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Product Defect Analysis of PDH Shirts Using Fault Tree Analysis and Failure Mode and Effect Analysis

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Abstract

CV. Graha Konveksindo Sidoarjo is a manufacturing company that produces garments, with PDH shirts as one of its products. Problems identified at CV. Graha Konveksindo include defects in PDH shirts, totaling 891 pieces, with a defect rate of 12.95 %. This study aims to determine the types and causes of defects and provide suggestions for improvement. The methods used are Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA). Based on the study results, four types of defects were found: reverse embroidery with an occurrence probability of 3.53%, untidy stitches with an occurrence probability of 3.34%, off-center emblems with an occurrence probability of 2.36%, and stains with an occurrence probability of 3.13%. Across these defect types, 15 root causes were identified as contributing factors. From the FMEA calculation results, the highest Risk Priority Number (RPN) was found in untidy stitch defects at 252, followed by the reverse embroidery defects emblem defects at 240, off center emblem defects at 210, and stain defects at 160. Some recommended improvement proposals to reduce product defects include providing operator training, conducting briefings before production, and routinely checking sewing and embroidery machines.

Introduction

Competition in the manufacturing industry is becoming increasingly intense due to technological advancements and evolving marketing strategies (Sanbella et al., 2024; Hu et al., 2024; Olurin et al., 2024). Every company must produce products that meet consumer needs and expectations. This drives quality improvement as a key factor in business success, as quality reflects a product's conformity to market standards and consumer preferences (Ishak et al., 2020; Gurnani & Gupta, 2025; Situngkir, 2024). Companies that prioritize quality as a strategic focus will find it easier to attract consumers, who tend to choose products that balance price and quality. Therefore, quality remains a major factor in purchasing decisions.

CV. Graha Konveksindo Sidoarjo is a garment company that manufactures a variety of products, including shirts, t-shirts, jackets, and hats. To maintain production efficiency and ensure product quality that meets customer demand, the company employs a Repetitive Manufacturing system. However, despite this approach, the company continues to face challenges in quality control. Based on production data from March 2024 to February 2025, PDH shirt products have a defect rate of 12.95%, significantly exceeding the company's tolerance limit of 3%. The most common defects include reverse embroidery, untidy stitching, off-center emblems, and stains. This high defect rate suggests that the current quality control

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system is not operating optimally. If left unaddressed, these issues could negatively impact product quality, customer satisfaction, and operational efficiency. Therefore, a comprehensive analysis is necessary to identify the root causes of defects and implement appropriate corrective measures (Kumar & Harsha, 2025; Ezukwoke et al., 2025; Wu et al., 2024).

To address these issues, this research analyzes the defect rate in PDH shirt products at CV. Graha Konveksindo Sidoarjo by applying the Fault Tree Analysis (FTA) method and developing improvement proposals using the Failure Mode and Effect Analysis (FMEA) approach. Fault Tree Analysis is employed to identify the root causes of product defects through a top-down approach, starting from the main failure assumption (top event) to determine the underlying causes (root causes). The relationships between these causal factors are then visualized in the form of a fault tree diagram (Wicaksono & Yuamita, 2022). Additionally, this research utilizes the Failure Mode and Effects Analysis (FMEA) method to assess the risks associated with each defect cause. FMEA prioritizes failures based on severity, occurrence, and detection, which are then calculated into a Risk Priority Number (RPN). By using RPN, companies can focus on addressing the most critical issues to reduce defects and enhance product quality (Firmansyah & Nuruddin, 2022; Wang et al., 2025; Sumasto et al., 2024).

Defective Products

Defective products are items that fail to meet predetermined quality standards. For consumers, a quality product is one that functions according to their needs and expectations. If a product does not perform as intended, it is considered defective (Muchisinin & Sulistiyowati, 2022). In the production process, defects can arise due to two main factors: order specifications that do not align with consumer needs and internal issues such as machine malfunctions, human error, or substandard raw materials. If not properly controlled, a high defect rate can reduce production efficiency, lower customer satisfaction, and harm the company's reputation (Indriani et al., 2024; Lodhi et al., 2024)

Quality Control

Quality control is a crucial technique that must be implemented throughout the entire production process, beginning before production starts, continuing during manufacturing, and concluding with the final product (Juwito & Faristy, 2022). The primary goal of quality control is to ensure that the predetermined product specifications are accurately reflected in the final output. This process is essential to guarantee that every item or product manufactured meets established quality standards (Febryan et al., 2023; Al Kurdi et al., 2024; Anozie et al., 2024). According (Tua et al., 2022), the factors that affect product quality are markets, money, management, people, motivation, materials, and machines. The benefits of quality control include improving company reputation, reducing product costs, increasing market share, expanding market reach, enhancing product accountability, building trust, and aligning with consumer preferences (Kimkuri & Buntu, 2021; Lubis & Muniapan, 2024; Jusuf, 2024).

