

Article

Product Quality Control of Shoes Using Statistical Process Control and Fault Tree Analysis Methods

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Abstract: PT X is a shoe manufacturing company in Sidoarjo, East Java that produces shoes. The company still faces a product defect rate that exceeds the quality standard of 5%, with an average defect rate of 8.11% so that systematic quality control is needed. This study aims to analyze the dominant types of shoe product defects and identify their root causes. The Statistical Process Control (SPC) method is a method used to ensure that each production process runs according to standards so that the resulting product meets consumer quality requirements, while Fault Tree Analysis (FTA) is a top-down analysis that traces cause-and-effect relationships to break down peak events to their root causes, and provide recommendations for improvement. Research data was obtained through observation, interviews, and production and defect data for the period May–October 2025. The results showed that the most dominant type of defect in the shoe production process was untidy stitching of 10,326 pieces. The causes came from human and machine factors, such as lack of operator accuracy, machine setting errors, and worn machine component conditions that caused product defects. To reduce this, recommendations for improvements are provided, such as improving operator skills and regular machine maintenance and adjustments.

Keywords: Quality Control, Statistical Process Control, Fault Tree Analysis, Shoe Manufacturing

1. Introduction

PT X is a company operating in the footwear manufacturing industry, specializing in the production of leather and synthetic shoes. The company has a substantial production capacity and carries out various activities ranging from cutting materials, sewing, gluing, assembly, to product finishing. PT Mustika Dharmajaya strives to maintain consistent quality to meet the quality standards set by customers. However, in its production process, PT X still experiences product defects such as messy stitching, imprecise material cutting, and loose gluing. If left unchecked, this can increase production costs and lead to customer complaints, indicating that quality control is not yet optimal.

Based on production data from May to October 2025, the defect rate for footwear products at PT X still exceeds the maximum standard of 5%. Out of a total production of 154,802 units, 12,552 defective units were found, resulting in an average defect rate of 8.11%. Although the process remains within statistical control limits (UCL 0.083 and LCL 0.079), this defect rate does not yet meet the company's standards. Therefore, more structured and sustainable improvements are needed to reduce defects and improve product quality. Product quality refers to the company's efforts to meet consumer needs through the products it produces[1]. In addition to service, product quality is a key factor influencing customer satisfaction and loyalty[2].

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Therefore, analysis using the SPC and FTA methods is required. Statistical Process Control (SPC) analysis is a method used to ensure that every production process runs according to standards so that the resulting products meet consumer quality requirements[3]. The FTA method is a top-down analysis that traces cause-and-effect relationships to break down an incident from its peak to its root cause[4]. The FTA method is used to trace and identify sources of risk in the production process that trigger failures[5]. Additionally, the FTA method uses a tree diagram to visualize the cause-and-effect relationships of failures, then traces the primary factors that trigger those failures[6].

Bimansyah's (2023) study found that the production process for stackable chair components at CV Metalindo Perkasa was not yet under control. Therefore, through SPC, the causes related to human, machine, and method factors could be identified, allowing for improvements such as operator training and machine maintenance to be implemented[7] Research by Suseno and Syahril (2022) showed that through FMEA and FTA, defects in leather bags at PT Mandiri Jogja Internasional were primarily caused by a lack of operator training, substandard working conditions, irregular machine maintenance, weak supervision, and the absence of standard procedures for checking materials and tools[8]. Hidayat's (2021) study showed that the combination of SPC and FTA is effective in identifying the root causes of defects and formulating quality improvements for isolating cocks at PT XYZ[9]. Drawing on previous research, the use of Statistical Process Control (SPC) and Fault Tree Analysis (FTA) has been shown to be effective in improving efficiency and reducing product defects, and this study therefore aims to identify the most dominant types of defects by examining their root causes as well as evaluating the level of control within the shoe production process. Additionally, this study is expected to provide improvement recommendations to enhance product quality.

