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Analysis of Process Quality in the Weaving Section Using Failure Mode and Effect Analysis and Fault Tree Analysis: A Case Study of PT XYZ

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ABSTRAK

Penelitian ini bertujuan untuk mengetahui penyebab utama cacat benang loncat (lusi loncat) dalam produksi kain abu-abu di PT XYZ menggunakan *Failure Mode and Effect Analysis (FMEA)* dan *Fault Tree Analysis (FTA)*. Analisis ini mengidentifikasi 2 (dua) penyebab utama, yaitu penurunan kinerja mesin dan kelelahan operator. Hasil FMEA menunjukkan bahwa faktor-faktor ini berkontribusi signifikan terhadap cacat produk, dengan kinerja mesin menunjukkan Angka Prioritas Risiko (RPN) tertinggi. Penelitian ini menunjukkan bahwa perawatan mesin rutin dan peningkatan manajemen tenaga kerja melalui pelatihan dan pengawasan yang lebih ketat sangat penting untuk mengurangi cacat dan meningkatkan efisiensi operasional.

Kata Kunci: Benang loncat, *Failure Mode and Effect Analysis (FMEA)*, *Fault Tree Analysis (FTA)*

ABSTRACT

This study aims to determine the main causes of warp-jump defects in gray fabric production at PT XYZ using Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). This analysis identified two main causes: decreased machine performance and operator fatigue. The FMEA results indicate that these factors contribute significantly to product defects, with machine performance having the highest Risk Priority Number (RPN). This study suggests that routine machine maintenance and improved workforce management through closer training and supervision are crucial to reducing defects and increasing operational efficiency.

Keywords: Skip yarn, *Failure Mode and Effect Analysis (FMEA)*, *Fault Tree Analysis (FTA)*

INTRODUCTION

The textile and textile products (TPT) industry has long been a strategic sector contributing significantly to Indonesia's national economy. According to the Ministry of Industry in 2023, the export value of Indonesia's TPT industry reached USD 13.28 billion in 2022, highlighting its role as one of the key drivers of economic growth (Yun & Kurniawan, 2023). However, increasing global competition requires textile companies to continuously improve their competitiveness by enhancing product quality, optimizing production efficiency, and adapting to advanced technologies. In this context, product quality serves as a critical determinant in securing market competitiveness. High-quality products not only meet established standards but also increase customer satisfaction, strengthen a company's reputation, and foster consumer loyalty (Fithri et al., 2018).

Maintaining product quality in the textile industry, however, presents significant challenges due to the complexity of production processes (Yun, 2020). This is particularly true during critical stages such as the weaving process, which plays a crucial role in defining the characteristics of the final product. PT XYZ, a leading textile company in Indonesia located in West Java, Indonesia, faces similar challenges. The company produces greige fabric a raw textile material used as the base for subsequent dyeing and finishing processes. The quality of greige fabric is essential in ensuring the success of later stages and enhancing the value of the final product.

The weaving process at PT XYZ involves several critical steps, including warp let-off motion, shedding motion, weft insertion, beating-up motion, and fabric take-up motion. Despite its importance, this process is prone to various technical issues that may result in defective products. Defects such as uneven yarn tension, inconsistent fiber distribution, visible marks on the fabric, and irregular weave structures have been observed. According to interviews with company representatives, the defect rate during the weaving stage often exceeds the company's maximum acceptable threshold of 2%. This not only increases production costs but also reduces operational efficiency and product quality.

To address these challenges, PT XYZ has implemented various quality control measures, such as raw material inspections, regular machine maintenance, and final product evaluations. However, these efforts have not been sufficient to reduce the defect rate to the desired level, indicating a need for more systematic approaches to identifying the root causes of failures and developing effective solutions. Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) are widely recognized methodologies for addressing quality issues in production processes (Pascu et al., 2020). FMEA systematically identifies potential failure modes at each production stage, evaluates their impact, and prioritizes corrective actions based on the Risk Priority Number (RPN) (Rusandi & Sulistiyowati, 2019). On the other hand, FTA provides a deeper understanding of the cause-and-effect relationships of identified failures, enabling a more comprehensive decision-making process. Previous studies have demonstrated the effectiveness of FMEA in identifying critical failure points and prioritizing mitigation measures (Hanum, 2022). However, other studies have highlighted limitations in its effectiveness when there is insufficient data or when proposed solutions are not consistently implemented (Chuenyindee & Prasetyo, 2020).