Quality Control Tools

In quality control using the Fault Tree Analysis (FTA) method, several supporting tools are required to facilitate data collection and analysis (Darsini & Suratno, 2025). Commonly used tools in the FTA method include check sheets for recording defect frequency, histograms for visualizing data distribution, Pareto diagrams for identifying the most dominant defect types, and fishbone diagrams for analyzing root causes. Check sheets systematically record defect frequency data. Histograms present defect distribution as bar graphs, making analysis easier. Pareto diagrams highlight the most frequent defect types, helping focus improvement efforts on the most critical issues. Meanwhile, fishbone diagrams, also known as cause-and-effect

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diagrams, illustrate the relationship between a problem and its potential causes, including human factors, machines, methods, or environmental conditions (Fath & Darajatun, 2022; Faisal et al., 2025; Ansori et al., 2024).

Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is a qualitative and quantitative method used to analyze system failures in a hierarchical, tree-like structure (Kumar et al., 2025; This approach illustrates the relationship between peak events (main failures) and basic events through the use of logic gates (Markulik et al., 2021). The Fault Tree Analysis (FTA) method consists of five stages: identifying key events to be analyzed and tracing their consequences, constructing a graphical representation of the Fault Tree, determining the minimum cut set of the Fault Tree, conducting a qualitative analysis, and performing a quantitative analysis (Safira & Damayanti, 2022).

Cut Set Method

A cut set is a combination of multiple events in Fault Tree Analysis (FTA) that, if all occur simultaneously, can lead to the occurrence of a top event or major system failure. Cut sets are used to understand how various factors or elements within a system contribute to overall failure. Additionally, they serve as a tool for evaluating system reliability by identifying the most critical failure paths. A cut set is referred to as a minimal cut set if it cannot be further reduced without losing its function as a cut set. The identification of minimal cut sets involves qualitative analysis using a Boolean algebraic approach (Nurfatha & Herwanto, 2023; Leblond et al., 2024).

Failure Mode Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is a method used to identify and analyze potential failures and their impacts, with the goal of designing an optimized production process that minimizes unwanted failures and losses (Susanto et al., 2022). Once failures are identified, each type is assigned a risk-based value and ranked using the Risk Priority Number (RPN) (Hidayat & Rochmoeljati, 2020). The FMEA method utilizes three main components Severity (S), Occurrence (O), and Detection (D) to determine the RPN value, which is calculated by multiplying these three factors. Severity measures the extent of a failure's impact on components affecting machine performance. Occurrence indicates how frequently a potential failure may arise. Meanwhile, Detection evaluates the system's ability to identify the failure's root cause early, allowing corrective action to be taken promptly (Daniallabib & Apsari, 2024).

Methods

This research adopts a quantitative approach, supported by qualitative elements, to gain a comprehensive understanding of the causes of product defects in PDH shirts at CV. Graha Konveksindo. The initial step involves conducting a literature review to establish a strong theoretical foundation and to select appropriate analytical methods, namely Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA). This is followed by a field study to directly observe conditions at the production site and identify the main problems encountered. The researcher then formulates the research objectives and determines the variables to be analyzed. In this study, the defect rate serves as the dependent variable, while production quantity, number of defects, and defect types are considered independent variables.

Data collection is carried out through two methods: interviews and document analysis. Interviews are conducted with three members of the Quality Control (QC) team who are directly involved in the PDH shirt inspection process. A semi-structured interview format is

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used to ensure consistency while allowing for in-depth exploration of information. To ensure data accuracy, the researcher performs member checking with respondents and triangulates the findings by comparing interview data with production documents. Document analysis is conducted on production reports and defect records covering the period from March 2024 to February 2025. Over this 12-month period, a total of 891 defect cases were recorded in PDH shirt products. This data is analyzed to identify defect patterns and determine the most frequently occurring defect types during the study period.

In the data analysis phase, the researcher employs two primary methods. First, Fault Tree Analysis (FTA) is used to trace the root causes of the most dominant defects. This method begins by identifying a top event, which represents the main problem, and constructing a fault tree diagram to map its potential causes. The diagram incorporates AND and OR logic gates to illustrate relationships among contributing factors. For instance, a stitching defect may occur due to both machine malfunction and operator error (AND gate), or due to either one of those factors individually (OR gate). This approach enables the researcher to pinpoint the most fundamental root causes and estimate the probability of failure. Second, Failure Mode and Effect Analysis (FMEA) is applied to assess the risk level of each type of defect. The assessment is based on three criteria: Severity, Occurrence, and Detection. Each criterion is rated on a scale from 1 to 10 by the QC team during an evaluation session facilitated by the researcher. These scores are then used to calculate the Risk Priority Number (RPN) using the formula: RPN = Severity × Occurrence × Detection. The defect type with the highest RPN is prioritized for immediate corrective action.

The entire research was conducted from February 2025 and completed in May 2025, after all necessary data were collected, validated, and thoroughly analyzed using both FTA and FMEA methods.

