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THE PRESENT STUDY PROPOSES A NOVEL INTEGRATION OF LOGIC TREE ANALYSIS (LTA) AND FUZZY FAILURE MODE AND EFFECT ANALYSIS (FUZZY-FMEA) IN THE DOMAIN OF PRODUCTION MACHINE MAINTENANCE PLANNING

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Abstract

The reliability and efficiency of machinery in a production system are contingent upon proper failure analysis. The objective of this study is to identify and evaluate the primary failure modes in machine components using the Failure Mode and Effect Analysis (FMEA) method and Risk Priority Number (RPN) calculation. The analysis results indicate that Belt Conveyors and Bearings have the highest RPN value (180), signifying a substantial risk of failure relative to other components. The study identified severity, occurrence, and detection as the primary factors contributing to failure. Additionally, the analysis categorized components based on risk level, with category B (outage) exhibiting a 100% proportion, signifying that all failures have a direct impact on system operations. The findings of this study provide a foundation for the development of a more effective maintenance strategy, aimed at minimizing the likelihood of failure and enhancing the performance of the production system.

Kata Kunci: *FMEA, RPN, analisis kegagalan, pemeliharaan preventif, keandalan sistem*

Abstrak

Keandalan dan efisiensi mesin dalam sistem produksi sangat bergantung pada analisis kegagalan yang tepat. Penelitian ini bertujuan untuk mengidentifikasi dan mengevaluasi mode kegagalan utama pada komponen mesin menggunakan metode Failure Mode and Effect Analysis (FMEA) dan perhitungan Risk Priority Number (RPN). Berdasarkan hasil analisis, Belt Conveyor dan Bearing merupakan komponen dengan nilai RPN tertinggi (180), yang menunjukkan tingkat risiko kegagalan yang signifikan dibandingkan komponen lainnya. Faktor utama penyebab kegagalan meliputi tingkat keparahan (Severity), frekuensi kejadian (Occurrence), dan kemudahan deteksi (Detection). Selain itu, penelitian ini mengelompokkan komponen berdasarkan kategori risiko, dengan kategori B (Outage) memiliki proporsi 100%, yang menandakan bahwa seluruh kegagalan berdampak pada penghentian operasi sistem. Hasil penelitian *ini dapat digunakan sebagai dasar untuk pengembangan strategi pemeliharaan yang lebih efektif, sehingga dapat mengurangi kemungkinan terjadinya kegagalan dan meningkatkan kinerja sistem produksi.*

INTRODUCTION

Modern production machines, especially in the manufacturing industry, are increasingly complex. [1]. The enhanced elements encompass components of quantity, as well as complex and sophisticated technological systems, including numerical control and systems. This increased complexity has been demonstrated to enhance the probability of failure for Java. Machines can induce significant downtime. [2] This period of inactivity has a direct impact on productivity, product quality, and operational costs. The financial repercussions of downtime resulting from machine failure can be substantial, encompassing expenses related to repairs, loss of production, and deterioration of reputation. [2]. Conventional maintenance methodologies, including time-based preventive maintenance and corrective maintenance, frequently prove ineffective when confronted with the challenges posed by complex contemporary machines, which are susceptible to unanticipated failures [3]. [4]. These methods frequently yield suboptimal maintenance schedules, leading to resource wastage and elevated risk of failure. [5]. The primary challenge in the management of production machinery maintenance is the uncertainty surrounding the prediction of failure and the determination of appropriate maintenance times. [6].