This study aims to address the need for an integrated and comprehensive approach to improving production quality in the weaving stage at PT XYZ. By combining FMEA and FTA methodologies, this research not only identifies specific types of defects and their root causes but also evaluates the effectiveness of proposed corrective actions in reducing the defect rate. The ultimate goal is to lower the defect rate to below 2%, aligning with the company's quality standards and reducing production losses. The novelty of this study lies in its integration of FMEA and FTA methodologies tailored specifically to address quality issues in the weaving process of the textile industry. Unlike previous studies that often employed these methods independently, this research combines them to provide a more holistic and actionable analysis. Furthermore, the study evaluates the implementation of proposed solutions in real-world settings, ensuring their practical applicability and effectiveness. By doing so, this research not only contributes theoretically to advancing quality management methodologies but also offers practical insights for improving operational efficiency and competitiveness in the textile industry, particularly in Indonesia.

METHODS

This research is a case study aimed at analyzing quality control in the weaving process at PT XYZ, located at West Java, Indonesia. The primary focus of the study is to identify the root causes of defects in the greige fabric produced during the weaving stage and provide solutions based on Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) (Östlund et al., 2011). The research population includes all operational processes within the weaving department, with primary data collected through in-depth interviews with the Head of Operations and document analysis of production defect data. The sample was selected purposively, specifically focusing on the defects found in the greige fabric produced during the weaving stage, chosen due to its critical role in determining the final fabric quality and its significantly higher defect rate compared to other stages.

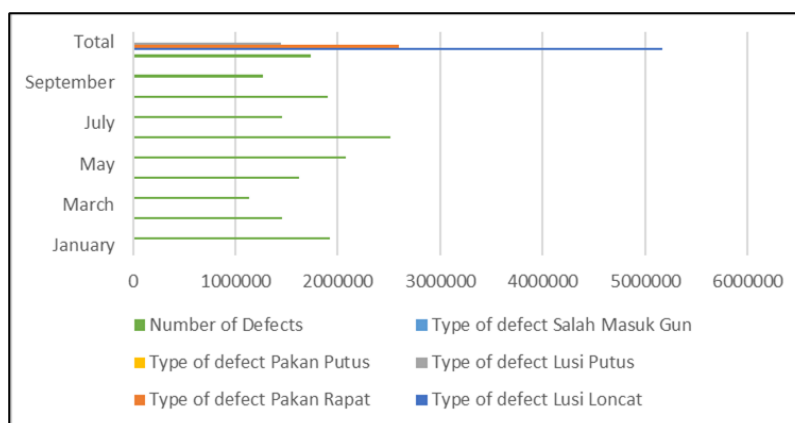
Data was collected using a combination of qualitative and quantitative methods. Qualitative methods involved direct observation of the production process, structured interviews with management, and the collection of internal company documents (Proudfoot, 2023). Meanwhile, the quantitative approach was employed by analyzing historical defect data from the weaving stage, which included various types of defects such as uneven thread tension, thread breakage, pattern errors, and inconsistencies in thread density (Venkatesh et al., 2013). The analysis stages in this study included identifying the types and frequencies of defects by categorizing them based on historical data and observations, and calculating their frequencies to understand dominant patterns (Aprila et al., 2023). A Root Cause Analysis was then conducted using the FMEA method to identify critical failure points, calculate the Risk Priority Number (RPN) for each failure, and prioritize the most significant risks for

improvement. Causal relationship mapping was carried out using the FTA method to analyze the logical relationships between causes and effects of defects and to understand the systemic factors influencing the quality of the greige fabric. Based on the FMEA and FTA analyses, corrective solutions were developed, including improvements in operational procedures, enhanced raw material quality control, and optimization of weaving machine performance (Andriansyah & Sulistyowati, 2021).

This study also employed data triangulation to ensure the validity and reliability of the analysis results. Data from interviews, observations, and company documents were compared and verified to eliminate potential bias. All results were systematically analyzed to generate practical and evidence-based recommendations aimed at improving the quality of greige fabric production in a sustainable manner. The findings of this research are expected to contribute significantly to reducing defects at the weaving stage, improving production efficiency, and providing added value to PT XYZ in achieving the desired quality standards.