Results and Discussion

In this study, the data used includes production quantities, defect types, and the number of defects in PDH Shirt products over a 12-month period from March 2024 to February 2025. The average product defect rate is 12.95%, with details of the defects presented in Table 1. There are four types of defects in PDH Shirt products, namely reverse embroidery defects, untidy stitching defects, off-center emblem defects, and stain defects.

Table 1 Data on the Number of Defective PDH Shirt Products

from March 2024 to February 2025

Month	Reverse Embroidery	Untidy Stitching	Off Center Emblem	Stain	Total
March	22	19	14	12	67
April	15	20	18	21	74
May	23	18	25	12	78
June	27	20	11	13	71
July	21	18	24	17	80
August	24	21	12	19	76
September	19	20	21	14	74
October	23	29	18	22	92
November	20	17	24	13	74
December	25	21	19	12	77
January	23	22	17	13	75
February	14	19	12	8	53
Total	256	244	215	176	891

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Based on the data in Table 1, the next step is to further process the data by creating histograms and Pareto diagrams to identify the most frequently occurring defect types or those with the highest percentage, as shown in the following figure.

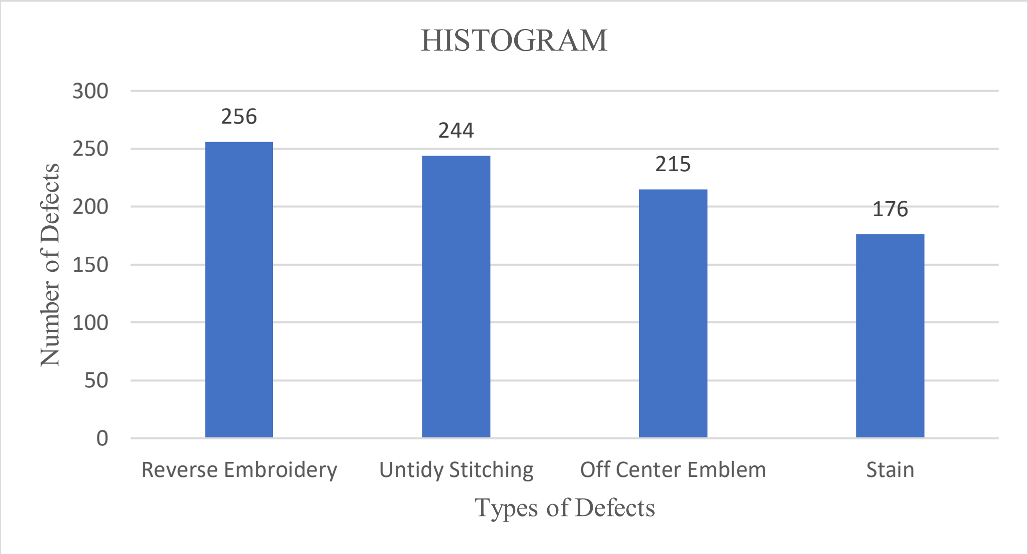

Figure 1. Histogram

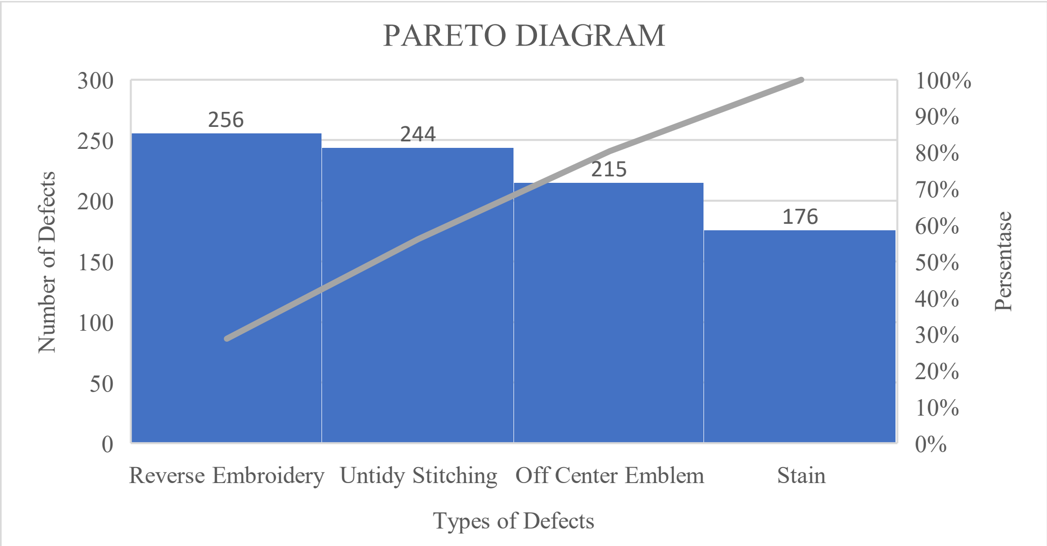

Figure 2. Pareto Diagram

Based on Figure 2, the most dominant defect in the production process of PDH shirts is reverse embroidery, with 256 defects or 28.73%. This is followed by untidy stitching with 244 defects or 27.38%, off-center emblem with 215 defects or 24.13%, and stains with 176 defects or 19.75%. Furthermore, a fishbone diagram was used to analyze and identify the causes of each type of defect.