The integration of Logic Tree Analysis (LTA) and Fuzzy Failure Mode and Effect Analysis (Fuzzy-FMEA) has been identified as a potential solution to the limitations of conventional methods in production machine maintenance planning. This integration is expected to enhance the accuracy of machine failure prediction. [7] which allows for more accurate and effective maintenance planning and scheduling [5]. Optimize maintenance schedules to minimize downtime and maximize machine availability with more accurate predictions. [8], which allows for more accurate and effective maintenance planning and scheduling [5]. Optimize maintenance schedules to minimize downtime and maximize machine availability with more accurate predictions. [8]. This will contribute to an overall reduction in the cost of maintenance. [9], Because maintenance can be performed promptly and focused on those components or systems that are most likely to fail. [10]. This integration aims to enhance the reliability and availability of production machinery, thereby increasing production efficiency and product quality. By comprehending potential failure modes and their ramifications, companies can implement suitable preventive measures to circumvent unanticipated failures and optimize operational efficiency. [11]

Logic Tree Analysis (LTA) is a system analysis technique that is used to identify and analyze a series of events that can cause a particular event, such as engine failure. [12], This method is particularly beneficial in the context of maintenance planning, as it facilitates the visualization of failure pathways. This, in turn, enables the maintenance team to prioritize interventions based on the criticality of the components in question. [13]. The utilization of LTA has been demonstrated to enhance the decision-making process by providing a logical framework for evaluating the impact of different maintenance strategies on system reliability and performance [14]. Fuzzy Failure Mode and Effect Analysis (Fuzzy-FMEA) represents an extension of the conventional Failure Mode and Effect Analysis (FMEA) that incorporates fuzzy set theory to address the uncertainty inherent in risk assessment. Integration of LTA and Fuzzy-FMEA has been demonstrated to enhance the

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precision of production machine failure prediction. [7], optimize the maintenance schedule[5], and minimize maintenance [9]. A comparison with conventional methods indicates that this integration results in more accurate and comprehensive failure mode prioritization[9]. This research contributes to the development of more effective and efficient maintenance methods for complex modern production machinery[8].

Background

The manufacturing industry is confronted with numerous challenges in ensuring the seamless operation of production processes, particularly concerning sustaining uninterrupted operations.PT. Jui Shin Indonesia, a prominent manufacturer of ceramics and granite, depends on a range of production machinery that functions optimally and without malfunction. Gasifiers and belt conveyors are pivotal components in the production process, as they are utilized in the coal gasification process to generate gas that serves as the primary fuel. The potential consequences of damage or failure to these machines are significant, as they can lead to substantial downtime, reduced productivity, and substantial financial losses.

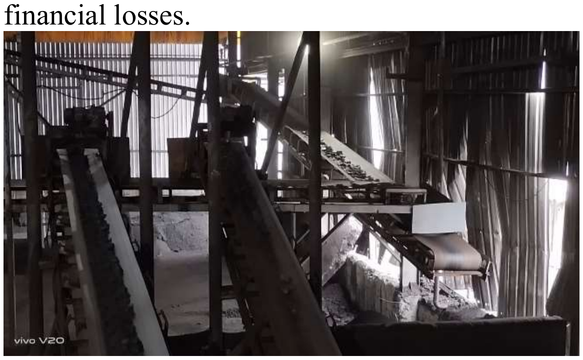

Figure 1 Belt Conveyor

Presently, PT. Jui Shin Indonesia employs a corrective maintenance system, signifying that repairs are undertaken solely in instances of machine malfunction.

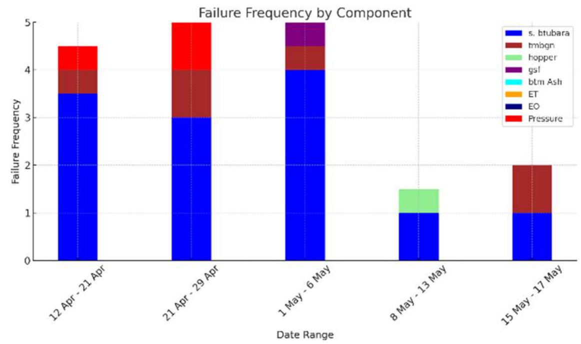

Figure 2 Breakdown Frequency Diagram

Unplanned maintenance systems have been shown to increase the likelihood of extensive damage that requires a prolonged period of repair and can disrupt the production process. Therefore, a more preventive and planned maintenance system is necessary to ensure the smooth operation of the production process. One maintenance method that can be applied to address this issue is Reliability Centered Maintenance (RCM). RCM is a maintenance approach that emphasizes enhancing the reliability of equipment and production systems through a systematic approach that integrates preventive and corrective maintenance, to minimize downtime and enhance operational efficiency. Employing the RCM approach enables companies to analyze and prioritize the necessary repairs to improve operational efficiency. The purpose of this study is to evaluate the machine maintenance system of PT. The focus of this study is on the belt conveyor and gasifier, which play a pivotal role in the coal gasification process.

