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# Enhancing reliability in garment manufacturing through FMEA and FTA

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***Keywords:*** Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), clothing production, manufacturing processes, product defects.

***Abstract:*** This study employs Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) to comprehensively investigate product defects in Biyan Konveksi's manufacturing processes, one of the growing SMEs producing clothing pieces. Analyzing critical failure modes, including tear failures, stitching irregularities, sizing discrepancies, and ribbon imperfections, the research employs FTA to trace root causes, revealing the interconnected nature of these failures. The initial defect percentage, attributed to human, machine, material, and environmental factors, stood above 3%, with culottes experiencing the highest defect percentage at 3.95%. After the company implemented the enhancement measures, the defect percentage dropped significantly, reaching a range of 1 to 1.25%. Subsequently, targeted enhancement strategies are proposed, encompassing the implementation of additional worker rest breaks to alleviate fatigue, comprehensive training for new staff, and stringent machine maintenance protocols. These interventions aim to curtail tear failures, refine stitching precision, rectify sizing errors, and enhance ribbon placement. Anticipated to yield a substantial reduction in overall defect percentages, the suggested improvements position Biyan Konveksi for sustained excellence, emphasizing proactive measures to enhance worker performance and optimize manufacturing processes. The study underscores the significance of a systematic approach, combining FMEA and FTA, in diagnosing and rectifying complex failure scenarios within manufacturing environments, offering practical implications for companies aiming to fortify their competitive edge in the market.

## 1 Introduction

The consumptive landscape of ready-made clothing in Indonesia is undergoing a positive developmental trend, showcasing the pivotal role played by the textile and fashion industry in the nation's economic growth, poverty alleviation, and job creation. In 2019, this sector demonstrated an outstanding performance, registering a growth rate of 15.35% [1], solidifying its position as one of Indonesia's top 10 commodities. Moreover, it has emerged as a fundamental element in the 2015-2035 National Industrial Development Master Plan (RIPIN), strategically aligned with the objectives outlined in the Indonesia 4.0 roadmap [2]. The ready-made clothing industry significantly contributes to the Gross Domestic Product (GDP), amounting to Rp139.33 trillion in 2022 at constant prices [3], this reflects a noteworthy 9.34% increase compared to the preceding year's figure of Rp127.43 trillion. The impetus behind this growth can be attributed to the burgeoning middle class in Indonesia, propelling a surge in demand for affordable and locally produced clothing, particularly in the women's apparel segment, anticipated to reach a market volume of US$10.25 million by 2023 [3].

The growth of the ready-made clothing industry in Indonesia propels the development of Small and Medium Enterprises (SMEs) in this sector. A notable example is Biyan Konveksi, located in Cirebon, West Java, producing various women's products such as culottes, pleated skirts, and baggy pants using raw materials like thread, fabric, and ribbed rubber obtained from suppliers. However, heightened consumer demand and intense regional competition have led to an increase in final products that deviate from the intended specifications. Manufacturing defects exist when the product comes off the production line in a condition different from what the manufacture intended [4]. The average defect rate exceeded 3% from May 2021 to April 2022, marking an increase from less than 2% in the preceding year.

Defects ranging from color disparities, material cutting errors, tears, uneven stitching, poorly applied ribbed rubber, weak stitching, to stains necessitate rework, adding to the production time for workers. Failures can lead to unmet production targets and discrepancies in the quality grade of products, thereby reducing profits for Biyan Konveksi. Although some defective products can be rectified through rework, the existence of defects resulting from rework imposes additional costs on the company [5]. These failures can lead to unmet production targets, differences in the quality grade of products, reducing profits for the company, and undermining consumer trust.

In response to the challenges faced by Biyan Konveksi, the company must implement stringent quality control measures to minimize defective products, uphold existing quality standards, and enhance the overall quality of its products. This study employs the Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) methods, with the objective of identifying factors causing defects in clothing products at Biyan Konveksi and further provides improvement suggestions based on priority, aiming to mitigate the occurrence of defective products.

## 2 Literature review

Efficient optimization of the reliability analysis process requires the application of suitable quality control tools, as exemplified by Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) [6]. Both Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) emerge as widely accepted methodologies for conducting failure analyses, providing a means to scrutinize critical parameters in the analyzed processes.