Fishbone Diagram

The Fishbone Diagram for the Reverse Embroidery defect was developed based on the researcher's interview with Quality Control (QC). Below is an illustration of the cause-and-effect diagram for defects such as Reverse Embroidery, Untidy Stitching, Off-Center Emblem, and Stains.

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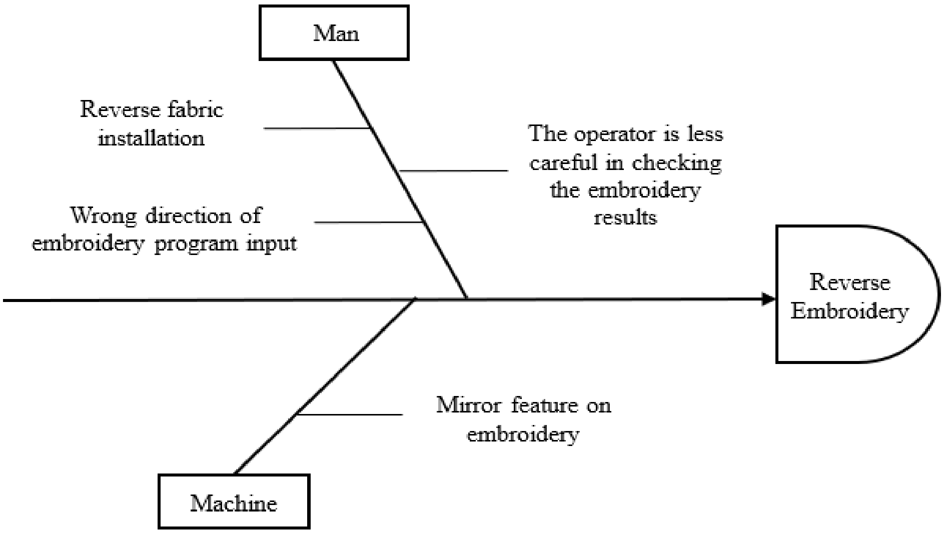