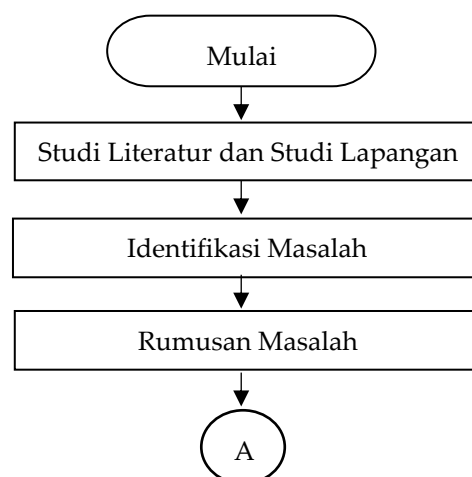
2. Materials and Methods

Time and Location of the Study

This study was conducted at PT X, located in Sidoarjo, East Java, a company engaged in shoe manufacturing. The study was carried out over a period of six months, from May to October 2025.

Research Process

This study was conducted in several stages designed in a structured manner to ensure that the entire research process could be carried out effectively and in accordance with the established objectives. Each stage was organized systematically to facilitate the implementation and analysis of the research. The stages of this study are described as follows:



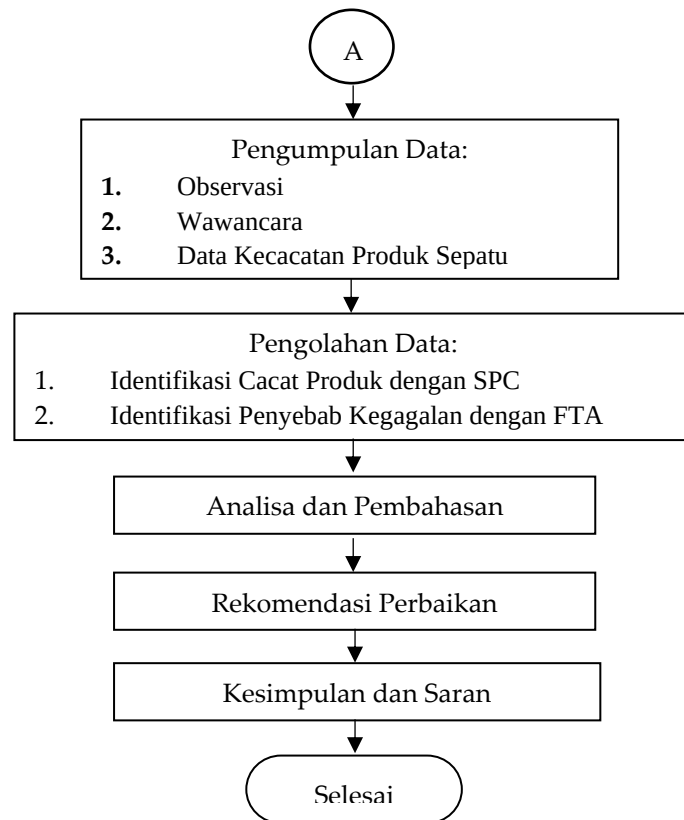


Figure 1. Flowchart

1. Literature Review and Field Study

The literature review involved examining textbooks, scientific journals, research articles, and other references relevant to the topic of product quality control. This study aimed to understand the concepts of quality, quality control, the shoe production process, as well as Statistical Process Control (SPC) and Fault Tree Analysis (FTA) as the theoretical foundation for the research.

2. Problem Identification

The problem identification phase was conducted by observing the initial conditions of the shoe production process at PT Mustika Dharmajaya. During this phase, various quality issues were identified, such as defective products occurring during the cutting, sewing, and gluing processes. The problem identification aimed to determine the actual conditions on-site and the potential causes of product defects.

3. Problem Formulation

Based on the results of the problem identification and literature review, the research problem was formulated systematically. The research problem was formulated to determine the focus of the study, namely how to apply SPC and FTA methods to analyze and minimize shoe product defects in the production process at PT X.