Recognized as a reliability management technique, Failure Mode and Effects Analysis (FMEA) finds common usage across diverse industries to ensure the security and reliability of systems, services, and projects [7]. FMEA, operating as a bottom-up method, demands a considerable time investment, particularly in systems with intricate components and parts. Conversely, Fault Tree Analysis (FTA), a top-down method, dissects the top event into sub-events, creating a fault tree. This tree aids in identifying the least cut-set and least path set of the fault tree, crucial for reliability control. The FTA used in this study is to find out factors causing failures in the FMEA manufacturing process, namely at the phase of determining the cause of failure [8].

### *2.1 Failure Mode and Effects Analysis (FMEA)*

The industry faces challenges such as increasing quality demands from customers, the necessary cost optimization of products and processes, higher complexity, and product liability imposed by legislation. Therefore, the FMEA method is employed to proactively address the technical aspects of risk reduction. Unlike other reliability management tools, FMEA serves as a proactive method to prevent system failures, rather than an after-the-fact analysis method [9,10]. FMEA, originating in the United States Defense Department in 1949, was applied by the national aeronautics and space administration (NASA) for the Apollo plan to enhance system reliability in the 1960s [11]. A complete FMEA typically consists of four stages:

a. Identifying all known or potential failure modes of a system.
b. Confirming the causes and effects of each failure.
c. Ranking the recognized failure modes by their risk priority numbers (RPNs).
d. Taking remedial actions for higher-risk failures.

The smallest RPN value is better than the largest because the largest value indicates the severity of the risk of failure. Although FMEA is a useful and popular tool for safety and reliability analysis, it suffers from various shortcomings when used in practice [12].

### *2.2 Fault Tree Analysis (FTA)*

The second method for failure analysis is Fault Tree Analysis (FTA), a top-down method used to identify relationships between events, such as subsystem failures and their causes. The logic gates commonly used in the FTA manufacturing process include AND gates used when all input events occur and OR gates used when one of the input events occurs [13]. The commonly used logic gates in FTA are the (1) OR-gate, (2) AND-gate, and (3) inhibit or conditional gate. The commonly used event types in FTA include the (1) top or intermediate event, (2) basic event, (3) diamond or undeveloped event, and (4) conditional event [14].

Although Fault Tree Analysis (FTA) is a highly effective and widely-utilized method for dependability analysis across various systems, it has several limitations, such as an inability to model sequence- or time-dependent dynamic behavior and to conduct quantitative analysis with uncertain failure data [15]. Despite its advantages over Failure Mode and Effects Analysis (FMEA), particularly when analyzing complex systems, FTA's structured approach is most beneficial for new systems with limited field-based failure data. This structured and deductive reasoning process reduces reliance on the analyst's practical experience, adding rigor to the analysis compared to FMEA. However, combining FMEA and FTA methodologies can enhance the overall efficiency of failure analysis [16].

## 3 Methods

FTA provides a comprehensive breakdown of faults leading to the undesired top event, while FMEA furnishes the exact fashion in which these faults exist and their direct effects on the top event, making the combination suitable for safety and reliability analyses [17]. The integration of FMEA and FTA presents a promising approach to enhance reliability control, especially in the post-detail design phase [18]. By combining these methodologies, a more comprehensive and structured approach can be achieved, leveraging the strengths of both FMEA and FTA. This integrated approach enhances the ability to manage reliability effectively, providing a robust framework for ensuring product reliability throughout its lifecycle.

The study employs Fault Tree Analysis (FTA) with the aim of determining the root causes of failures in Biyan Konveksi's production by modeling them into a problem tree. Subsequently, the causes are identified using FMEA, aiming to determine variable values (failure impact level, failure cause level, and assessment capability of product or process control). The Risk Priority Number (RPN) is calculated using the values derived from the variables of severity, failure detection, and frequency, this computation highlights the relationship between these variables to identify risks that necessitate corrective action [19]. Further analysis is conducted using 5W+1H (What, Where, When, Why, Who, How) to provide recommendations to improve Biyan Konveksi's production.

