Analysis of Knitting Machine Maintenance Management in the Binong Jati Convection Industry Using the Failure Mode and Effects Analysis (FMEA) Method as the Basis for Preventive Maintenance

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ABSTRACT

Knitting machines are key equipment in the textile industry production process that greatly affect the smooth operation and quality of products. In small to medium-sized textile industries, common problems include high frequency of machine breakdowns, production downtime, and reduced knitting quality due to corrective maintenance systems. This study aims to identify failure modes in knitting machines, analyze the risk level of each failure using the Failure Mode and Effects Analysis (FMEA) method, and develop improvement proposals based on preventive maintenance. The research method used was descriptive qualitative-quantitative with data collection techniques through field observation, operator interviews, historical damage data, and machine maintenance records. FMEA analysis was carried out by assessing the Severity, Occurrence, and Detection levels to obtain the Risk Priority Number (RPN) value as the basis for determining risk priorities. The results of the study show that the failures with the highest RPN values include lack of lubrication, frequent thread breakage, worn or broken knitting needles, and frequent machine jamming. These failures have a significant impact on increased downtime and reduced product quality. A number of previous studies have shown that the Failure Mode and Effects Analysis (FMEA) method is widely used in the analysis of production machine maintenance and has been proven to be capable of identifying critical potential failures and setting priorities for corrective actions. Studies on the application of FMEA to knitting machines in small-to-medium-sized textile industries are still limited. Therefore, this study was conducted to fill this gap through failure risk analysis and the formulation of maintenance proposals tailored to actual conditions in the field. As an improvement measure, this study proposes the implementation of preventive maintenance through the establishment of a routine maintenance schedule, periodic inspection of critical components, scheduled lubrication, standardization of maintenance procedures, operator training, and recording of machine damage history. The implementation of these proposed improvements is expected to reduce the risk of failure, increase machine reliability, and support the smooth running of the production process on an ongoing basis.

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1. Introduction

The textile industry is one of the manufacturing sectors that plays an important role in supporting economic growth, especially in small and medium industries. One of the main stages in the textile production process is the knitting process, which is highly dependent on the performance of knitting machines as the main means of production. The reliability of knitting machines has a direct impact on the smoothness of the production process, the quality of the fabric produced, and the level of company productivity. In practice, many small and medium-sized textile industries still face various problems related to the performance of knitting machines. Common problems include high machine failure rates, significant production downtime, and a decline in knitting quality. Forms of damage that often occur include easily broken threads, worn or broken knitting needles, machine jams, and malfunctions in the drive system. This situation has resulted in delays in the production process, increased repair costs, and a decline in customer satisfaction. One of the main causes of these problems is the implementation of a corrective machine maintenance system, which involves repairs being carried out after the machine has broken down. This approach increases the risk of sudden production stoppages and increases the likelihood of further damage to other machine components. Therefore, an analysis method is needed that can identify potential machine failures early on so that preventive measures can be taken in a more planned manner.

Failure Mode and Effects Analysis (FMEA) is a systematic analysis method for identifying failure modes, causes, and impacts on machine performance. Cardiel-Ortega et al. (2021) state that the FMEA method can be used to identify critical components and failure modes in knitting machines to determine repair priorities. Through assessing severity, occurrence, and detection, FMEA produces a Risk Priority Number (RPN) that can be used as a basis for determining risk priorities. The results of this analysis can then be used to develop a more effective and targeted preventive maintenance program. The research by Özyazgan and Engin (2013) applied the FMEA method to identify defects in the knitted fabric production process and determine risk priorities based on RPN values. The results of this study showed that most failures originated from knitting machines and inaccurate machine settings, proving that FMEA is effective in identifying critical points in the production process. However, the study still focused on product defects and did not specifically discuss the machine maintenance management system as the main cause of failure. In addition, the proposed improvement recommendations were still general and not directed at developing a structured preventive maintenance strategy.

Based on these conditions, this study aims to identify failure modes that often occur in knitting machines, analyze the level of failure risk using the FMEA method, and determine repair priorities based on RPN values. Furthermore, this study also aims to develop preventive maintenance-based improvement proposals to reduce the risk of machine damage, improve equipment reliability, and support the smoothness and efficiency of the production process in small and medium-scale textile industries.