Figure 3. Fishbone Diagram of Reverse Embroidery Defect

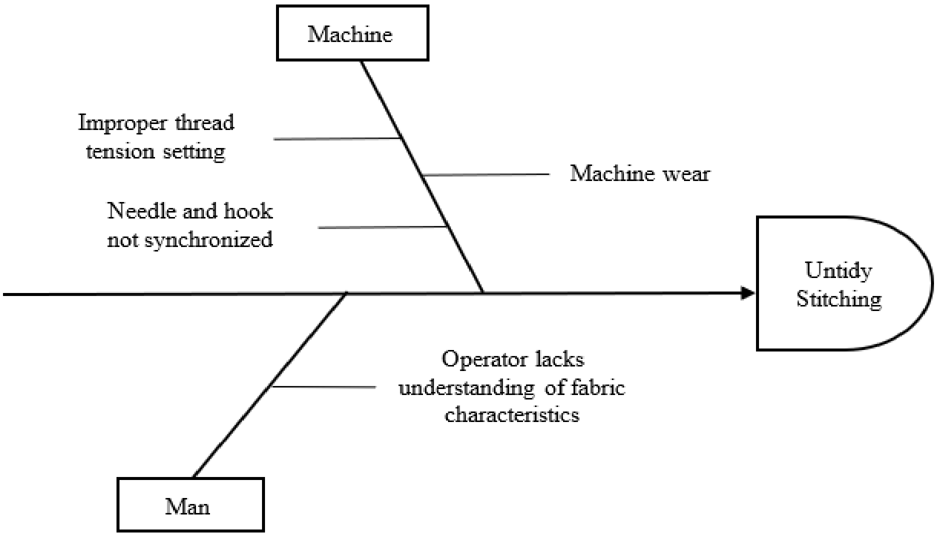

Figure 4. Fishbone Diagram of Untidy Stitching Defect

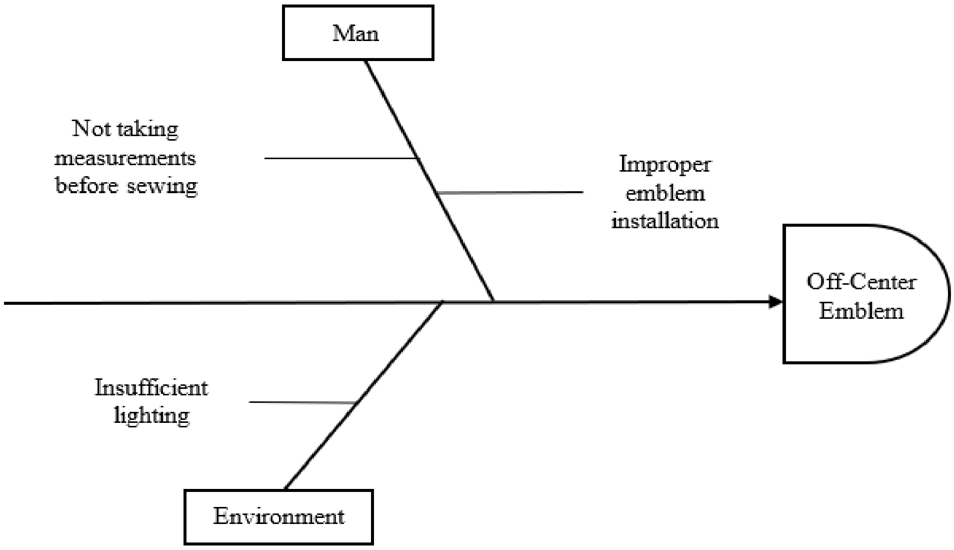

Figure 5. Fishbone Diagram of Off-Center Emblem Defect

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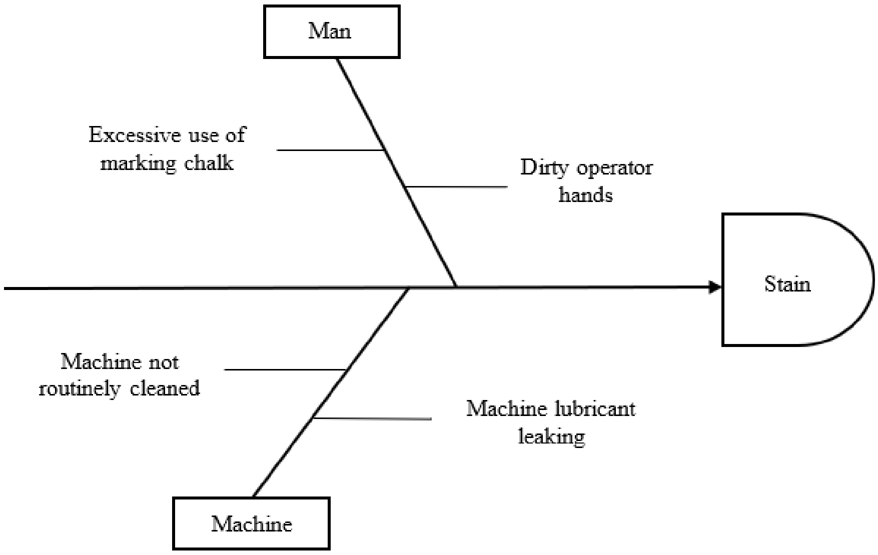

Figure 6. Fishbone Diagram of Stain Defect

Fault Tree Analysis of Reverse Embroidery Defects

Based on the cause-and-effect diagram derived from the interview with the QC team, the next step is to create a Fault Tree Analysis (FTA) diagram for each top event. Figure 7 below presents the FTA for the reverse embroidery defect.

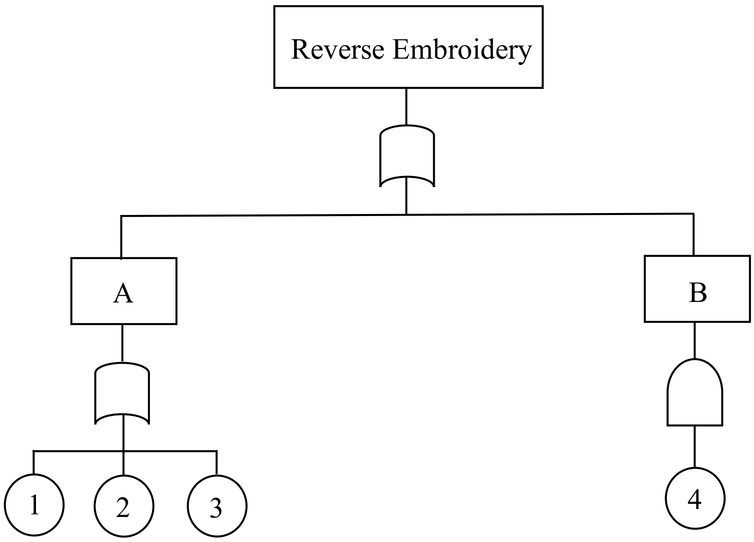

Figure 7. Fault Tree Analysis of Reverse Embroidery Defects

Description:

A : Human

B : Machine

1 : Reverse Fabric Installation

2 : The Operator is Less Careful in Checking the Embroidery Results

3 : Wrong Direction of Embroidery Program Input

4 : Mirror Feature on Embroidery Machine Active

The next step is to evaluate defects by compiling a cut set matrix of the root causes of reverse embroidery defects, as shown in Figure 8 below.