## 4 Results and discussion

Data processing was conducted to analyze product defect-related data, employing tools and methods relevant to the identified issues. The utilization of Fault Tree Analysis (FTA) in conjunction with Failure Mode and Effect Analysis (FMEA) is pivotal in this research. FTA is employed to identify failure causes and discern prevalent defect types, aiding in pinpointing the root causes that may lead to product failure. The outcomes of the failure mode identification based on FTA are subsequently processed using the FMEA method to analyze each production process sequence contributing to errors. This facilitates the understanding of failure sources and the results of the FMEA identification are proposed as design improvements to address the current issues at Biyan Konveksi.

### *4.1 Identifying types of defects*

The initial step involves the identification of failure modes. Potential failure modes are outlined by detailing each production process stage, followed by data processing using a Pareto diagram. The Pareto diagram is instrumental in prioritizing defect data, emphasizing the most critical issues for immediate rectification based on the 80/20 principle, where 80% represents problems (mismatches) caused by triggers (causes) accounting for 20%. Figure 1 displays the Pareto diagram for each type of disability.

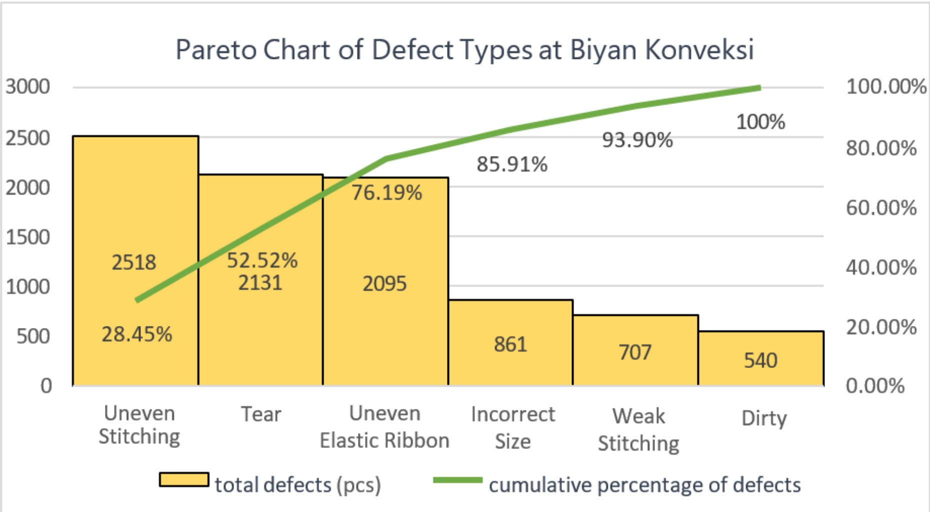


*Figure 1 Pareto chart of defect types at Biyan Konveksi*

Based on the Pareto diagram, dominant defects constituting the 80% principle include uneven stitching, tears, irregular ribbons, and incorrect sizing. The cumulative defect percentage depicted in the Pareto diagram highlights the most prevalent or recurring defects.

### *4.2 Identification of Defect Causes Using FTA*

The outcomes of the Pareto diagram are further analyzed using the Fault Tree Analysis (FTA) method, constructing a fault tree diagram for an in-depth examination towards other basic events. Logic gates are employed to determine the root causes of product failures at Biyan Konveksi. The identification of factors causing failure using fault tree analysis is illustrated in Figure 2 - Figure 6.