2. Literature Review

Machine maintenance management is a structured approach that aims to ensure that all production equipment is in a reliable, safe, and ready-to-use condition in accordance with its function. This activity includes the processes of planning, implementing, controlling, and evaluating maintenance activities to achieve operational effectiveness and efficiency. Maintenance activities are a combination of all actions taken to maintain an item in accordance with specified standards (Rusdin et al., 2018). According to Mobley (2002), maintenance management focuses not only on repairs when damage occurs, but also on controlling assets so that they can operate optimally throughout their life cycle. With a good maintenance management system, companies can minimize downtime, reduce repair costs, and increase productivity and production quality. Machine maintenance is one of the important functions in supporting the sustainability and competitiveness of the manufacturing industry.

Preventive maintenance is a scheduled maintenance system for equipment/components designed to improve machine reliability and anticipate any unplanned maintenance activities (Worsham, 2002). The implementation of preventive maintenance aims to reduce the possibility of sudden damage, extend the service life of equipment, and maintain stable machine performance. The implementation of preventive maintenance can also reduce production downtime and help maintain consistent product quality. Preventive maintenance is an important approach in modern maintenance management systems, especially in industries that are highly dependent on the reliability of production machinery. FMEA is a methodology used to evaluate failures that occur in a system, design, process, or service. Potential failures are identified by assigning a value or score to each failure mode based on the occurrence, severity, and detection rates (Stamatis, 1995). FMEA is used to evaluate every possible failure from the early stages so that risks can be controlled before they cause greater losses. This method helps companies identify critical points in the production process and determine areas that require special attention. In the context of machine maintenance, FMEA is very useful for identifying components that are prone to damage and developing more effective and targeted maintenance strategies. Risk assessment is carried out using three main parameters, namely severity, occurrence, and detection. Severity (S) indicates the level of severity of the impact caused if a failure occurs, whether on the production process, safety, or product quality. Occurrence (O) describes the level of possibility or frequency of such failures occurring within a certain period. Detection (D) indicates the ability of existing systems or procedures to detect failures before their impact is felt directly. These three parameters are usually assessed using a numerical scale of 1 to 10, where a higher value indicates a greater level of risk. The assessment of these three aspects forms the basis for determining the priority level of a failure.

Risk Priority Number (RPN) is a quantitative indicator used in the FMEA method to determine the priority level of risk management. The RPN value is obtained from the multiplication of severity (S), occurrence (O), and detection (D), namely $RPN = S \times O \times D$. The higher the RPN value, the greater the risk of failure and the more urgent it is to address the failure immediately. According to Stamatis (1995), RPN serves as a decision-making tool in determining the priority order of improvements and the allocation of maintenance resources. By using RPN values, companies can focus improvement actions on failures that have the most significant impact on the performance and reliability of production systems.

3. Research Methods

The object of this study is knitting machines used in small and medium-scale textile industries. These machines were chosen because they play an important role in the production process and have the potential for damage that can affect operational smoothness, product quality, and company productivity.

Data collection in this study was conducted using several techniques to obtain complete and accurate information. The techniques used included:

a. Direct observation of the condition of knitting machines and production process activities to determine the actual conditions in the field.
b. Interviews with machine operators and technicians to obtain information related to the types of damage, causes, and repair actions that are commonly performed.
c. Collection of historical data on machine damage as a basis for analyzing the frequency and patterns of failure.

FMEA analysis is conducted in a step-by-step and systematic manner to identify and prioritize the risk of failure in knitting machines. The stages of analysis include:

a. Identification of work processes and key components in knitting machines.
b. Identification of potential failure modes for each component.
c. Determination of the effect and cause of each failure.
d. Assessment of the Severity (S), Occurrence (O), and Detection (D) values for each failure mode.
e. Calculating the Risk Priority Number (RPN) value as the product of S × O × D.
f. Determining risk priority based on the highest RPN value
g. Preparing improvement proposals based on preventive maintenance as an effort to reduce the risk of failure.

The assessment of Severity, Occurrence, and Detection parameters in this study uses a scale of 1 to 10. The scale is grouped to facilitate the interpretation of risk levels, namely:

a. A score of 1–3 indicates a low risk level, which means that the impact or possibility of failure is relatively small
b. Values 4–6 indicate a moderate level of risk, which requires attention and control so that it does not develop into something more serious.
c. Values 7–10 indicate a high level of risk, which needs to be a top priority in planning corrective actions and preventive maintenance.

4. Results and Discussion

The results of identifying failure modes that occur in knitting machines based on observations, interviews, and maintenance data. This identification aims to determine the types of failures that frequently occur, along with their causes and impacts on the production process. This stage forms the basis for applying the Failure Mode and Effects Analysis (FMEA) method to determine the level of risk and priority for repairs. The identification of knitting machine failure modes is shown in Table 1.