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1			
2			
3			

Figure 8. Cut Set Matrix for Reverse Embroidery Defect

Reverse embroidery defects result from both human and machine factors. Human-related causes include inverted fabric installation and the operator's lack of precision in checking the embroidery results. Meanwhile, machine-related causes involve directional errors in the embroidery program input and the accidental activation of the mirror feature on the embroidery machine.

Based on calculations using the Fault Tree Analysis method, the probability results before evaluation are 0.0353 or 3.53%, while the probability after evaluation is 0.0356 or 3.56%. These results indicate that the two methods have not changed significantly, and both achieve optimal outcomes.

Fault Tree Analysis of Untidy Stitching Defects

Based on the cause-and-effect diagram derived from the interview with the QC team, the next step is to create a Fault Tree Analysis (FTA) diagram for each top event. Figure 9 below presents the FTA for the untidy stitching defect.

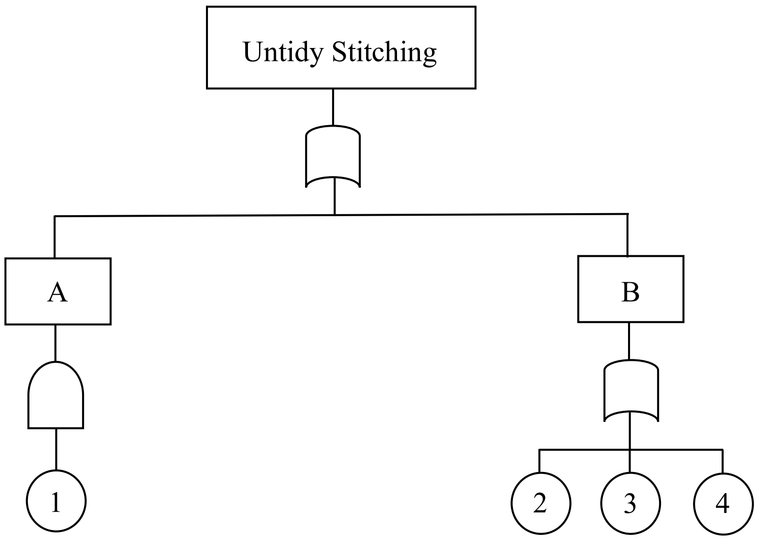

Figure 9. Fault Tree Analysis of Untidy Stitching Defects

Description:

A : Human

B : Machine

1 : Operator Lacks Understanding of Fabric Characteristics

2 : Needle and Hook Not Synchronized

3 : Machine Wear

4 : Improper Thread Tension Setting

The next step is to evaluate defects by compiling a cut set matrix of the root causes of untidy stitching defects, as shown in Figure 10 below.

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1			
2			
3			
4			

Figure 10. Cut Set Matrix for Untidy Stitching Defect

Untidy stitching defects result from both human and machine factors. The human-related cause is the operator's lack of understanding of fabric characteristics. Meanwhile, machine-related causes include the needle and hook being out of sync, incorrect thread tension, and wear and tear on the sewing machine.

Based on calculations using the Fault Tree Analysis method, the probability before evaluation is 0.0334 or 3.34%, while the probability after evaluation is 0.0336 or 3.36%. These results indicate that the two methods have not changed significantly, and both achieve optimal outcomes.

Fault Tree Analysis of Off-Center Emblem Defects

Based on the cause-and-effect diagram derived from the interview with the QC team, the next step is to create a Fault Tree Analysis (FTA) diagram for each top event. Figure 11 below presents the FTA for the off-center emblem defect.

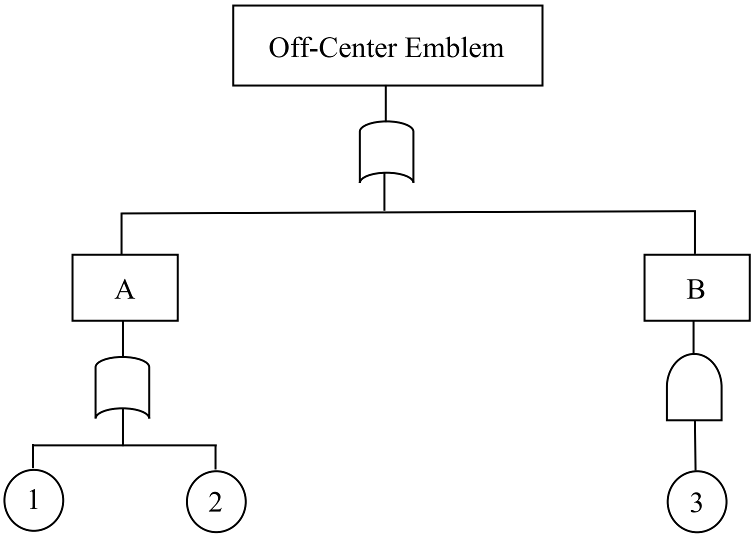

Figure 11. Fault Tree Analysis of Off-Center Emblem Defects

Description:

A : Human

B : Environment

1 : Improper Emblem Installation

2 : Not Taking Measurements Before Sewing

3 : Insufficient Lighting

The next step is to evaluate defects by compiling a cut set matrix of the root causes of off-center emblem defects, as shown in Figure 12 below.

