonstrating differences in reliability among individual production units. Reliability evaluation using MTBF and MTTR confirmed that machines FS6 and FS7 exhibited the lowest operational reliability because they experienced frequent failures despite relatively short repair durations. Pareto analysis further revealed that a limited number of machine failures contributed to the majority of cumulative production downtime, indicating that maintenance improvement efforts should prioritize the most critical production units rather than distributing maintenance resources uniformly. Root cause analysis using the Fishbone Diagram demonstrated that recurring failures were influenced by the interaction of machine condition, maintenance methods, technician practices, environmental exposure, material conditions, and maintenance documentation quality. These findings confirm that equipment reliability depends not only on technical maintenance activities but also on the effectiveness of maintenance management implemented through PMMS. The study therefore demonstrates that integrating reliability indicators with systematic maintenance management provides a more comprehensive basis for improving production continuity in cement fiber manufacturing.

The implementation of PMMS proved capable of supporting evidence-based maintenance decision-making by integrating maintenance scheduling, inspection activities, equipment history, and operational performance evaluation into a unified management framework. Reliability-based preventive maintenance scheduling demonstrated that maintenance intervals should be adjusted according to individual machine characteristics instead of applying identical maintenance frequencies to all production equipment. Machines with lower MTBF values require more frequent preventive maintenance because their operational risk is considerably higher than machines exhibiting stable reliability performance. The proposed maintenance intervals provide practical guidance for reducing unplanned downtime while improving maintenance efficiency and equipment availability. The integration of operational monitoring, reliability assessment, and root cause analysis also strengthens maintenance planning by enabling maintenance engineers to prioritize preventive actions according to measurable operational evidence. Such a structured maintenance strategy supports the transition from conventional corrective maintenance toward proactive and data-driven maintenance management. Consequently, PMMS can be considered an effective maintenance management approach for improving operational reliability within continuous manufacturing environments.

From a practical perspective, the findings suggest that preventive maintenance schedules should be continuously optimized using updated MTBF and operational performance data so that maintenance interventions are conducted before recurring failures significantly affect production continuity. Maintenance effectiveness can also be enhanced through continuous technical training for maintenance personnel, standardized inspection procedures, improved maintenance documentation, and greater compliance with PMMS reporting practices to ensure the accuracy of maintenance information used for decision-making. The availability of critical spare parts should be consistently maintained to minimize repair duration and prevent extended production interruptions during unexpected equipment failures. Periodic evaluation of reliability indicators should become part of routine maintenance management to ensure that preventive maintenance intervals remain aligned with changing machine operating conditions. Future implementation of PMMS may also benefit from integrating digital monitoring technologies capable of supporting real-time equipment condition assessment and predictive maintenance analysis. Further studies are encouraged to combine PMMS with machine learning, Internet of Things (IoT), or predictive analytics techniques to improve maintenance optimization and maintenance decision support. Such developments would strengthen the application of intelligent engineering principles in industrial maintenance management while contributing to more sustainable manufacturing performance.

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