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Jersey Production Quality Control Using Six Sigma and FMEA Methods To Minimize Product Defects

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ABSTRACT

CV. Genethics is a company engaged in the field of clothing with a primary focus on product quality and customer satisfaction. Based on production data for September 2022 to September 2023, defective products were still found in the jersey production process, with the percentage of defects exceeding the company's tolerance limit of 2%. The defects often occur include white spots, wrinkles, ink buildup, faded ink, non-uniform color, and shadow lines. This research aims to identify the causes of defects in the production process, find the root of the problem, and provide improvement recommendations to reduce the percentage of defects so that it approaches the tolerance limit set by the company. The research uses Six Sigma and Failure Mode and Effect Analysis (FMEA) methods to analyze the problem. The main factors that cause defects are people, information, and methods. Based on the FMEA analysis, it was found that the cause of failure with the highest RPN value was the absence of written information regarding standard work procedures, which could potentially cause various types of defects. The proposed solution is to design a new Standard Operating Procedure (SOP) supported by additional documentation. This recommendation is expected to reduce the defect rate and improve quality control in the jersey production process.

Keywords: *Quality, Defects, FMEA, Six Sigma, Jersey Products*

Introduction

Along with changes in consumer dynamics and technological advances, customers not only consider the function and price of a product but demand high quality and a satisfying experience. According to [1], [2], [3], one factor influencing consumers' decisions to buy a product or service is the quality of the product. According to [4], [5], [6], [7], product quality is a form of value given to a product based on how well the product functions and how well the product can meet consumer expectations. Therefore, products must be of good quality per customer standards, needs, and desires, and every process must run correctly to ensure quality.

CV. Genethics is a company operating in the apparel sector with the company's focus being product quality and customer satisfaction. One of the products produced is jersey clothing, which will be the focus of this research. The company applies critical quality (CTQ) to achieve quality following established specifications and standards. The company has product CTQ to meet product quality standards and process CTQ to meet production process performance quality standards. If an inappropriate product CTQ is inappropriate, the jersey product can be considered defective.

In the jersey production process, products often do not comply with (defect) the company's standard specifications. The defects found include shadow lines, dissimilar colours, white spots, faded ink, the buildup of ink, and wrinkles on the fabric. These defects greatly affect the final product of the jersey because the percentage of defects produced still exceeds the company's defect tolerance of 2%. This causes many defective products to be thrown away, which can cause losses. Efforts that need to be focused on this problem are reducing defects in the jersey production process.

Based on problems identified previously, improvements need to be made using a method that can reduce the risk of defective products and improve quality control per the CTQ of existing products in the company. One method that can help overcome this problem is the FMEA (Failure Mode and Effect Analysis) method. According to [8], FMEA analysis is a method used to identify failures in a product or process and analyze the impact and possibility of these failures occurring. According to research by [9], some problems arise, namely that there are still defects in t-shirt products during the process, this is analyzed using Six Sigma and FMEA to provide suggestions for improvement.

Research Methods

Quality

Quality is the main factor that is very important so that the product produced can meet or satisfy customers [10]. According to [6], [11], [12], [13], eight dimensions of quality include Performance, Features, Reliability, Conformance, Durability, Serviceability, Aesthetics, Perceived Quality

Six Sigma

Six Sigma is a quality development methodology that relies heavily on data and statistics to improve the quality of products or services. The basic principle of Six Sigma is to direct product or service improvement by focusing on improving the processes that produce the product or service to achieve the desired level of perfection. This approach aims to identify aspects related to errors in the production or service process and reactions that will incur additional costs [14], [15], [16], [17].