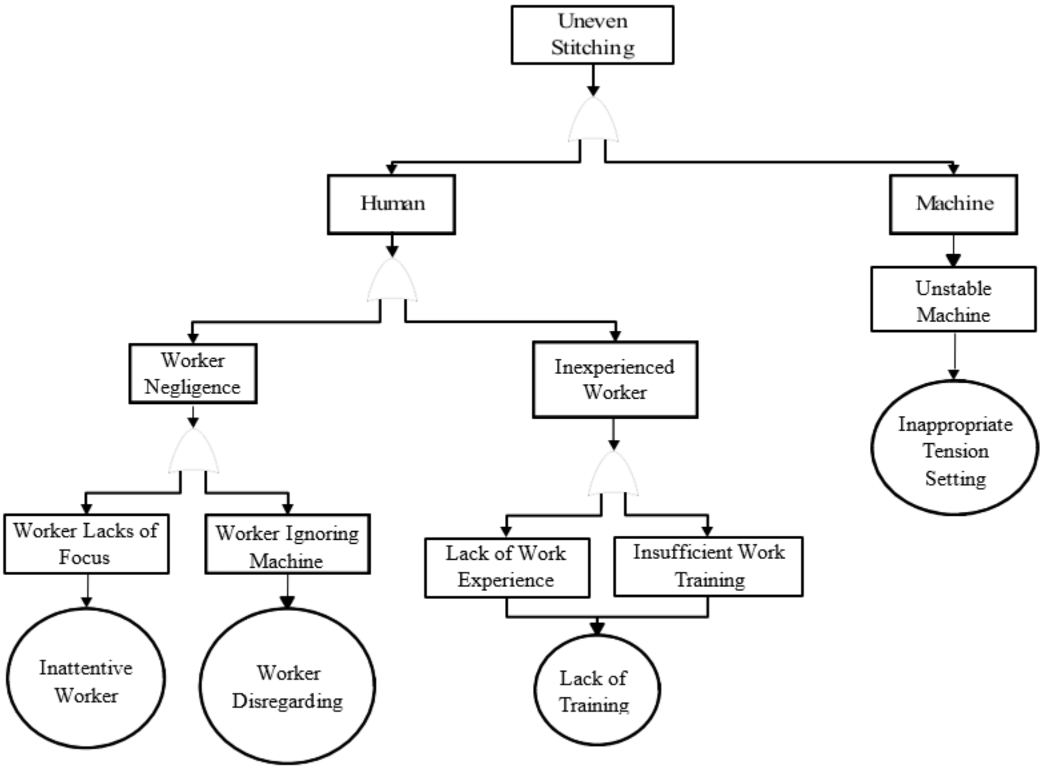


*Figure 2 FTA uneven stitching*

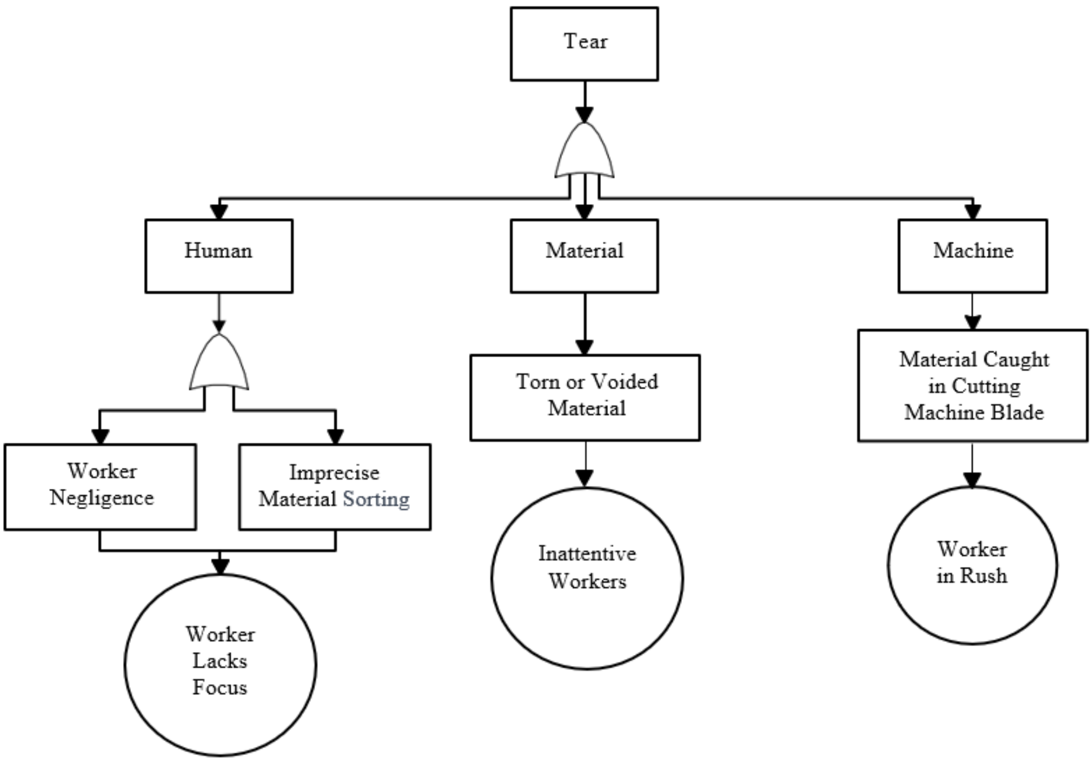


*Figure 3 FTA tear*