4. Data Collection

The data in this study consists of primary and secondary data. The primary data in this study was obtained directly from research activities conducted at PT X. A number of methods, including field observation, interviews, and literature review, were used in the data collection procedure. In order to find quality problems that arise at every level of the production process, field observation was carried out by closely examining every step of the shoe production process, from cutting the material to stitching, gluing, assembly, and finishing. In order to get more specific information about the causes of product failures, interviews were also done with individuals directly involved in manufacturing activities, such as supervisors and the head of the production department. In the

meantime, information gathered indirectly from PT X or from outside reference sources makes up the secondary data used in this investigation. Standard operating procedures (SOPs), production records, quality control reports, company documentation, and other internal records supporting the study comprise the data. The history of shoe product problems, which includes the kind of defect, the frequency of each defect, the stage of the process where the problem occurred, and the time period during which the defect happened, is one of the main datasets used. The data for this study was obtained from PT X in the form of production volume data and defect data from the shoe manufacturing process; the data collected covers the period from May through October 2025.

5. Data Processing

1. Statistical Process Control

Statistical Process Control is a procedure used to monitor standards, take measurements, and implement corrective actions while the production process is still underway[10]. Statistical Process Control utilizes several key statistical tools that serve as supportive tools in quality control activities, including check sheets, control charts, histograms, and Pareto diagrams[11]. The following are the steps in using the Statistical Process Control method:

1. Check Sheet

A check sheet is a data recording form used to monitor an activity over a specific period. This tool helps make the data collection process more systematic, structured, and efficient[12].

2. Histogram

A histogram is a bar chart used to illustrate the frequency distribution of product quality data, making it easier to observe the spread of values and the level of variation. Through a histogram, one can identify data trends whether the distribution is normal or if there are significant deviations[13].

3. Pareto Chart

A Pareto chart is a bar graph used to display various issues that occur, then sorted from the most frequent to the least frequent occurrences[14].

4. Control Chart

A control chart is a tool used to monitor the stability of the production process by distinguishing between variation that is still acceptable (normal) and variation that requires corrective action[15].

a. Calculating the percentage of defects/damage

$$p = \frac{np}{n} \dots\dots\dots(1)$$

Source: [11].

Notes:

np = Number of defective items in the subgroup

n = Number of items inspected in the subgroup

b. Calculating the Center Line (CL)

$$CL = \bar{p} = \frac{\sum np}{\sum n} \dots\dots\dots(2)$$

Source: [11].

Notes:

$\bar{p}$ = Average product defect rate

$\sum np$ = Total number of defective items

$\sum n$ = Total number of items inspected

c. Calculating the Upper control limit

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \dots\dots\dots(3)$$

Sumber:[16].

Notes:

$\bar{p}$ = Average product defect rate

- n = Total Production
- d. Calculating the Lower control limit

$$LCL = \bar{p} - 3 \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \dots \dots \dots (4)$$

Source:[16].

Notes:

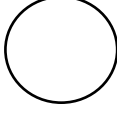
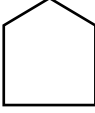
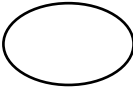
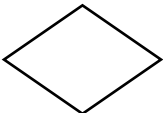
$\bar{p}$ = Average product defect rate

n = Total Production

2. Fault Tree Analysis Method

Fault Tree Analysis is one of the most commonly used failure analysis methods for identifying various possible pathways that can lead to the failure of a system or component[17]. In applying the FTA method, the analysis typically begins with the top event, then traces its direct and indirect causes step by step from higher levels to lower levels. Afterward, the root causes of the failure are identified, and the logical relationships between events are depicted through a fault tree structure[18]. The following are the symbols and definitions used in FTA:

Table 1. FTA Symbols

Symbol	Meaning	Symbol	Meaning
	<i>Basic Event:</i> A basic error handling mechanism that does not require further development		<i>External Event:</i> The expected event
	<i>Conditioning Event:</i> Specific conditions that can be applied to various logic gates		AND Gate: Manual errors resulting from all input issues that occur
	<i>Undevelopment Event:</i> Event which cannot be further developed because the information is not available		OR Gate: The error occurred due to an issue with one of the inputs

Source: [19].

The steps involved in performing the FTA (Fault Tree Analysis) method are as follows[20]:

1. Identify the Top-Level Event

Identify the various types of failures that occur in order to analyze system faults. Knowledge of the system is obtained by gathering all relevant system information or its scope.