The following is a process stability calculation formula using a p-control chart [18]

1. Calculate the proportion of defects (p)

$$P = \frac{np}{n} \tag{1}$$

Information:
np : Number of failures in subgroup
n : The number checked in the subgroup

2. Calculate the Central Line (CL) to calculate the average number of defective products ($\bar{p}$)

$$CL = P = \frac{\sum np}{\sum n} \tag{2}$$

Information:
$\sum np$: Total amount damaged
$\sum n$: Total number checked

3. Calculate the Upper Control Limit (UCL)

$$UCL = \bar{p} + {}^{3}\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}} \tag{4}$$

Information:
$\bar{p}$: Average product nonconformity
n : Production quantity

4. Calculate the Lower Control Limit (LCL)

$$LCL = \bar{p} - {}^{3}\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}} \tag{5}$$

Information:
$\bar{p}$: Average product nonconformity
n : Production quantity

The following are the levels of achieving the sigma level, namely as follows [19]:

Table 1. DPMO and Sigma Level

Defect per Million Opportunity	Sigma Level
691.462	1
308.538	2
66.807	3
6.210	4
233	5
3,4	6

The following is a formula for measuring process capability [20]

1. Calculate the Defect per Unit (DPU)

$$\text{DPU} = \frac{Number\ of\ Defective\ Products}{Numbers\ of\ Products\ Produced} \tag{6}$$

2. Calculate the Defect per Opportunities (DPO)

$$\text{DPO} = \frac{Numbers\ of\ Defective\ Products}{Production\ Amount\ x\ Number\ of\ Potential\ CTQs} \quad (7)$$

3. Calculate the Defect per Million Opportunities (DPMO)

$$\text{DPMO} = \text{DPO x } 10^6 \quad (8)$$

4. Calculating the Sigma Value

$$\text{Sigma Value} = \text{NORM.S.INV } \frac{10^6 - DPMO}{10^6} + 1{,}5 \quad (9)$$

Failure Mode and Effect Analysis (FMEA)

According to [21], [22] Failure Mode and Effect Analysis (FMEA) is a method used to determine the causes of defects or failures during the production process by evaluating risk priorities and formulating handling actions to avoid identified risks. The purpose of the FMEA Method, namely:

1. Identify potential risks from a process
2. Evaluate the risks of a process and its impact
3. Help determine corrective actions
4. Eliminate and reduce the possibility of failure.

According to [23], [24], [25], Recommendations for action resulting from FMEA analysis must be formally evaluated and determined through proper implementation. The following is an explanation regarding the FMEA analysis assessment categories, which include severity, occurrence, and detection:

- *Severity*: To assess how significant the impact of a failure or defect is on customers, the greater the effect, the higher the rating value given will be
- *Occurrence*: To assess how often the cause of failure occurs, the more often the cause of failure occurs, the higher the rating value given will be
- *Detection*: How big the cause of failure can be detected, the more difficult it is to detect, the higher the rating value given will be (p is the estimated probability of failure not being detected)

Next, calculations will be carried out to obtain the risk priority number or Risk Priority Number (RPN):

$$\text{RPN} = severity \times occurrence \text{ x } detection \quad (10)$$

Results and Discussion

Defect Identification

Defect identification will be carried out from September 2022 to September 2023 so that further identification can occur. The following is a table containing production quantities, number of defects, percentage of defects, and defect tolerances set by the company:

Table 2. Defect Identification

Month	Production Total (pcs)	Number of Jersey Defects (pcs)	Defect Percentage	Defect Toleration
September-2022	2.091	80	4%	2%
October-2022	1.151	58	5%	2%
November 2022	1.038	45	4%	2%
December-2022	1.002	43	4%	2%
January-2023	847	36	4%	2%
February-2023	1.053	55	5%	2%
March-2023	763	34	4%	2%
April-2023	144	12	8%	2%
May-2023	978	43	4%	2%
June-2023	1.312	54	4%	2%
July-2023	1.659	77	5%	2%
August-2023	1.941	68	4%	2%
September-2023	1.375	71	5%	2%

The percentage of defects and tolerance of the percentage of defects in the company are compared using graphs to show that there is a gap and it still exceeds the tolerance limit given. The following is the form of a comparison graph of the percentage of defects:

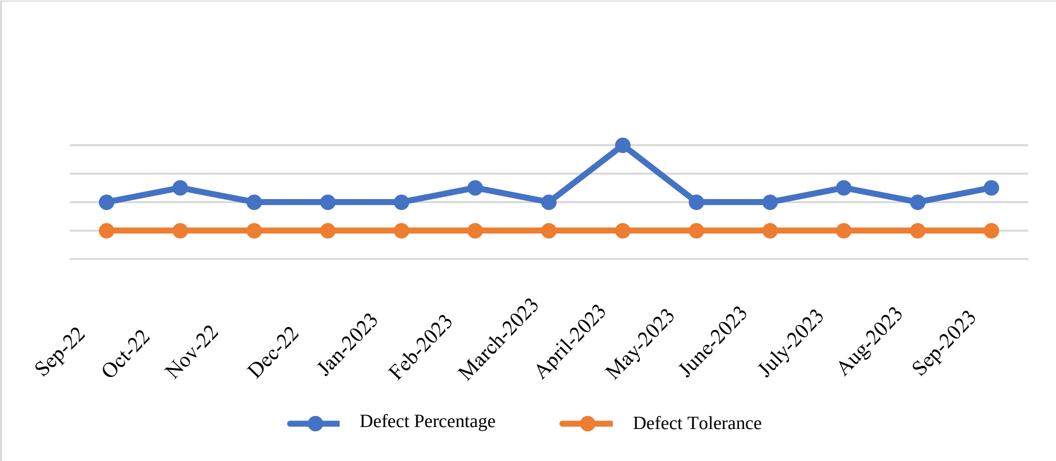

Figure 1. Comparison of Defect Percentage and Defect Percentage Tolerance

The following are the results of an analysis regarding the types and number of defects in the jersey production process from September 2022 – September 2023:

Table 3. Cumulative Percentage of Types of Defects

No.	Type of Defect	Defect Total (pcs)	Defect Percentage (%)	Cumulative Percentage (%)	Priority
1	White Spots	154	23%	23%	1
2	Wrinkles	127	19%	42%	2
3	Ink buildup	117	17%	59%	3
4	Faded Ink	111	16%	75%	4
5	Colors Are Not The Same	87	13%	88%	5
6	Line Shadow	80	12%	100%	6
	Total	676	100%		

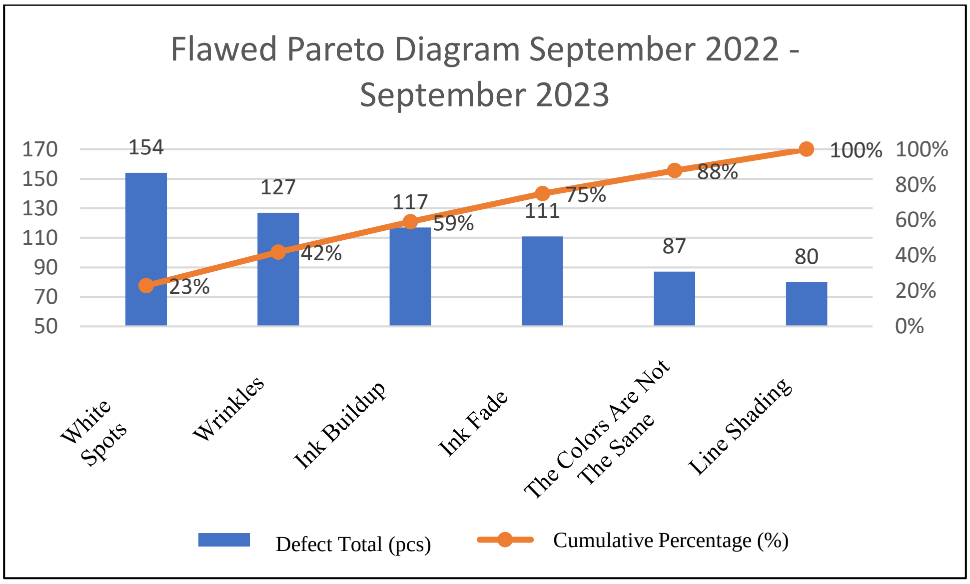

Figure 2. Deformed Pareto Diagram

After calculating the percentage of defects and cumulative defects, a Pareto diagram in Figure 2 illustrates the dominant types of defects in jersey production.