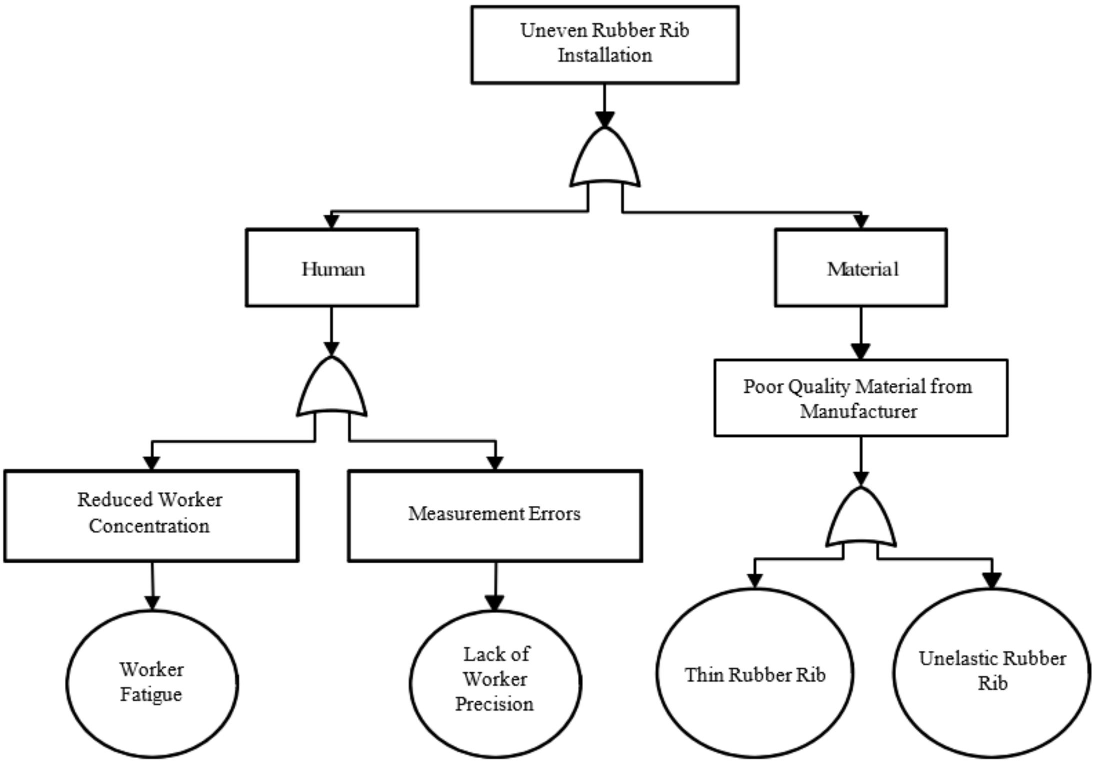


*Figure 4 FTA uneven rubber rib installation*

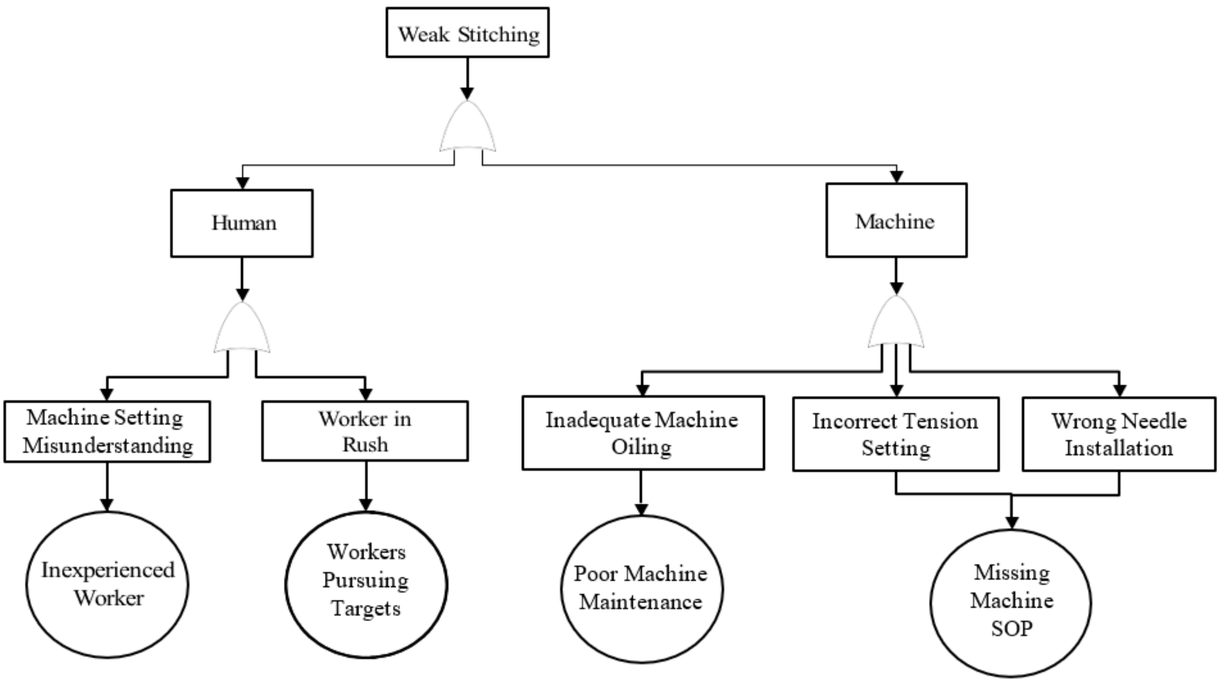