RESULT

This study presents data collected through observations and direct interviews, identifying five types of defects in the weaving process for grey fabric production at PT XYZ. These defects include Lusi Loncat, Pakan Rapat, Lusi Putus, Pakan Putus, and Salah Masuk Gun. Throughout the period from January to October, Pakan Rapat was the most predominant defect, particularly in May, June, July, and September, with the highest occurrences recorded in June (975) and July (2,108). Lusi Putus also exhibited significant frequencies, although the occurrence varied across months. In contrast, Salah Masuk Gun and Lusi Loncat occurred less frequently, contributing minimally to the overall defect count. Overall, defects recorded during this period totaled 7,059,008.69 kg, with Pakan Rapat accounting for the largest share, totaling 2,598,902 defects, followed by Lusi Putus with 1,441,041 defects.



source: processed data

Figure 1
Defect type data in the weaving process stage

From a theoretical standpoint, the importance of Quality Control (QC) in production management is evident. Effective quality control during the weaving process is critical to minimizing defects and improving production efficiency. In this context, Total Quality Management (TQM) theory is particularly relevant. TQM emphasizes the application of quality principles throughout all stages of production to reduce defect rates. It advocates for integrated and continuous quality control through gradual process improvements, with the ultimate goal of achieving customer satisfaction and minimizing waste. These concepts align with the findings of this study, where uncontrolled weaving processes lead to an increase in certain defects, especially Pakan Rapat.

Additionally, Failure Mode and Effect Analysis (FMEA) theory offers a systematic approach to identifying and analyzing potential defects within a process. FMEA is valuable for pinpointing issues at various stages of production, enabling companies to prioritize corrective actions for high-risk areas. Based on the findings of this study, defects related to Pakan Rapat, which occur frequently, should be further examined using FMEA to reduce the likelihood of recurring defects (Mulyana et al., 2022).

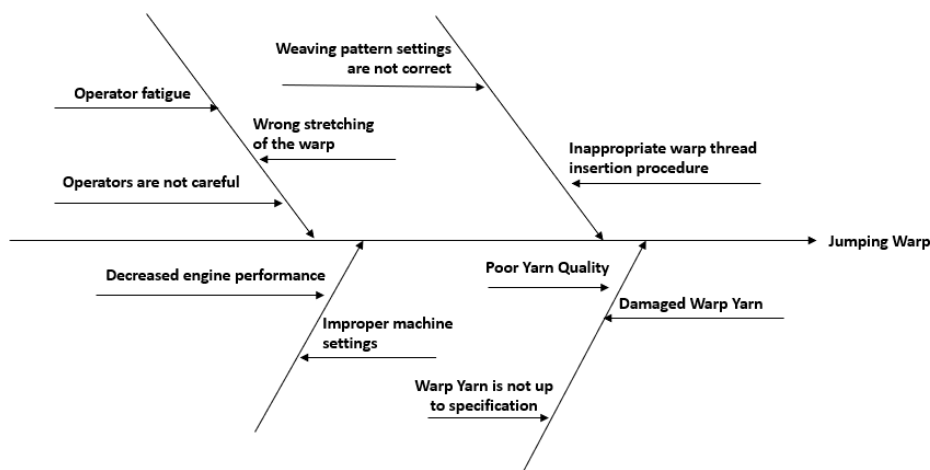
In terms of industry standards, this study aligns with ISO 9001, which outlines quality management system requirements for manufacturing companies, including those in the textile sector. ISO 9001 encourages strict quality control measures at each stage of production to ensure products are defect-free and meet established specifications (Neves et al., 2024). As such, PT XYZ must ensure that its weaving machines operate according to proper standards, that raw materials are of high quality, and that operators are adequately trained to minimize errors during production.

This study also corroborates previous research, which highlighted that Pakan Rapat is the most common defect in grey fabric production, often resulting from improperly adjusted machine tension settings (Mislán & Hardi Purba, 2020). Additionally, emphasized that close monitoring of the warp and weft yarn quality can significantly reduce defect frequencies (Novianti & Rochmoeljati, 2023). These findings are consistent with the results of this study, reinforcing the importance of quality control in preventing defects in the weaving process. Consequently, this study suggests that improvements in machine settings and comprehensive quality control systems are necessary to reduce defect rates in grey fabric production at PT XYZ.

The Fishbone diagram

The Fishbone diagram, also known as the cause-and-effect diagram, is a tool used to analyze and identify the various factors that contribute to product defects. This diagram helps uncover the root causes of quality issues that arise during the production process. The name "Fishbone" comes from the diagram's shape, which resembles a fish skeleton, with the "bones" representing the main categories of causes, and the "ribs" pointing to more specific factors that affect product quality (Li, 2024).