2. Creating a Fault Tree Diagram

Creating a fault tree to understand how top-level events can occur within the system.

3. Analyzing the Fault Tree

Analyzing the fault tree to obtain transparent information about the system and the necessary improvements.

6. Analysis and Discussion

The results of data processing are analyzed and discussed in depth to explain the quality conditions of the shoe production process. At this stage, SPC results regarding process stability and dominant defect types are discussed, along with FTA results

indicating the primary factors causing product defects—whether related to human factors, machinery, methods, materials, or the work environment.

7. Improvement Recommendations

Based on the results of the analysis and discussion, improvement recommendations are formulated with the aim of reducing the product defect rate and improving the quality of the shoe production process. The improvement recommendations are tailored to the root causes identified through the SPC and FTA methods.

8. Conclusions and Recommendations

The final stage of the study involves drawing conclusions that summarize the overall research findings, including the predominant types of defects and the primary causes of product defects. In addition, recommendations are provided for the company to consider in improving quality, as well as for future researchers to guide further research.

3. Results

A. Data Collection

1. Defect Criteria

Critical to Quality (CTQ) is a method for measuring product or process quality, in which performance standards or specification limits are set based on customer satisfaction levels[21].

The following table shows the product defect criteria at PT X:

Table 2. CTQ (Criteria to Quality) Defect Criteria:

Defect Criteria	Description
Uneven Stitching	The stitching lines are not straight
	The spacing between stitches is inconsistent
	The stitching is off the pattern
Imprecise Material Cutting	The fabric size does not match the pattern
	The cut edges are uneven
	The pattern shifts during cutting
Incomplete Bonding	The adhesive is not evenly distributed on the surface
	The sole is not fully adhered
	Weak adhesion after the pressing process

Sumber:[22].

2. Check Sheet

The following data pertains to defects in footwear products collected by the company over a six-month period from May through October 2025. The data includes production volumes and types of defects observed during the study. The research data is presented in Table 3 below:

Table 3. Production Volume and Types of Defects

No	Month	Production Quantity	Defective Product Types			Total Defects per Month	Percentage	% Max
			Unneat Stitching	Imprecise Material Cutting	Incomplete Bonding			
1	May	22.750	1.386	347	133	1.866	8,20%	5%
2	June	24.368	1.694	121	125	1.940	7,96%	5%
3	July	25.520	1.692	298	109	2.099	8,22%	5%
4	August	26.396	1.850	152	145	2.147	8,13%	5%
5	September	27.768	1.876	176	143	2.195	7,90%	5%
6	October	28.000	1.828	300	177	2.305	8,23%	5%

Total	154.802	10.326	1.394	832	12.552	48,66%	5%
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Based on Table 3 regarding production volume and defect types for the May–October period, total production reached 154,802 units with 12,552 defective units, or 48.66%, over the six-month period. The most prevalent defect was uneven stitching, accounting for 10,326 units, followed by imprecise material cutting at 1,394 units and loose gluing at 832 units. In percentage terms, the monthly defect rate ranged from 7.90% to 8.23%, all exceeding the company's maximum limit of 5%, with the highest number of defects occurring in October (2,305 units) and the lowest in May (1,866 units), indicating the need for quality control and improvement in the production process.

3. Histogram

Based on the histogram in Figure 2 below, it can be seen that the defect type with the highest number is uneven stitching, totaling 10,326 pieces. This is followed by imprecise material cutting, with 1,394 pieces, and the lowest number of defects is found in loose bonding, with 832 pieces. This indicates that the main problem in the production process lies in the sewing stage.