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1			
2			
3			

Figure 12. Cut Set Matrix for Off-Center Emblem Defect

Off-center emblem defects result from both human and environmental factors. Human-related causes include improper emblem placement and failure to take measurements before sewing. Meanwhile, the environmental factor is insufficient lighting.

Based on calculations using the Fault Tree Analysis method, the probability before evaluation is 0.0236 or 2.36%, while the probability after evaluation is 0.0237 or 2.37%. These results indicate that the two methods have not changed significantly, and both achieve optimal outcomes.

Fault Tree Analysis of Stain Defects

Based on the cause-and-effect diagram derived from the interview with the QC team, the next step is to create a Fault Tree Analysis (FTA) diagram for each top event. Figure 13 below presents the FTA for the stain defect.

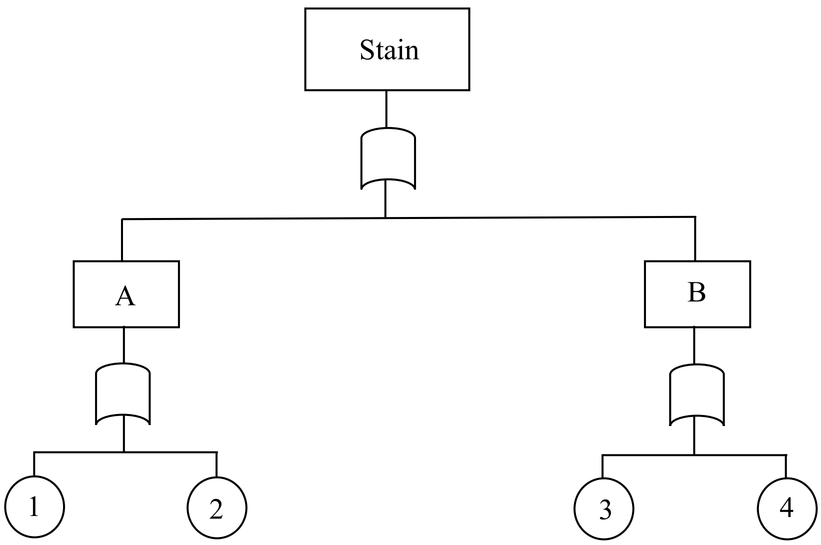

Figure 13. Fault Tree Analysis of Stain Defect

Description:

A : Human

B : Machine

1 : Excessive Use of Marking Chalk

2 : Dirty Operator Hands

3 : Machine Not Routinely Cleaned

4 : Machine Lubricant Leaking

The next step is to evaluate defects by compiling a cut set matrix of the root causes of stain defects, as shown in Figure 14 below.

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1			
2			
3			
4			

Figure 14. Cut Set Matrix for Stain Defect

Stain defects result from both human and machine factors. Human-related causes include dirty operator hands and excessive use of marking chalk. Meanwhile, machine-related causes involve inadequate cleaning and lubricant leaks.

Based on calculations using the Fault Tree Analysis method, the probability before evaluation is 0.0313 or 3.13%, while the probability after evaluation is 0.0316 or 3.16%. These results indicate that the two methods have not changed significantly, and both achieve optimal outcomes.

Failure Mode Effect Analysis (FMEA)

After identifying the type of component failure using the Fault Tree Analysis (FTA) method, the next step is to prioritize improvements to enhance the quality of PDH shirt production using the Failure Mode and Effect Analysis (FMEA) method. This stage involves applying the FMEA method by assessing each failure mode based on three main criteria: Severity (S), Occurrence (O), and Detection (D). Based on these three values, the Risk Priority Number (RPN) is calculated to determine which failures require immediate attention. Details of the FMEA analysis results are presented in Table 2.