Based on the Pareto diagram in Figure 2, it can be seen that during the production process from September 2022 to September 2023, defects in the form of "White Spots" had the highest number, with 154 cases, accounting for 23% of the total defects. Other significant defect types include "Wrinkles" and

"Ink Buildup", amounting to 127 and 117 cases, respectively, with the cumulative percentage accounting for 59% of the total production defects.

P Control Map

Based on previous data, the jersey production process still produces many defects, so it is necessary to evaluate the performance of a process to find out whether the process is within control limits. The following are the results of the control chart calculation p, which consists of the proportion of defects, Central Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL):

Table 4. Control Map P

Period	Month	Production Total (pcs)	Number of Jersey Defects (pcs)	Defect Proportion (p)	CL	UCL	LCL
1	September-22	2.091	80	0,038	0,044	0,0490	0,0391
2	October-22	1.151	58	0,050	0,044	0,0490	0,0391
3	November-22	1.038	45	0,043	0,044	0,0490	0,0391
4	December-22	1.002	43	0,043	0,044	0,0490	0,0391
5	January-23	847	36	0,043	0,044	0,0490	0,0391
6	February-23	1.053	55	0,052	0,044	0,0490	0,0391
7	March-23	763	34	0,045	0,044	0,0490	0,0391
8	April-23	144	12	0,083	0,044	0,0490	0,0391
9	May-23	978	43	0,044	0,044	0,0490	0,0391
10	June-23	1.312	54	0,041	0,044	0,0490	0,0391
11	July-23	1.659	77	0,046	0,044	0,0490	0,0391
12	August-23	1.941	68	0,035	0,044	0,0490	0,0391
13	September-23	1.375	71	0,052	0,044	0,0490	0,0391

The following is a statistical visualization of the results of the p control chart calculation:

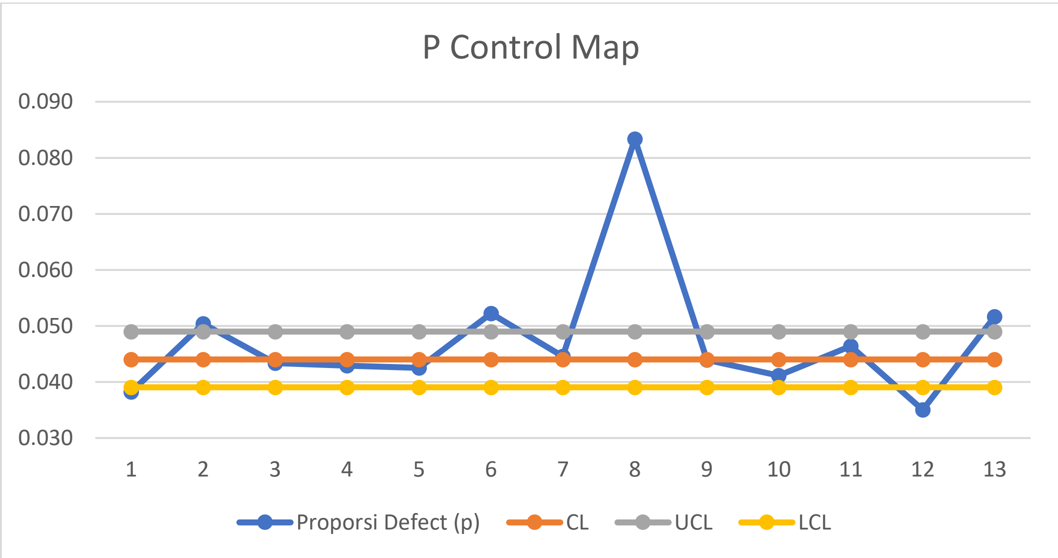

Figure 3. P Control Map Graph

Based on the results of the control chart calculation p presented in the graph, it can be seen that there are still processes that are outside the control limits. Therefore, elimination needs to be carried out during that period. The following are the results of iteration 1:

Table 5. P Control Map Iteration 1

Period	Month	Production Total (pcs)	Number of Jersey Defects (pcs)	Defect Proportion (p)	CL	UCL	LCL

1	September-22	2.091	80	0,038	0,043	0,049	0,0376
3	November-22	1.038	45	0,043	0,043	0,049	0,0376
4	December-22	1.002	43	0,043	0,043	0,049	0,0376
5	January-23	847	36	0,043	0,043	0,049	0,0376
7	March-23	763	34	0,045	0,043	0,049	0,0376
9	May-23	978	43	0,044	0,043	0,049	0,0376
10	June-23	1.312	54	0,041	0,043	0,049	0,0376
11	July-23	1.659	77	0,046	0,043	0,049	0,0376

The following is a graph of the results of the control chart calculation p which was carried out in the first iteration:

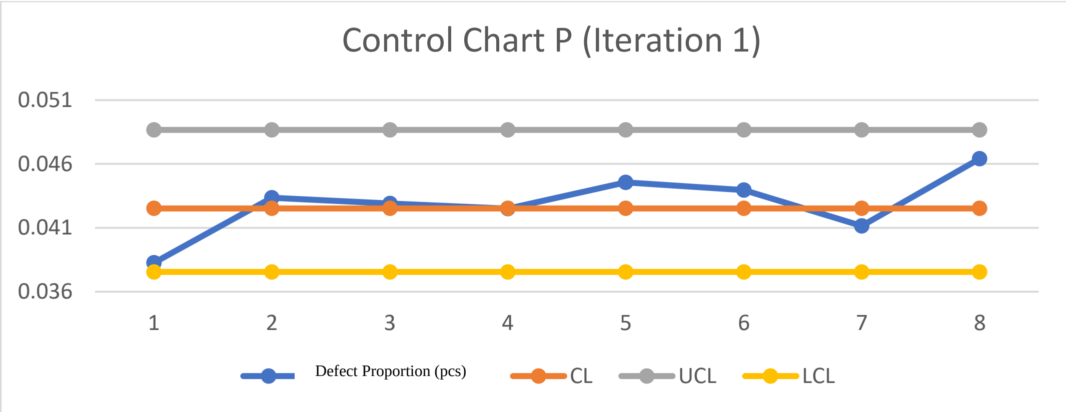

Figure 4. P Control Map Graph Iteration 1

The graph presented in Figure 4 shows that there are no longer any graphs below or above the control limit. This ensures processes remain in control, assisting in achieving and maintaining desired quality standards.

Calculation of DPMO and Sigma Value

Measurements were made regarding the ability of a process to produce jersey products in good condition. So, the DPMO calculation is carried out to see the quality of the jersey production process in the period that is within the control limits:

Table 6. Calculation of DPMO and Sigma Value

Month	Production Total (pcs)	CTQ Total	Defect Total	DPO	DPMO	Sigma Level
September-22	2.091	6	80	0,0064	6376,53	3,99
Oktober-22	1.151	6	58	0,0084	8398,49	3,89
November-22	1.038	6	45	0,0072	7225,43	3,95
December-22	1.002	6	43	0,0072	7152,36	3,95
January-23	847	6	36	0,0071	7083,83	3,95
February-23	1.053	6	55	0,0087	8705,29	3,88
March-23	763	6	34	0,0074	7426,82	3,94
April-23	144	6	12	0,0139	13888,89	3,70
May-23	978	6	43	0,0073	7327,88	3,94
June-23	1.312	6	54	0,0069	6859,76	3,96
July-23	1.659	6	77	0,0077	7735,58	3,92
Agustus-23	1.941	6	68	0,0058	5838,91	4,02
September-23	1.375	6	71	0,0086	8606,06	3,88
Total	15.354		676			
Average				0.0079	7894,30	3,92

Based on the calculation results in Table 6, it can be seen that during the period within the control limits, it had a sigma value of 3.92 with a possible 7894,30 DPMO