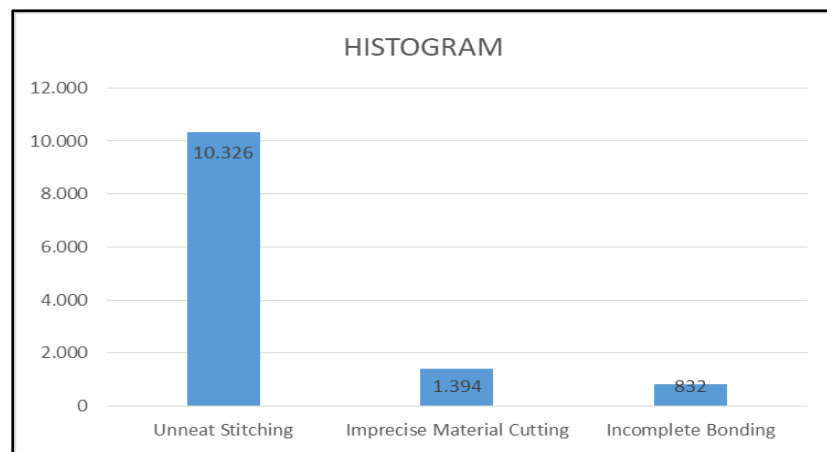


Figure 2. Histogram of Defect Types

B. Data Processing

1. Pareto Chart

A Pareto chart is a bar graph used to display various problems that occur, which are then arranged from the highest to the lowest frequency of occurrence[14]. The following table presents the percentage of defects in shoe products as follows:

Table 4. Defect Percentage and Cumulative Percentage

Type of Defect	Total Defects	Percentage of Defects	Cumulative Percentage
Unneat Stitching	10.326	82%	82%
Imprecise Fabric Cutting	1.394	11%	93%
Incomplete Bonding	832	7%	100%
Total	12.552	100%	

After obtaining the defect percentage and cumulative percentage from the table above, Figure 3 will be created next. A Pareto chart will be used to visually illustrate the comparison of defect percentages for easier understanding:

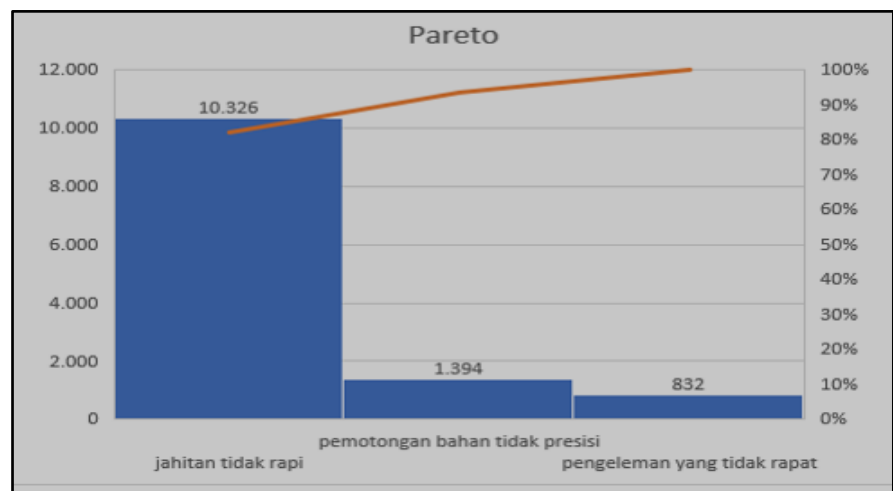


Figure 3. Pareto Chart

Based on Figure 3 (Pareto Diagram), it can be seen that the total product defects amount to 12,552 pcs or 100%. Uneven stitching is clearly the most frequent defect, with 10,326 pairs affected, making up 82% of the total. This is followed by imprecise material cutting, which accounts for 1,394 pairs or 11%, bringing the cumulative percentage to 93%. Meanwhile, improper gluing contributes 832 pairs or 7%, completing the total at 100%. From these results, it's evident that uneven stitching should be the top priority for improvement, as it represents the largest share of overall defects.

2. Control Chart

A control chart is a tool used to monitor the stability of a production process by distinguishing between variation that is still within acceptable limits (normal) and variation that requires corrective action[15]. The following are calculations of the defect proportion, LCL, and UCL for shoe products:

a. Percentage of Problems (Product Defects)

$$\begin{aligned}
 \text{May} &= p = \frac{np}{n} = \frac{1.866}{22.750} = 0,082 \\
 \text{June} &= p = \frac{np}{n} = \frac{1.940}{24.368} = 0,080 \\
 \text{July} &= p = \frac{np}{n} = \frac{2.099}{25.520} = 0,082 \\
 \text{August} &= p = \frac{np}{n} = \frac{2.147}{26.396} = 0,081 \\
 \text{September} &= p = \frac{np}{n} = \frac{2.195}{27.768} = 0,079 \\
 \text{October} &= p = \frac{np}{n} = \frac{2.305}{28.000} = 0,082
 \end{aligned}$$

b. Center Line Calculation

$$CL = \bar{p} = \frac{\sum np}{\sum n} = \frac{12.552}{154.802} = 0,081$$

c. Calculating the Upper Control Limit (UCL)