Novelty

The application of Reliability Centered Maintenance (RCM) in the ceramic and granite industries, particularly in coal gasification systems, has received scant attention from the academic community. The majority of extant RCM applications are found in power generation or other large manufacturing industries. Therefore, the present study focuses on evaluating failure modes and their impact on the smooth production process of PT. Jui Shin Indonesia. The present study employs a combination of Failure Mode and Effect Analysis (FMEA) and Logic Tree Analysis (LTA) to provide a comprehensive assessment of potential damage and to design a maintenance system that can mitigate the risk of failures that disrupt production.

State of the Art

Reliability-centered maintenance (RCM) has emerged as a pivotal strategy for enhancing the reliability of production systems across diverse industrial sectors [15][16][17]. This approach transcends conventional preventive and breakdown maintenance strategies, seeking to optimize maintenance expenditures while ensuring system availability [15]. The fundamental principle of RCM is to preserve system functionality within the context of ongoing operations [16][18].

The implementation of RCM has been limited in the ceramics industry, particularly in the context of coal gasification processes. Research on the application of RCM in these settings remains scarce.PT. Jui Shin Indonesia, for instance, encountered substantial challenges due to machine downtime resulting from failures in gasifier and belt conveyor components. Consequently, this study aims to investigate the applicability of RCM in the analysis and design of maintenance systems at PT. The study will examine the application of FMEA and LTA in identifying and addressing critical engine problems, to enhance production efficiency and reliability.

Proposed LTA/Fuzzy FMEA integration applies to various industries and production systems::

1. **Marine Industry Applications**: The initial paper demonstrates the implementation of interval type-2 fuzzy numbers and the ORESTE method within the marine industry, particularly for the analysis of risk in ocean fishing vessels [19]. This case study underscores the efficacy of fuzzy logic in managing uncertainty within intricate systems, a principle that finds extension in the domain of production engine maintenance planning.
2. **Food Production Application**: Paper 2 implements the intelligent FMEA framework in the context of an edible oil refining facility, thereby substantiating the efficacy of the SVM algorithm in failure mode ranking [20]. This case study underscores the significance of precise RPN calculations in ensuring operational safety and maintenance efficiency. The integration of LTA and Fuzzy-FMEA has been identified as a potential avenue for enhancing these outcomes.
3. **Automotive Industry Applications**: Paper 3 centers on the assessment of quality issues in the automotive industry. It employs the FMEA-based fuzzy TOPSIS methodology to prioritize critical quality errors [21]. This approach is adaptable for utilization in the realm of production machine maintenance planning, thereby ensuring the identification and prompt addressing of the most critical failure modes.
4. **General Industrial Applications**: Paper 4 presents a comparative study of K-Means clustering and a new ranking algorithm for RPN analysis in FMECA, using data from 20 real-world cases [22]. This study demonstrates the effectiveness of advanced algorithms in prioritizing maintenance actions. These algorithms can be integrated with LTA to develop a comprehensive maintenance planning framework.

RESEARCH METHODS

This study employs a quantitative descriptive approach, which aims to analyze and describe the frequency of damage to related machines and components using data collected over a specified period [23]. The study focuses on Failure Mode and Effect Analysis (FMEA) and the application of Reliability Centered

Maintenance (RCM) to identify and prioritize the components most susceptible to damage.