Fishbone Diagram

After knowing the existing problems, the next step will be to identify the roots of the problems using the fishbone diagram tool. The following is a fishbone diagram with the main problem in the fish head, namely, the percentage of defects still exceed the company's tolerance limit (2%):

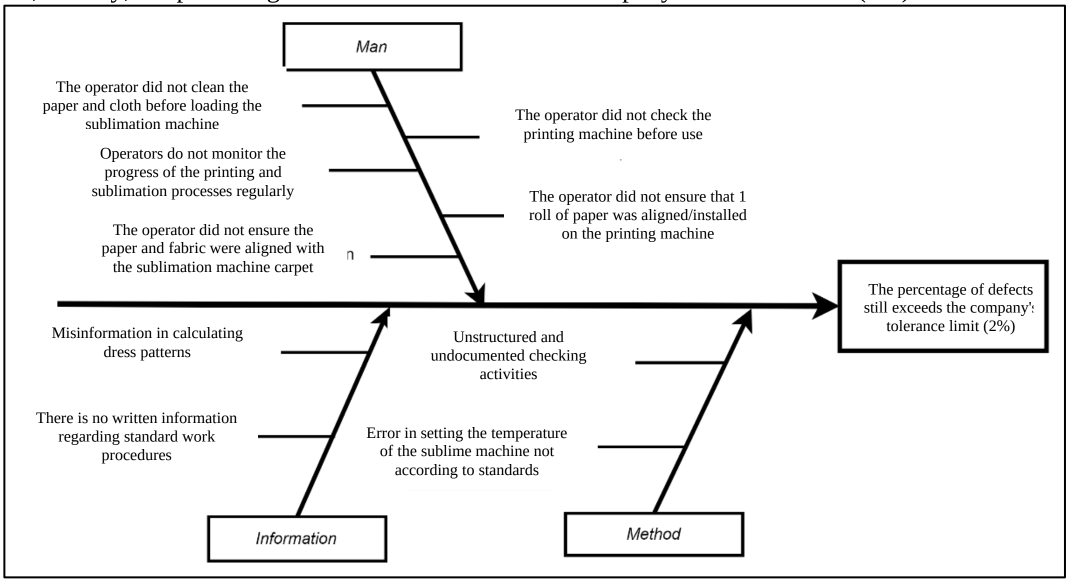

Figure 5. Fishbone Diagram

The fishbone diagram identified three main factors contributing to product defects: human, information, and method factors. Human factors involve operators' lack of attention to procedures, while information factors relate to inaccuracies in data and written procedures. Method factors include errors in machine settings and lack of documentation of checking activities.

FMEA analysis

Once the root of the problem is known, an analysis will be carried out using FMEA. At this stage, failure modes, failure effects, failure causes, and current control will be determined to obtain severity, occurrence, and detection values to calculate the Risk Priority Number (RPN). The results with the highest RPN value will be prioritized for recommendations for improvement. The following is an FMEA analysis table to get the highest RPN value:

Table 7. FMEA analysis

Factor	Failure Mode	Consequences of Failure	Severity	Causes of Failure	Occurrence	Current Control Process	Detection	RPN
Man	The operator did not clean the paper and cloth before loading the sublimation machine	There is dirt that is printed on the cloth, preventing the ink from sticking to the cloth and causing white spots	6,67	The operator only refers to the information provided at the start of work and daily activities	7	Clean by hand if you see fabric fibres	3	140,07