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0,081 + 3\sqrt{\frac{0,081(1-0,081)}{154.802}} = 0,083$$

d. Calculating the Lower Control Limit (LCL)

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0,081 - 3\sqrt{\frac{0,081(1-0,081)}{154.802}} = 0,079$$

Table 5. Proportion of Defects, LCL, and UCL of Shoe Products

No	Month	Total Production	Total Defects	Proportion	CL	UCL	LCL
1	May	22.750	1.866	0,082	0,081	0,083	0,079
2	June	24.368	1.940	0,080	0,081	0,083	0,079
3	July	25.520	2.099	0,082	0,081	0,083	0,079
4	August	26.396	2.147	0,081	0,081	0,083	0,079

5	September	27.768	2.195	0,079	0,081	0,083	0,079
6	October	28.000	2.305	0,082	0,081	0,083	0,079
Total		154.802	12.552				

Based on Table 5, which presents the defect proportions and control limits, the total production from May to October reached 154,802 pcs with a total of 12,552 defective units. The monthly defect proportion ranges between 0.079 and 0.082. The center line (CL) is 0.081, with an upper control limit (UCL) of 0.083 and a lower control limit (LCL) of 0.079. All monthly defect proportion values fall within the upper and lower control limits. Therefore, the chart can be illustrated as follows:

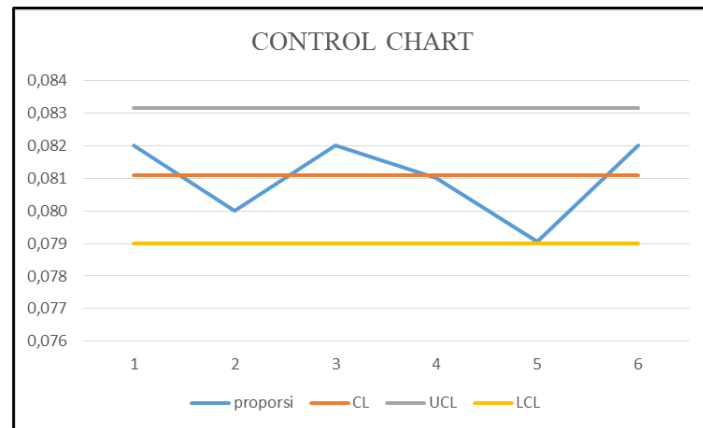


Figure 4. Control Chart

Figure 4 shows that the proportion of defects in shoe products from May to October is in a stable condition within the range of 0.079–0.082. All data points (blue line) are observed to be within safe limits, as they remain between the upper control limit (UCL) of 0.083 and the lower control limit (LCL) of 0.079, with the center line (CL) at 0.081. This indicates that the production process over the six-month period is statistically under control, with no deviations exceeding the control limits.

C. Analysis and Discussion

In applying the FTA method, the analysis typically begins with the critical event, then traces its direct and indirect causes step by step from higher levels to lower levels. After that, the root cause of the accident is identified, and the logical relationships between events are illustrated using a fault tree structure[18].