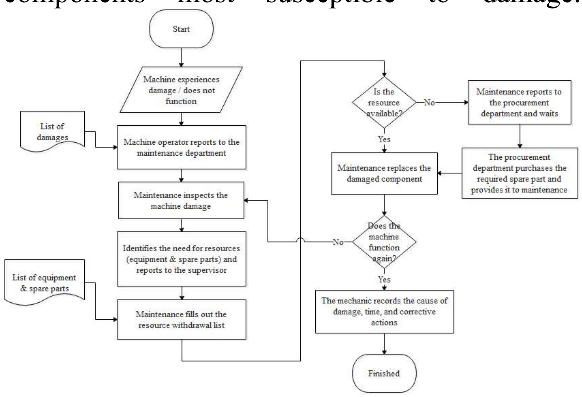

Figure 3 Research process flow diagram

The data used in this study is made up of two types of data:

1. Primary data: Data obtained directly from field observations, interviews with operators and technicians, and daily records of machine maintenance and damage.
2. Secondary data refers to data obtained from company documents, previous maintenance reports, and historical data regarding engine and component failures recorded in the company system.

Techniques of Data Collection

Observation: Direct observation of the engine maintenance process and the condition of the engine during operation.

Interview: Interview with operators and technicians to obtain information about failures that have occurred and the maintenance procedures performed.

Documentation Study: Collection of data related to engine failure frequency, maintenance records, and component failure analysis.

Steps in Data Analysis:

1. The identification of critical components entails the determination of machine elements that are susceptible to frequent damage.
2. RPN Calculation: The RPN value for each component is determined by the following formula: RPN = Severity × Occurrence × Detection.
3. FMEA and LTA analysis: Analyze the effects of failure on the system and design appropriate preventive measures.
4. Use RCM: Plan maintenance based on the results of the analysis to minimize damage and downtime.

RESULTS AND DISCUSSION

PT. Jui Shin Indonesia's maintenance system is predicated on a "correction maintenance" approach, wherein components are replaced solely in instances of damage. Consequently, a component replacement schedule is not currently in place, as replacement is performed only after the occurrence of damage.

1. Analysis of Current Maintenance Systems

The maintenance system currently in place is predicated on a corrective approach, entailing the execution of repairs in the aftermath of damage. This methodology is inherently vulnerable to significant deficiencies, including the following:

- The absence of a component replacement schedule constitutes a significant deficiency.
- The high level of production downtime due to inadequate resource preparation.
- It is imperative to acknowledge that damage frequently arises from a confluence of human factors, machine characteristics, operational methodologies, and environmental influences.

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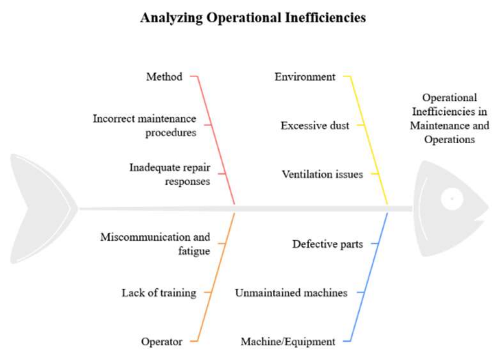

Figure 4 Cause and Effect Diagram of the Damage to the Gasifier Machine

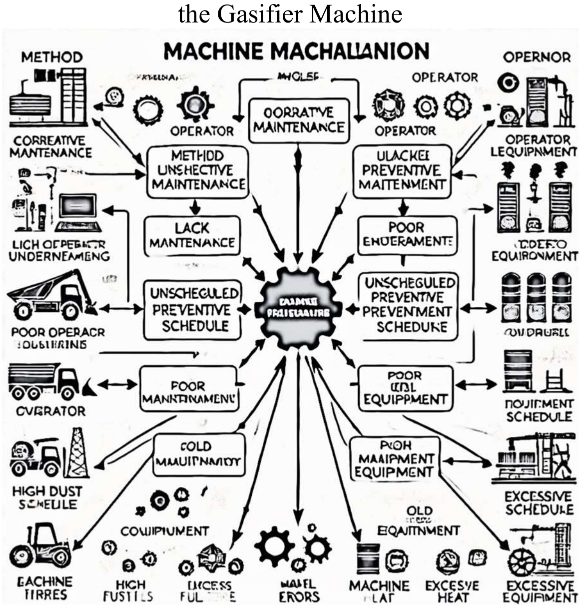

Figure 5 The following illustration depicts a fishbone diagram of damage to a gasifier engine.