*Figure 5 FTA weak stitching*

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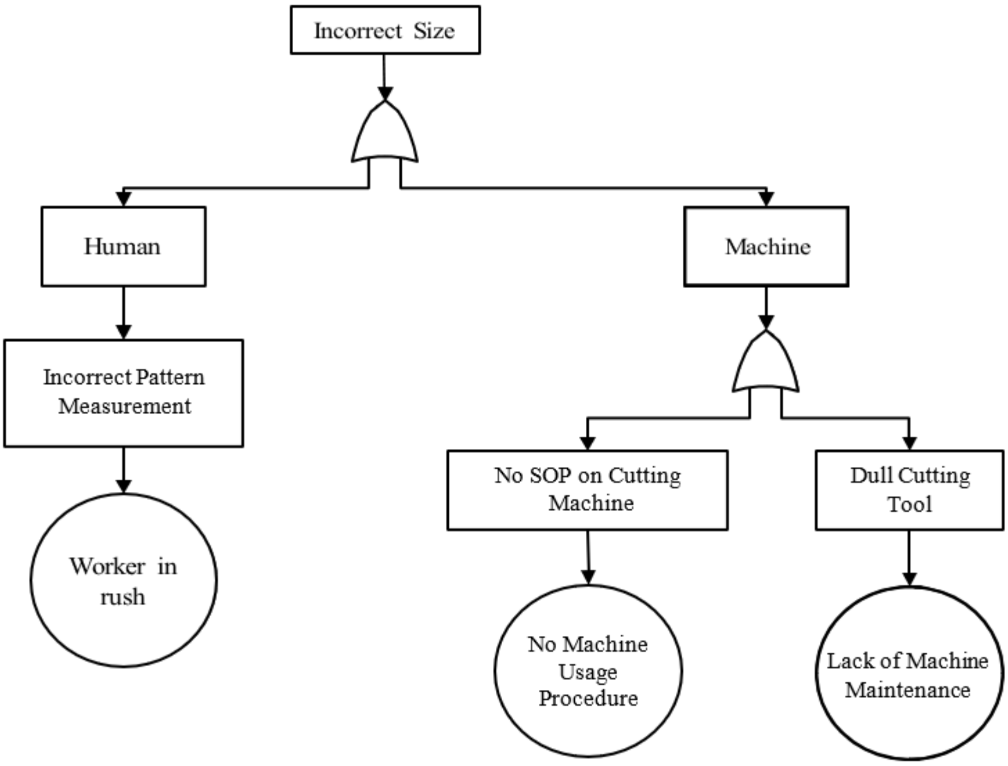