Table 1. Identification of Knitting Machine Failure Modes

No.	Failure Mode	Causes	Impact on Production
1	Frequent yarn breakage	Unstable tension, poor yarn quality	Production stops, fabric defects
2	Worn/broken knitting needle	Long service life, high friction	Defective knitted output, machine downtime
3	Unstable yarn tension	Incorrect settings, dirty sensors	Inconsistent knitting quality
4	Machine jamming often	Dirt buildup, insufficient lubrication	Production process stops
5	Insufficient lubrication	No lubrication schedule	Increased component wear
6	Motor overheating	Overload, poor ventilation	Risk of motor failure
7	Excessive machine vibration	Loose bolts, poor balance	Component damage and increased noise

Based on the table above, most knitting machine failures are related to a lack of routine maintenance, especially in terms of lubrication, adjustment, and machine cleanliness. These failures have a direct impact on the interruption of the production process, a decline in the quality of knitting results, and an increased potential for damage to machine components.

After the failure mode has been identified, the next step is to perform an FMEA analysis to determine the level of risk for each failure. The assessment is carried out by determining the Severity (S), Occurrence (O), and Detection (D) values based on the severity of the impact, frequency of occurrence, and ability to detect failures before they cause an impact. The RPN value is obtained from the product of S × O × D and is used as the basis for determining risk priority. The FMEA for knitting machines is shown in Table 2.

Table 2. Knitting Machine FMEA

Process	Failure Mode	Effect	Cause	S	O	D	RPN
Yarn system	Frequent yarn breakage	Production stops, fabric defects	Unstable tension	7	7	5	245
Knitting needle	Needle wear/breakage	Defective product	Long service life	8	6	5	240

Tension control unit	Unstable thread tension	Reduced product quality	Non-standard setting	6	6	6	216
Machine mechanism	Machine jamming	High downtime	Dirt buildup, lack of oil	8	5	6	240
Lubrication system	Insufficient lubrication	Rapid component wear	No routine lubrication schedule	7	6	7	294
Drive motor	Motor overheating	Machine stops	Overloading	9	4	6	216
Machine structure	Excessive vibration	Secondary damage	Loose bolts	6	5	5	150

The FMEA analysis results show that the Risk Priority Number (RPN) value for knitting machines is in the range of 150–294, which indicates a medium to high level of risk. The highest RPN value was found in the insufficient lubrication failure mode with a value of 294, which is the result of multiplying Severity = 7, Occurrence = 6, and Detection = 7. The magnitude of the Risk Priority Number (RPN) value in lubrication failure is mainly influenced by the high Detection value (D = 7). This value indicates that failures due to inadequate lubrication are relatively difficult to identify at an early stage, so that the component wear process occurs gradually without clear indications. Within the FMEA theory framework, a high detection value indicates a low ability of the maintenance system to detect potential failures, which generally occurs in small to medium-sized industries that have not implemented a machine condition monitoring system or condition-based maintenance.

Conversely, the mode of excessive machine vibration failure produced the lowest RPN value, namely 150, even though the occurrence rate was quite frequent with an Occurrence value of 5. This condition was caused by relatively lower Severity and Detection values, because the symptoms of excessive vibration can be easily recognized by operators through sound indicators and visual observation. Thus, corrective actions can be taken more quickly before the failure develops into more serious damage.

Comparison of Risks Between Failure Modes

Based on the FMEA calculation results, there are four failure modes that have a Risk Priority Number (RPN) value above 240, namely insufficient lubrication (RPN = 294), frequent thread breakage (RPN = 245), worn or broken knitting needles (RPN = 240), and frequent machine jamming (RPN = 240) . The high RPN values for these four failures indicate a combination of significant impact severity, relatively high occurrence frequency, and limited detection capabilities. In FMEA literature, RPN values exceeding 200 are generally categorized as critical risks that need to be prioritized for improvement because they have the potential to cause increased production downtime and high maintenance costs. Conversely, the failure mode of the heat engine, despite having a high severity level with a Severity value of 9, resulted in a lower RPN value of 216 due to its low occurrence rate with an Occurrence value of 4. This finding shows that the magnitude of the impact of failure does not automatically determine the level of risk priority, but is greatly influenced by the frequency of failure and the effectiveness of the detection system, as explained in the basic principles of the FMEA method.