Table 2. Failure Mode Effect Analysis (FMEA)

Potential Failure Mode	Potential Effect of Failure	S	Potential Cause	O	Current Control	D	RPN
Reverse Embroidery	Reverse embroidery results can make the product's appearance inconsistent with the original design, compromise aesthetics, and potentially lead to customer complaints	8	• Reverse fabric installation • The operator is less careful in checking the embroidery results • Wrong direction of embroidery program input • Mirror feature on embroidery machine active	5	• Marking fabric sides with chalk • Checking the embroidery results regularly • The embroidery program is checked twice before it is run • Checking embroidery machine settings before starting production	6	240
Untidy Stitching	Untidy stitching can reduce the perceived quality of a product, make it look less professional, and increase the risk of faster damage, potentially leading	7	• Operators lack understanding of fabric characteristics • Needle and hook are out of sync • Improper thread tension setting • Machine wear and tear	6	• Developed pre-sewing fabric preparation procedures such as how to check fabric fiber direction and seam testing methods • Check the position of the needle against the hook at	6	252

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	to customer complaints				the beginning of each shift and test the stitches before starting production • Checking thread tension before production • Develop a regular machine lubrication schedule to maintain optimal sewing machine performance		
Off-Center Emblem	Off-center emblems can disrupt product symmetry, indicate a lack of precision in production, and diminish customer trust	5	• Emblem placement is not appropriate • Not taking measurements before sewing • Insufficient lighting	6	• Marking the position of the emblem using marking chalk • Operators are required to measure the position of the emblems before sewing • The work area is provided with sufficient lighting	7	210
Stain	Stains on products make them look dirty and unmarketable, reducing their visual appeal, harming brand reputation, and leading to consumer complaints	8	• Operator dirty hands • Excessive use of marking chalk • Machine is not cleaned regularly • Machine lubricant leaks	4	• Operators are required to wash their hands before work • The use of marking chalk is limited so as not to leave marks • The machine is cleaned every day after use Regular checks are carried out to ensure there are no lubricant leaks	5	160

Recommendation for Improvement

Based on the Risk Priority Number (RPN) calculation, the causes of process failures leading to product defects can be identified. These causes are then ranked by RPN value, from highest to lowest, enabling targeted improvement recommendations for each issue. The details of these recommendations are presented in Table 3.

Table 3. Recommendation for Improvement

Priority	Potential Failure Mode	RPN	Recommendation
1	Untidy Stitching	252	• Conduct pre-production briefings to introduce fabric characteristics and train operators on fabric properties • Check the needle position against the hook at the beginning of each shift and perform test stitches before starting production

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			• Perform a 10 cm test run before sewing the product • Organize a regular machine lubrication schedule to maintain optimal sewing machine performance
2	Reverse Embroidery	240	• Mark the outer and inner sides of the fabric • Check the embroidery results periodically • Create a checklist of embroidery programs that must be signed by the operator before starting • Verify the embroidery machine settings before starting production
3	Off-Center Emblem	210	• Mark the position of the emblem using marking chalk • Operators must measure the position of the emblem before sewing • Ensure the work area is provided with sufficient lighting
4	Stain	160	• Operators must wash their hands before starting work • The use of marking chalk is limited to prevent residual marks • The machine is cleaned daily after use, and a machine cleaning form is completed • Routine checks are conducted to ensure there is no lubricant leakage

The entire study was done in order to explain the origin, maturement and continuity of defects in PDH shirt manufacturing in the manufacturing chain of CV Graha Konveksindo Sidoarjo. The Fault Tree Analysis and Failure Mode and Effect Analysis helped in usage to investigate the issue beyond the surface level and allow the underlying structure of the problems to be seen. All the categories of defects were tracked to their root cause, which gave a better representation of loci of failures and why they would occur again. In such perspective, the study does not just measure the number of defects but also clarifies the culture of work, technical consistency, operator attentiveness as well as equipment preparedness that determines the eventual output.

The results show that quality disruptions relying on a combination of both human conduct, machine functioning, and discipline in procedures imply that quality enhancement efforts should consist of technical procedures and human capacity building. The risk prioritization supported by the probability calculations provide a practical model to the decision-makers who emphasize on remediation. The company is now able to understand which issues should be addressed immediately and which spheres can be reinforced gradually in the process of continuous quality improvement. In such a way, the analytical outcomes have increased relevance not only to the intellectual knowledge but also to the actual change in production.

Conclusion

There are four types of defects in PDH shirt products: reverse embroidery defects, untidy stitch defects, off-center emblem defects, and stain defects. Among these four defect types, there are 15 root causes that contribute to their occurrence. The probability of occurrence for reverse embroidery defects is 3.53%, untidy stitch defects 3.34%, off-center emblem defects 2.36%, and stain defects 3.13%. To reduce PDH shirt defects based on the Risk Priority

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Number (RPN) value, several improvements can be implemented, including: establishing fabric preparation procedures before sewing, such as checking fabric fiber direction and stitch testing methods; verifying needle position relative to the hook at the start of each shift and testing stitches before beginning production; inspecting thread tension before production; creating a regular machine lubrication schedule to maintain optimal sewing machine performance; marking fabric exterior and interior using chalk; performing regular embroidery checks; reviewing the embroidery program twice before execution; inspecting embroidery machine settings before starting production; requiring operators to wash their hands before working; limiting the use of marking chalk to prevent residue; cleaning machines daily after use; and conducting routine inspections to ensure there are no lubricant leaks. Suggestions for further research should explore alternative methods for analyzing defect types at CV. Graha Konveksindo Sidoarjo to support future developments.

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