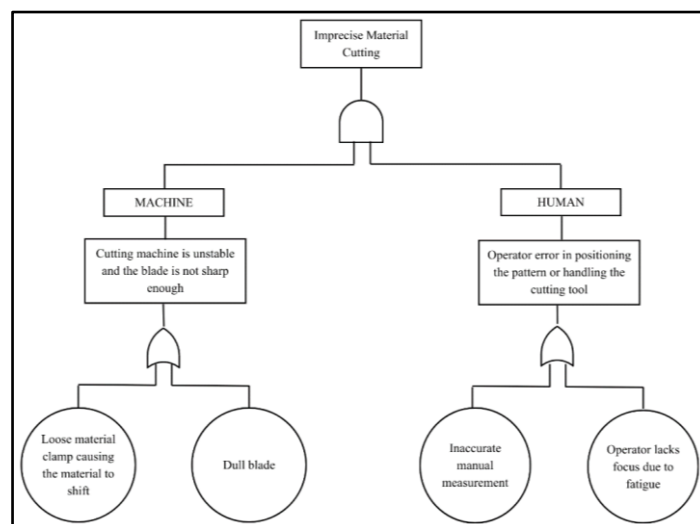


Figure 5. Fault Tree Analysis of Improper Material Cutting

Based on Figure 5. Fault Tree Analysis (FTA), the issue of imprecise material cutting is triggered by a combination of technical failures and human factors. On the machine side, deviations in the cut result from an unstable cutting unit and a dull blade. This condition is exacerbated by loose clamps, which cause the material to shift during the cutting process. Meanwhile, from the human side, errors in positioning the pattern or holding the cutting tool, as well as a lack of precision during manual measurement and a decline in the operator's focus due to fatigue, contribute to the issue.

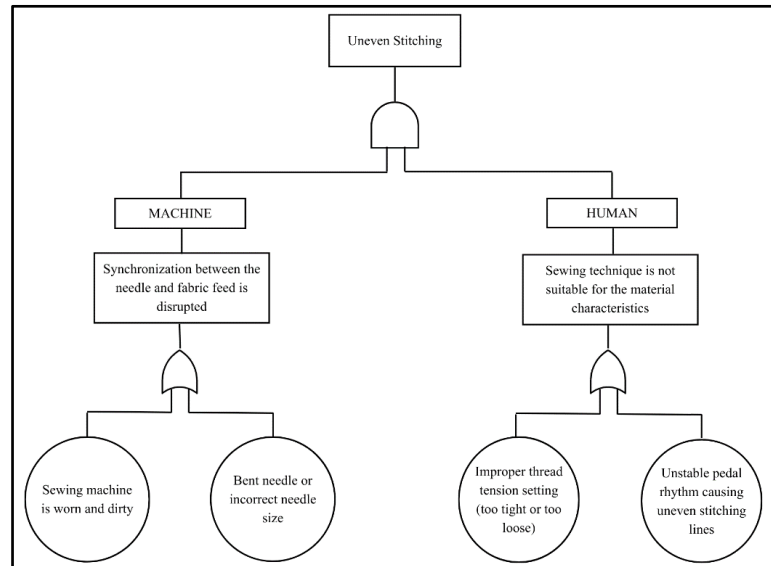


Figure 6. Fault Tree Analysis of Uneven Stitching

Based on Figure 6, the results of observations and interviews, the shoe production failure in the form of uneven stitching analyzed using the Fault Tree Analysis (FTA) method was caused by technical and human factors. From a technical perspective, this defect is triggered by a synchronization issue between the needle's movement and the fabric feed mechanism, where worn-out and dirty feed dogs, along with the use of bent needles, cause the fabric flow to stall. Meanwhile, from a human perspective, the operator's lack of precision in adjusting thread tension, along with the habit of an unstable pedal rhythm while sewing, resulted in uneven stitching lines that deviated from the standard pattern. Overall, this analysis indicates that the instability of the operator's work rhythm and suboptimal machine component conditions are the primary root causes that increase the risk of defects in the stitching results.