Analysis of the Causes of High RPN Values Based on the Maintenance System

The high Risk Priority Number (RPN) values for most failure modes indicate that the knitting machine maintenance approach applied is still oriented towards corrective maintenance. Conceptually, corrective maintenance patterns tend to result in high Occurrence and Detection values, because failures are only addressed after operational disruptions occur, allowing potential damage to develop without early control. For example, in the mode of frequent thread breakage, an Occurrence value of 7 indicates a relatively frequent occurrence in a production cycle. This condition is closely related to the absence of thread tension standards and the lack of periodic inspections, which cause uncontrolled process variations. In maintenance management theory, high process variation contributes to an increased probability of failure while reducing product quality consistency. In addition, a fairly high Detection value ($D \geq 5$) in the majority of failure modes reflects a weak early detection system for potential damage. This indicates that the company has not implemented supporting mechanisms such as damage history records, inspection checklists, or machine condition indicators. Based on maintenance literature, these conditions are common characteristics in small-to-medium industries that still rely on operator experience without the support of structured standard operating procedures.

The Implications of RPN Values on Productivity and Quality

Failure modes with high RPN values have a direct impact on increased production downtime, as incidents such as machine jams and broken threads cause the production process to stop temporarily and reduce daily output. In addition, failures in knitting needles and thread tension instability increase the number of defective products, thereby increasing rework and scrap costs. Therefore, a high RPN value can be used as a quantitative indicator of low machine maintenance system effectiveness.

Analysis of the Effectiveness of Preventive Maintenance as a Solution

Based on the determined risk priorities, preventive maintenance-based corrective action proposals were developed to reduce the likelihood of failure and mitigate the impact. The preventive maintenance corrective proposals are listed in Table 3.

Table 3. Proposed improvements to preventive maintenance

Failure Mode	RPN	Preventive Maintenance Action	Improvement Impact
Insufficient lubrication	294	Routine lubrication schedule and daily checklist	Reduces wear, extends machine lifespan
Frequent yarn breakage	245	Inspect yarn tension and yarn quality	Ensures more stable production
Needle wear/breakage	240	Periodic needle replacement	Reduces defect rate on knitted products

Machine jamming	240	Regular cleaning and component inspection	Minimizes downtime
Unstable thread tension	216	Standardize machine tension settings	Improves knitting quality consistency
Motor overheating	216	Check motor load and temperature	Prevents motor damage and operational stops
Excessive vibration	150	Tighten bolts and balance rotating components	Increases operational stability

Proposals for preventive maintenance focused on failure modes with the highest RPN will theoretically significantly reduce the Occurrence and Detection values. For example, the implementation of a routine lubrication schedule is estimated to reduce the Occurrence value from 6 to 3, and Detection from 7 to 3, thereby reducing the lubrication RPN value from 294 to 63.

This decrease in RPN indicates that preventive maintenance has a direct impact on controlling the risk of machine failure. This is in line with maintenance management theory, which states that preventive maintenance can shift the pattern of damage from sudden to planned, thereby increasing machine reliability and production stability.

5. Conclusion

Based on the results of data processing and analysis, it can be seen that the high rate of knitting machine damage in small and medium-sized textile industries is mainly influenced by the suboptimal machine maintenance system. The main problems found are inconsistent lubrication, improper tension settings, and unmonitored component wear. The application of the Failure Mode and Effects Analysis (FMEA) method provides a clear picture of various potential failures, the causes of damage, and the level of risk for each failure through the determination of the Risk Priority Number (RPN) value. The findings of this study are consistent with the results of Özyazgan and Engin (2013), which state that the main source of failure in the knitting process stems from the condition and settings of the knitting machine. The study identified that mechanical disturbances, machine setting errors, and component damage have a relatively high level of risk. The similarity of these results shows that knitting machines are a critical element that greatly affects the smoothness of the production process and the quality of the knitting results. The main difference between this study and previous studies lies in the focus of the analysis. Previous studies emphasized the identification of product defects as the end result of the production process, while this study focused on evaluating the machine maintenance system as a factor causing failure. In addition, the recommendations for improvement in previous studies were still general in nature and did not focus on the implementation of a systematic machine maintenance program.

As a development of previous research, this study utilizes the results of FMEA analysis as a basis for formulating a preventive maintenance program. A structured preventive maintenance approach has been proven to reduce the potential for machine damage, minimize production downtime, extend equipment life, and maintain stable production quality. The combination of the FMEA method and preventive maintenance can be used as a sustainable strategy to improve the effectiveness of knitting machine maintenance management in small and medium-scale textile industries.

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