	Clean by hand if you see fabric fibers	1. The paper can move slowly at an angle during the process so that the paper can hit the printing machine head, which can cause line shadows to appear 2. The fabric can accumulate on other parts of the fabric when it comes out of the sublime machine if it is not monitored when it comes out, causing the ink to bleed onto other parts.	5,33	The operator only refers to the information provided at the start of work and daily activities	6	Repeat the process with more focus on the ongoing process	3,67	117,37
	The operator did not ensure that the paper was straight and parallel to the fabric	1. Paper and fabric can wrinkle during the sublimation process, resulting in wrinkles in the sublimation results 2. There is a buildup of ink on the paper and cloth because the cloth and paper are not aligned	5,67	The operator only refers to the information provided at the start of work and daily activities	5,33	Repeat the process with more care	2,33	70,42
	The operator did not check the printing machine before use	The machine can error in the middle of the process and the ink can get clogged during the printing process	3,33	There is no maintenance schedule for the machine	4	Carry out ink testing before starting the printing process	4,67	62,20
	The operator did not ensure that 1 roll of paper was aligned/installed on the printing machine	There is a head collision between the paper and the printing machine	3,67	The operator only refers to the information provided at the start of work and daily activities	4	Repeat the process more carefully and thoroughly	4,33	63,56
Information	There is no written information regarding standard work procedures	Errors in the jersey production process did not meet the standards	7	Operators do not have written work guidelines	7,33	Referring to daily habits and briefings when starting work	3,67	188,31

	Referring to daily habits and briefings when starting work	There is a lack of patterns, or the pattern of one shirt is incomplete	3	There is no structured data collection format yet	4,67	Recalculate and recreate missing patterns	2,67	37,41
Method	Recalculate and recreate missing patterns	Defective products pass to the next process	6,67	There is no documentation of inspection activities	7,33	There is no documentation of inspection activities	2,67	130,54
	Error in setting the temperature of the sublime machine not according to standards	The ink on the fabric does not stick optimally, which causes the ink to fade	6,67	The operator only refers to the information provided at the start of work and daily activities	6,67	Make sure the temperature is up to standard	3,33	148,15

Based on the results of the FMEA analysis, the RPN value was calculated from the highest value to the lowest value. Then, you can discover the causes of problems that result in defective products. The following is a table that presents the order of problems from the highest RPN value to the lowest RPN, along with recommended solutions that can be provided:

Table 8. Order of Repair Priority

Priority	Failure Mode	Potential defects	RPN	Potential Defects
1	There is no written information regarding standard work procedures	All defects may occur	188,31	Designing Standard Operating Procedures (SOP) with additional documents
2	Error in setting the temperature of the sublime machine not according to standards	Ink fades	148,15	Create work instructions to minimize errors in conformity to work standards
3	The operator did not clean the paper and cloth before loading the sublimation machine	White Spots	140,07	Create work instructions to minimize errors in conformity to work standards
4	Unstructured and undocumented checking activities	All Defects Pass	130,54	All Defects Pass
5	Operators do not monitor the progress of the process regularly	line shading & ink fade	117,37	Make a sensor device to stop the machine
6	The operator did not ensure the paper was straight and parallel to the fabric	wrinkling and ink buildup	70,42	Create work instructions to minimize errors in conformity to work standards
7	The operator did not ensure that 1 roll of paper was aligned/installed on the printing machine	Line shading	63,56	Create visual displays to assist operator work instructions
8	Create visual displays to assist	Unequal colours & line shading	62,20	Create a machine maintenance schedule

	operator work instructions			
9	Error calculating the dress pattern	Ink fades	37,41	Create additional documents in the form of order checksheets and clothing patterns

It can be seen in the table above that the cause of failure which has the highest RPN of 188.31 is 'no written information regarding standard work procedures' which can provide potential defects 'all defects can occur' with a recommended solution that can be given in the form of 'designing a Standard Operating Procedure (SOP) with additional documents'.

Conclusion

Quality control in the jersey production process at CV. Genethics shows that there are still periods where the production process is out of control. Six Sigma and FMEA methods successfully identified the main cause of product defects, with the highest RPN value of 188.31. This was due to the absence of written information regarding standard work procedures, which could potentially cause all types of defects. One proposed recommendation is to design a new Standard Operating Procedure (SOP) equipped with additional documents to reduce potential defects.

This research is expected to solve the problem of defects in the jersey production process, focusing on improving work procedure documentation. In addition, future researchers should design and implement the proposed improvements to compare the conditions before and after the implementation of the solution and ensure that the process remains within the control limits.

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