*Figure 6 FTA incorrect size*

### *4.3 Calculating RPN Values*

Risk Priority Number (RPN) is a priority risk value that aids in assessing the significance of various risks. It is based on the severity of the risk's effect, the likelihood of failure causes, and the speed of detection if a failure occurs. RPN values are calculated to determine the highest failure risk level for each failure mode. The RPN value is calculated by multiplying the severity, occurrence, and detection values derived from assessing the effect of failure and potential causes for each failure mode. The results are ranked by the magnitude of these products, prioritizing issues with the highest RPN values for risk reduction. Initially, three indicators—occurrence probability (O), severity (S), and detection probability (D)—are defined. Based on the scoring criteria (see Table 1), the relationship RPN = S × O × D is established. Values are assigned to S, O and D, then converted using the entropy weight method, followed by a consistency check [20]. Table 2 presents the top RPN value as a reference for enhancement.

*Tabel 1 Scoring standards of S, O, D*

| Severity | | Occurance | | Detection | |
|---|---|---|---|---|---|
| **Probability** | **Rating** | **Probability** | **Rating** | **Probability** | **Rating** |
| Extremely serious | 9–10 | High-risk factor, hardly be avoided | 9–10 | Extremely low | 10 |
| Very serious | 8 | High-risk factor, recurring | 7–8 | Very low | 7-9 |
| More serious | 7 | The risk factor is moderate, happens occasionally | 5–6 | Lower | 5-6 |
| General serious | 5-6 | The risk factor is low, rarely occurs | 3–4 | Higher | 3-4 |
| Relatively slight | 4 | The risk factor is extremely low, hardly occurs | 1–2 | Extremely high | 1-2 |
| Slight | 2-3 | | | | |
| No effect | 1 | | | | |

*Table 2 RPN values calculation using FMEA*

| *Potential Failure Mode* | *Potential Failure Effect* | *Severity (S)* | *Pontetial Causes* | *Occurrence (O)* | *Current Control* | *Detection (D)* | *Risk Priority Number (RPN)* | *Ranking* |
|---|---|---|---|---|---|---|---|---|
| Uneven stitching | Uneven stitching, rough stitching, stitching not straight | 6 | Worker negligence | 6 | Owner's supervision | 4 | 144 | 5 |
| | | | Worker ignores owner's instructions | | Worker receives reprimand | 3 | 108 | 8 |
| | | | Lack of training for workers | | Providing training to workers | 5 | 180 | 2 |
| | | | Incorrect tension setting | | Adjusting tension for each type of material | 2 | 72 | 12 |
| Tear | Voided products, loss of aesthetic elements, reduced product functionality | 8 | Worker lacks focus | 6 | Providing break time during production | 4 | 192 | 1 |
| | | | Worker's inattention in material sorting | | Worker receives reprimand | 3 | 144 | 5 |
| | | | Worker in rush | | Owner's supervision | 2 | 96 | 10 |
| Uneven elastic ribbon | Reduced comfort or product functionality | 7 | Worker fatigue | 6 | Providing break time during production | 4 | 168 | 4 |
| | | | Lack of attentiveness | | Worker receives reprimand | 3 | 126 | 7 |
| | | | Poor quality raw materials from the supplier | | Separating poor quality raw materials | 3 | 126 | 7 |
| Incorrect size | Product does not meet pre-determined standards | 7 | Worker pursuing production targets | 5 | Enhancing production control through supervision | 4 | 140 | 6 |
| | | | Lack of machine usage procedures | | Providing guidance for workers | 3 | 105 | 9 |
| | | | Insufficient machine maintenance | | Workers checking machine conditions in the production process | 5 | 175 | 3 |
| Weak stitching | Stitching easily comes off, the product quickly becomes damaged | 5 | Inexperienced worker | 5 | Providing training to workers | 3 | 75 | 11 |
| | | | Worker pursuing production targets | | Enhancing production control through supervision | 3 | 75 | 11 |
| | | | Lack of standard procedure for operating machine | | Providing machine operation guidance | 3 | 75 | 11 |