Each "main bone" in the diagram represents a broad category of potential causes, such as people, machines, methods, materials, or work environment. The branches extending from each category depict more detailed factors that, if not managed properly, can lead to defects in the product. With this visualization, production teams can easily map out the issues and take systematic corrective actions (Riptanti et al., 2023). The Fishbone diagram is often used after conducting a Pareto Chart analysis, which helps map out the most significant defects. Based on this data, the diagram helps identify the most critical root causes, enabling companies to prioritize improvements in areas that have the greatest impact on product quality. This approach offers a comprehensive view of how various factors interact, making the applied solutions more targeted and effective.



source: processed data

Figure 2
The Fishbone diagram

Based on the Fishbone diagram, the defect Lusi Loncat in the grey fabric production process at PT XYZ is influenced by four main factors: human, material, machine, and method. The human factor is related to operator errors, such as improper yarn tension adjustments or insufficient training, which can lead to uneven movement of the warp yarn during the weaving process. The material factor concerns the quality of the yarn used. Poor-quality yarn, such as weak or inconsistent thickness, can cause uneven

tension, leading to the warp yarn jumping. The machine factor refers to the condition and calibration of the weaving machines. Malfunctioning machines or inaccurate tension settings can disrupt the smooth movement of the yarn, resulting in Lusi Loncat defects. Lastly, the method factor pertains to the procedures followed during production. Inconsistent or improper machine settings and weaving techniques can increase the occurrence of defects. By addressing these four factors, PT XYZ can reduce Lusi Loncat defects and improve overall product quality.

Table 1
Failure Mode and Effect Analysis (FMEA) Results

Failures	Factor	Failure Mode	Case	Impact	S	O	D	RP N	Improvement Measures
Lusi Loncat	Man	Operator Fatigue	Long working hours, less rest	Decreased work consistency	8	7	6	336	Balanced scheduling and adequate rest
		Wrinkling of the Lusi	Lack of training	Thread tangling or skipping	8	5	6	240	Train and teach operators about stretching the warp, use assistive devices
		Operator is not thorough	Lack of training	Fabric defects, low efficiency	6	5	5	150	Provide regular training and increase supervision
	Method	Improper Weaving Pattern Setting	Human error in machine settings	Fabric pattern is not suitable	9	4	6	216	Conduct initial inspection of weaving patterns before production begins
		Non-conformance of Warp Thread Insertion Procedure	Operators do not follow SOPs	Loose warp threads	7	6	6	252	Socialize the SOP for warp insertion, post the procedure diagram near the machine.
		Machine	Decreased Engine Performance	The machine is rarely serviced	The machine does not work optimally and weaving results are inconsistent	9	7	6	378
Improper Engine Settings	Operator is wrong in setting		Unstable warp threads	8	5	6	240	Create a machine manual	
Material	Sticky Warp Yarn	Room conditions are too humid	The warp sticks together	7	5	7	245	Control room humidity, use threads with nonstick coatings	
	Brittle Warp Yarn	Low thread quality	Thread breaks frequently	9	5	6	270	Use quality yarn, do yarn quality testing before production	

source: processed data

Based on the failure analysis conducted using the Failure Mode and Effect Analysis (FMEA) method, the failure mode with the highest Risk Priority Number (RPN) is "Decreased Machine Performance", with an RPN value of 378. The primary cause of this failure is the lack of regular maintenance on the weaving machines, which results in suboptimal machine performance, inconsistent

fabric quality, and reduced productivity. The impact of this failure is significant, as it not only decreases operational efficiency but also compromises the final product quality, such as grey fabric, which may diminish the company's competitiveness in the market.

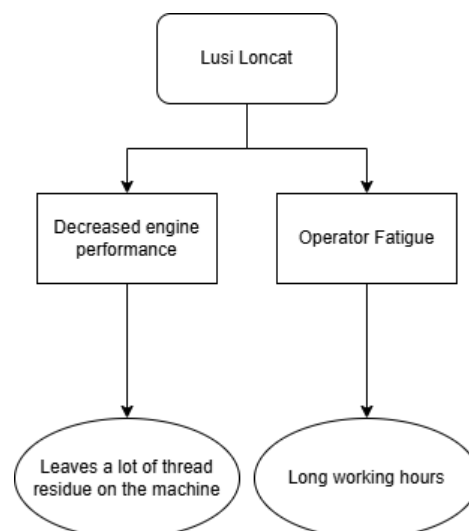
To address this issue, it is crucial for the company to implement routine machine maintenance by establishing a structured and scheduled service plan. Consistent preventive maintenance will ensure that machines operate optimally, reduce the risk of unexpected failures, and minimize downtime that disrupts the production process. Given the substantial impact of decreased machine performance on both productivity and quality, addressing this issue should be a top priority to minimize defects, improve output, and maintain smooth production operations.