Table 1 Damage Frequency

Components	April 12th-April 21st	April 21st-April 29th	May 1st-May 6th	May 8th-May 13th	May 15th-May 17th	Total
Coal Filter	3	4	3	2	1	13
Scales	1	1	1	-	-	3
Hopper	-	-	-	-	-	0
Gasifier	1	1	-	-	-	2
Bottom Ash	1	1	-	-	-	2
Electrik Tar (ET)	1	1	-	-	-	2
Electrik Oiler (EO)	1	-	-	-	-	1
Pressure	1	1	-	-	-	2

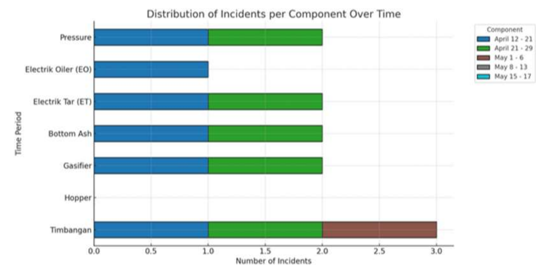

Figure 6 Damage frequency chart

The Failure Mode and Effect Analysis (FMEA) of gasifier engine components is predicated on the identification of the root cause of engine failure, as indicated by the Risk Priority Number (RPN). The RPN is influenced by the severity and likelihood of failure occurrence. The identification of problems has led to the determination that boiler delays are attributable to damage to engine components. The RPN value of each component is enumerated in Table 2.

Table 2 RPN Failure of Gasifier Engine Component

No	Components	RPN
1	Driving Motor	64
2	*Belt Conveyor*	180
3	*Bearing*	180
4	*Van Belt*	64
5	*Spring*	64

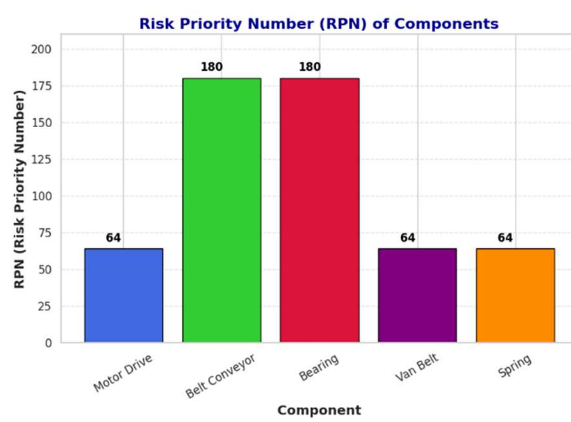

Figure 7 graphic of the failure of the gasifier engine component

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1. FMEA (Failure Mode Effects Analysis)

FMEA is used to identify failure modes and their impacts. The RPN value is calculated using the formula:

RPN=Severity×Occurrence×Detection

Table 3 FMEA (Failure Mode and Effect Analysis)

No	Components	Failure Mode	Severity	Occurrence	Detection	RPN
1	Driving Motor	Burned	8	2	4	64
2	Belt Conveyor	Damaged	10	3	6	180
3	Bearing	Damaged	10	3	6	180
4	Van Belt	Disconnect	8	2	4	64
5	Spring	Regardless	8	2	4	64