## 5 Results analysis

The primary focus of our analysis lies in identifying critical failure modes and assessing their severity through Risk Priority Number (RPN) values. Tear failures, with an RPN of 192, emerged as the foremost concern, leading to the loss of both aesthetic appeal and product functionality. Following closely is the uneven stitching issue, ranking second with an RPN of 180, highlighting its significant impact on product quality. Additionally, incorrect sizing and irregular ribbons, with RPN values of 175 and 168 respectively, contribute significantly to the overall product defects.

The identified failures stem from a combination of human, machine, material, and environmental factors. Tear failures result from workers' lack of focus due to insufficient rest breaks, while uneven stitching is attributed to a lack of training for new workers. Incorrect sizing is linked to inadequate machine maintenance, emphasizing the importance of regular checks on production machines. The irregular ribbons issue is connected to worker fatigue, emphasizing the need for periodic rest breaks. Understanding these causal factors is crucial for devising effective strategies to address and mitigate these failures.

To address the identified failures and improve overall product quality, several enhancement measures are proposed. These include implementing consistent rest breaks during specific production periods to combat worker fatigue and improve focus. Providing comprehensive training for both new and existing workers, especially in the context of using production machines, can significantly enhance the precision of stitching. Moreover, introducing direct supervision from Biyan Konveksi's management during crucial production stages, such as the stitching process, can ensure meticulous attention to detail and reduce defects caused by worker oversight.

Post-implementation of the proposed improvement measures, there is a noteworthy decrease in the overall defect percentage. The initial defect percentage, attributed to human, machine, material, and environmental factors, stood above 3%, with culottes experiencing the highest defect percentage at 3.95%. After the company implemented the enhancement measures, the defect percentage dropped significantly, reaching a range of 1 to 1.25%. This substantial reduction underscores the effectiveness of the suggested enhancements in minimizing defects and improving the overall quality of Biyan Konveksi's products.

## 6 Conclusion

The comprehensive analysis using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) has resulted critical insights into the primary failure modes impacting Biyan Konveksi's production processes. The identified failure factors—human, machine, material, and environmental aspects—highlight the complex challenges the company faces in maintaining product quality. FTA enabled tracing the root causes of these failures, revealing the interconnectedness of various contributing factors. Conversely, FMEA facilitated a systematic assessment of the severity, occurrence, and detection of each failure mode, thereby enabling the prioritization of improvement efforts.

Tear failures, with a Risk Priority Number (RPN) of 192, were identified as the foremost concern, significantly affecting both the aesthetic appeal and functionality of the products. Uneven stitching, with an RPN of 180, was the second most significant issue, impacting product quality. Incorrect sizing and irregular ribbons, with RPN values of 175 and 168 respectively, also contributed substantially to overall product defects. Initially, the defect percentage, attributed to human, machine, material, and environmental factors, exceeded 3%, with culottes experiencing the highest defect percentage at 3.95%. Following the implementation of the suggested enhancements, the defect percentage significantly decreased, reaching a range of 1 to 1.25%.

The proposed enhancements, derived from these analyses, provide a strategic roadmap for Biyan Konveksi to elevate its production processes and enhance product quality. Addressing issues such as inadequate rest breaks, insufficient training for new workers, and lax machine maintenance can significantly reduce the occurrence of tear failures, uneven stitching, incorrect sizing, and irregular ribbons. These improvements are aimed at optimizing worker performance, refining manufacturing processes, and ultimately lowering the overall defect percentage. The proactive implementation of these suggestions positions Biyan Konveksi on a path toward sustained improvement.

It is recommended to further investigate the long-term impacts of these enhancements on production efficiency and product quality. Additionally, exploring the integration of advanced quality control technologies and continuous training programs for workers could provide deeper insights and further improvements. Continued monitoring and adaptation of the implemented measures will be crucial for maintaining the trajectory of sustained improvement and ensuring the highest standards of product quality at Biyan Konveksi.

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**Review process**

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