This approach is in line with the Total Productive Maintenance (TPM) theory, which emphasizes the importance of structured maintenance and the involvement of the entire workforce to achieve optimal machine performance and reduce machine-related losses (Maynard & Zandin, 2001). Furthermore, regular preventive maintenance is supported by fundamental principles of production management, which argue that proper maintenance can prevent unforeseen breakdowns, reduce repair costs, and enhance operational efficiency (Tortorella et al., 2021). These findings are consistent with prior studies, which highlight that inadequate maintenance leads to machine failures, resulting in increased product defects and operational losses (Fithri et al., 2023).

The implications of this study suggest that implementing scheduled machine maintenance can improve machine performance and reduce production defects while optimizing both efficiency and quality. The results are not only applicable to PT XYZ but also offer valuable insights for the broader textile industry in better managing machines and production processes. Additionally, the findings support regulatory guidelines set by the Ministry of Industry of the Republic of Indonesia, which mandate manufacturing companies to comply with machine maintenance standards to ensure product quality and productivity, as outlined in Regulation of the Minister of Industry No. 16/2019.

Fault Tree Analysis (FTA)

Based on the analysis conducted using Failure Mode and Effect Analysis (FMEA) with Risk Priority Number (RPN) and Pareto Diagram, two primary factors were identified as the top-level events causing the defect of skip yarn (lusi loncat): decreased machine performance and operator fatigue. These factors play a critical role in the occurrence of the defect, making it imperative to take immediate corrective actions. The Fault Tree Analysis (FTA) derived from this analysis provides a deeper understanding of the relationship between these contributing factors, as shown in Figure 3: Fault Tree Analysis for the defect of skip yarn (lusi loncat).



source: processed data

Figure 3
Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) plays a crucial role in identifying the root causes of the skip yarn (lusi loncat) issue in the production of grey fabric. By examining key factors such as inadequate machine maintenance and inefficient workforce management, the company can pinpoint the core problems that need rectification. To mitigate the risk of skip yarn, it is essential for the company to enhance its routine machine maintenance to ensure that the machines remain in optimal condition, preventing disruptions to the production process. Furthermore, improving workforce management by providing proper training and implementing stricter supervision is critical in minimizing human errors that contribute to the occurrence of skip yarn defects. Establishing clear work procedures and a well-defined task allocation system can also reduce the likelihood of mistakes, which are a common source of defects. By investing in better machine maintenance practices and more efficient workforce management, the company can significantly improve the quality of its grey fabric and minimize the incidence of skip yarn defects.

This approach aligns with the principles of Total Productive Maintenance (TPM), which emphasizes the need for proactive machine care to prevent breakdowns and improve overall equipment effectiveness (Maynard & Zandin, 2001). Additionally, effective workforce management, as supported by Lean Manufacturing principles, stresses the importance of eliminating inefficiencies and ensuring optimal human resource utilization to enhance product quality and process efficiency (Tortorella et al., 2021). Prior studies, also highlight the significant impact of machine maintenance and workforce optimization on reducing defects and enhancing operational performance. Their findings suggest that inadequate maintenance and insufficient operator training are key factors leading to defects like skip yarn (Romadhoni & Dahdah, 2024).

The implications of this research suggest that improving both machine maintenance and workforce management are fundamental to enhancing product quality and operational efficiency. This study not only provides practical recommendations for PT XYZ but also offers valuable insights for the broader textile industry in managing machine performance and workforce capabilities. Moreover, this aligns with the regulatory standards set forth by the Ministry of Industry of the Republic of Indonesia, which mandates compliance with proper machine maintenance and workforce management practices to ensure the production of high-quality products. According to the Regulation of the Minister of Industry No. 16/2019, companies are required to adopt preventive maintenance practices and ensure optimal human resource management to reduce defects and increase productivity.

CONCLUSION

This study reveals that decreased machine performance and operator fatigue are the two primary factors contributing to the skip yarn (lusi loncat) defect in the production of grey fabric. Based on the analysis using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA), regular machine maintenance and more efficient workforce management are essential for reducing the occurrence of this defect. Improvements in machine maintenance, as well as better training and supervision of operators, can significantly enhance product quality and operational efficiency, ultimately improving the company's competitiveness in the global market.

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