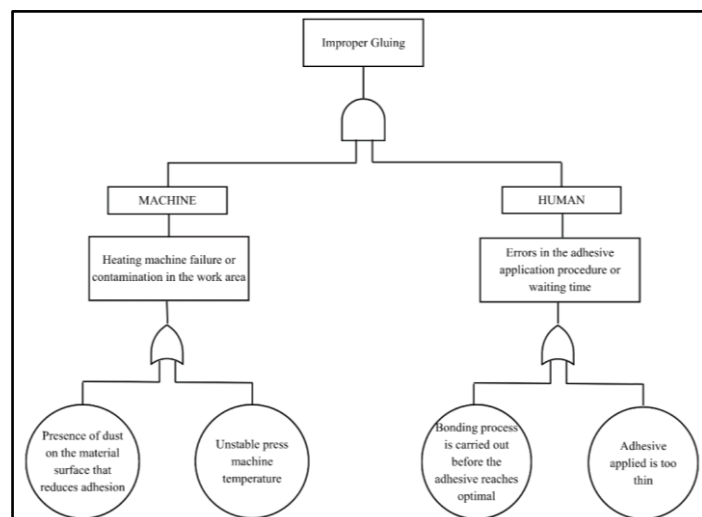


Figure 7. Fault Tree Analysis of Improper Bonding

Based on Figure 7. The results of the mapping using Fault Tree Analysis (FTA) indicate that failures in the Non-Adhesive Bonding process are triggered by the correlation between human work procedures and machine technical conditions. From the human aspect, low adhesive strength is caused by uneven glue application and errors in determining the waiting time before the material is bonded. Meanwhile, from the machine's perspective, issues arise due to the heating tool (press) not reaching optimal temperature standards and dust contamination on the material's surface. Overall, insufficient control over machine temperature parameters and carelessness in adhesive application techniques are the primary factors causing components to detach easily.

D. Recommendations for Improvement

Recommendations for Addressing Various Shoe Production Challenges at PT X: Improvement measures are needed that cover both technical and work management aspects. Regarding cutting issues, the primary focus is on sharpening the blade, coupled with the use of more stable cutting patterns to minimize manual errors caused by operator fatigue[22]. To improve stitch neatness, daily inspections of the fabric feed system (feed dogs) and precise thread tension adjustments must become standard operating procedures, supported by technical training to ensure operators do not force the material through. Meanwhile, bonding issues can be addressed by installing digital temperature indicators on the press machine to ensure consistent heat, as well as strict monitoring of material surface cleanliness and adherence to curing times to ensure the adhesive reaches its optimal bonding strength. These recommendations align with research conducted by Bimansyah (2023), which found that the production process for stackable chair components at CV Metalindo Perkasa was not yet under control; after applying SPC methods, causes related to human, machine, and process factors could be identified, allowing for improvements such as operator training and machine maintenance[7]. It is hoped that through monitoring and evaluation, the product defect rate can be reduced.

4. Discussion

The results show that although the shoe production process at PT X is statistically under control, the defect rate still exceeds the company's 5% quality standard, indicating that a stable process does not necessarily meet quality targets. The dominance of uneven stitching defects (82%) highlights that the sewing stage is the most critical point affecting product quality. Through SPC, the main problem can be identified, while FTA reveals that defects are caused by the interaction of human factors such as lack of accuracy, skills, and work consistency and machine factors, including improper settings and worn components. These results are consistent with previous studies, showing that defects are largely influenced by both human and machine factors, and they also confirm that combining SPC and FTA is an effective approach, where SPC is useful for monitoring process stability and identifying the most dominant defects, while FTA helps trace their root causes in more detail, so that continuous improvement efforts such as operator training, routine machine maintenance, and process standardization can be carried out to reduce defect levels and achieve the expected quality standards.

5. Conclusion

The conclusions from the research are as follows:

1. Based on the analysis using the Statistical Process Control (SPC) method on shoe production data at PT Mustika Dharmajaya for the period May–October 2025, it is found that the defect rate still exceeds the company's quality standard, which is set at 8.11%. The most dominant type of defect is untidy stitching, accounting for 7% of the total product defects.

2. Based on the analysis using the Fault Tree Analysis (FTA) method, it is identified that the main causes of untidy stitching defects originate from human factors and machine factors. Mechanical issues, such as worn-out machine components and inaccurate machine settings, can negatively affect stitching quality, while human factors like operators' limited accuracy and skill during the stitching process also contribute to the occurrence of defects.
3. Based on this analysis, the company can take several steps to improve the process, such as strengthening operator skills through regular training, ensuring machines are properly checked and set before production starts, and carrying out routine maintenance to keep equipment in good condition. The implementation of these improvements is expected to reduce the defect rate and improve the quality of the shoes produced.

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