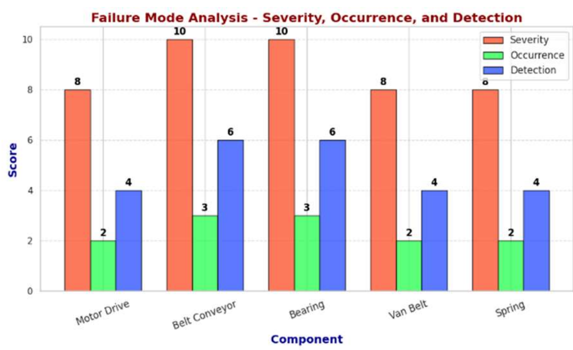

Figure 8 *FMEA graphic chart*

2. Analysis Logic Tree Analysis (LTA)

According to the LTA analysis, the failure categories of each engine component can be obtained. The categorization of components is based on several considerations, including:

a. Category A (safety problem): These are components that have the potential to result in safety hazards for operators and the environment.
b. Category B (outage problem): These are components that have the potential to fail all or part of the system.
c. Category C (economic problem): These are components that These components may not result in the complete failure of the system, but they can lead to financial losses for the company due to reduced component functionality.
d. Category D (Hidden failure) encompasses components that are not recognized as defective due to their location or other factors, making them difficult for operators to detect.

Table 4 Analisis Logic Tree Analysis (LTA)

Categories	Number of Components	Percentage
A (Safety)	0	0%
B (Outage)	5	100%
C (Economic)	0	0%
D (Hidden)	0	0%
Total	5	100%

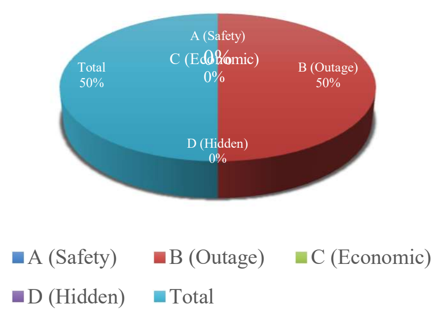

Figure 9 *Analisis Logic Tree Analysis (LTA)*

3. Recapitulation of Maintenance Actions

According to the findings of the FMEA and LTA, maintenance actions are classified into two categories:

a. Condition Directed (CD): To detect initial damage.
The second type is
b. Time Directed (TD), which is intended for the periodic replacement of components.

Table 5 maintenance actions

No	Type of Action	Number of Components	Percentage (%)
1	Condition Directed (CD)	2	40%
2	Time Directed (TD)	3	60%
3	Finding Failure (FF)	0	0%
	Total	5	100%

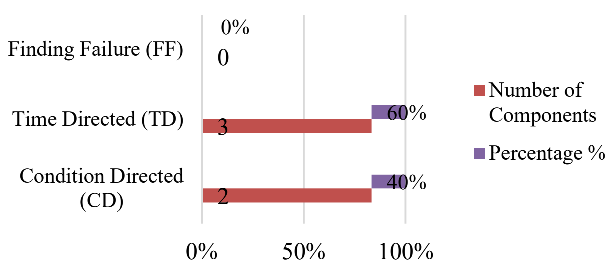

Figure 10 treatment action chart

CONCLUSION

1. The process is to identify the failure modes.
   - According to the results of the FMEA analysis, the components with the highest risk level are the Belt Conveyor and the Bearing, which each have an RPN value of 180.
   - The Drive Motor, Van Belt, and Spring components have a lower RPN value (64), but they can still contribute to potential system malfunctions.
2. Risk Factor Analysis
   - The highest severity level is observed in the Belt Conveyor and Bearing components, which received a score of 10, indicating that the failure of these components can have a significant impact on the system.
   - The highest Occurrence factor (3) is observed in the Belt Conveyor and Bearing, suggesting that these components are more susceptible to failure than others.
   - Finally, both components share the highest detection category, indicating that failure is difficult to detect before it occurs.
3. Failure Risk Category
   - All components that fail are in Category B (Outage), with a 100% percentage, indicating that each failure directly disrupts operations.
   - No components are included in Categories A (Safety), C (Economic), or D (Hidden), indicating that the impact of failure is more operationally oriented than in terms of safety or economics.
4. The following section will address the implications and recommendations that arise from these findings.
   - A more effective preventive maintenance strategy is needed, especially for components with high RPN values, to reduce the risk of system failure.
   - Improved early detection of failure modes can be achieved through condition monitoring sensors and periodic inspections.
   - Improvements in maintenance planning can be made by considering the RPN value as the basis for maintenance priorities.

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