

Quality Control of Sandal Outsole Using Six Sigma Method and Failure Mode and Effect Analysis (FMEA)

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ABSTRACT

Objective: The aim of this research is to determine the type of product defect, determine the production process capability, determine the RPN value, and provide recommendations for improvement. **Method:** The method used is the Six Sigma method and Failure Mode and Effect FMEA. **Results:** The research results show that there are 3 types of product defects with a DPMO value of 5109, and a sigma of 4.07. The dominant defect is a rupture defect with a percentage of 70.55%. The main cause of failure is that the engine's heat temperature is unstable. Corrective action that can be taken is to carry out machine maintenance and use a blower in the production area. **Novelty:** CV. Carita Niaga is a footwear manufacturing company. Sandal outsole is a product that has a lot of demand so it is produced most often and often experiences problems, namely product defects in quite large quantities, namely 1.7%.

INTRODUCTION

Quality is the degree of goodness or the level of a product [1]. Quality can be said to be a quite important component for creating a company's strategy because the better the product quality, the higher the attraction to that product, and vice versa [2]. To maintain product quality, a company needs to implement quality control in its production process so that the resulting product quality can always be maintained [3]. Quality control can be said to control the quality of a product from the production process until it becomes a finished product to prevent the emergence of products that do not meet the characteristics of product quality [4].

CV Carita Niaga is one of the many footwear manufacturing companies in East Java. This company specializes in producing PDL, PDH, and safety shoes. In producing its shoes, this company also manufactures its own outsoles. In addition to shoe outsoles, the company also produces sandal outsoles. Based on company data, the sandal outsole is a product with high demand and is frequently produced at this company. As the company received a large number of requests, problems arose. One of the frequent problems that arises is product defects during the production process. This is due to a lack of quality control [5]. The extent of product defects occurring at this company is approximately 1.7%, which is not considered a good production result given the company's defect tolerance of no more than 1% of total production. This is evidenced by the fact that from August to October, the company produced 37,620 pairs of sandal outsoles with 640 pairs of product defects. Normally, the number of outsole defects should not exceed 376 pairs. From the existing problems, it can be said that CV. Carita Niaga needs to implement

quality control to reduce defects in the outsole sandal production process. To perform self-quality control, the Six Sigma and Failure Mode and Effect Analysis (FMEA) methods can be used. The Six Sigma method will be used to analyze the causes of product defects [5]. And the Failure Mode and Effect Analysis (FMEA) method will be used to find the sources of problems and the root causes of a product quality issue, which can then provide improvement suggestions [6].

Research objectives: (1) To identify the types of outsole sandal product defects. (2) To determine process capability for outsole sandal products. (3) To determine the Risk Priority Number (RPN) in the outsole sandal production process. (4) To provide improvement recommendations to improve the quality of outsole sandals.

RESEARCH METHOD

This research was conducted with the aim of controlling the production process of sandal outsoles to minimize defects, using the DMAIC (Define, Measure, Analyze, Improve, and Control) stages of the Six Sigma method to identify the types of product defects in the production process. Next is to improve using the FMEA (Failure Mode and Effect Analysis) method.

A. Six Sigma

Six Sigma is one of the continuous and sustainable efforts aimed at creating products with zero defects [7]. The Six Sigma method involves 5 stages: Define, Measure, Analyze, Improve, and Control. These steps in Six Sigma are commonly referred to as DMAIC.

B. Failure Mode and Effect Analysis (FMEA)

The FMEA method is used to identify and prevent as many failure modes as possible [6]. Failure Mode and Effect Analysis, or FMEA, is also a method used to find the source and root cause of problems related to product quality. In FMEA, there is a calculation for RPN (Risk Priority Number). RPN itself can indicate the risk ranking in the production process. To determine the RPN value, you can multiply the parameters in FMEA. These parameters are severity (impact on the system), occurrence (probability of failure), and detection (likelihood of detecting failure) [8].

C. Six Sigma Calculation thru the DMAIC Stages

1. Define

In the define stage, the production process and various types of defects that occur in the product are identified. To understand the outsole production process, it can be illustrated using a SIPOC diagram [9]. A SIPOC diagram is a tool used for identification, explaining the elements related to the production process [10].

2. Measure

In this measure stage, process capability will be measured. The purpose of process capability itself is to determine whether a product meets its quality standards. In measuring the performance baseline using the unit DPMO or

Defects per Million Opportunities, which is useful for determining the sigma level [11]. Before performing the DPOM calculation, it is necessary to determine the control chart (P-Chart). Control charts are a tool used to understand how a process changes over time [12]. In presenting a control chart, there are several necessary data points. The data includes the Control Limit (CL), the Upper Control Limit (UCL), and the Lower Control Limit (LCL) [13]. Here are the calculations performed at this stage:

- a. Percentage of disability

$$P = \frac{\text{Number of Defects}}{\text{Production Quantity}} \dots\dots\dots(1)$$

Source: [13]

- b. Center Line (CL) Calculation

$$CL = \frac{\text{Total defect}}{\text{Total Samples}} \dots\dots\dots(2)$$

Source: [13]

- c. Calculation of the Upper Control Limit (UCL)

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

Source: [13]

- d. Calculation of the Lower Control Limit (LCL)

$$UCL = p - 3 \sqrt{\frac{p(1-p)}{\text{Samples}}} \dots\dots\dots(4)$$

Source: [13]

- e. Calculation of DPO

$$DPO = \frac{\text{Number of Defects Found}}{\text{Number of Units Inspected} \times \text{CTQ}} \dots\dots\dots(5)$$

Source: [14]

- f. Calculation of DPMO

$$DPMO = DPO \times 1.000.000 \dots\dots\dots(6)$$

Source: [14]

- g. Calculation of Sigma Value

$$\text{Sigma} = \text{NORMSINV} (1 - \text{DPMO}/1.000.000) + 1,5 \dots\dots\dots(7)$$

Source: [14]

3. Analyze

In the analyze stage, the causes of product defects are identified and analyzed according to the dominant CTQ (Control to Quality) using a fishbone diagram or cause-and-effect diagram. The analysis using a fishbone diagram will be based on human factors (man), machines (machine), raw materials (material), and methods (method) [15].

4. Improve

The improve stage is the effort used to make improvements based on the identification of failure modes and causes in the production process. At this stage, this will be done with the help of the FMEA (Failure Mode and Effect Analysis) method. This method is capable of preventing potential product

defects and can select the appropriate actions based on the Risk Priority Number (RPN) value [15]. To determine the RPN, it can be calculated using the following formula:

5. Control

The control stage is the final phase in Six Sigma. The purpose of control is to document the results of the improvements that have been made and to use it for monitoring so that the production process remains maintained and implemented.

The following is the research flowchart, which can be seen in the image below:

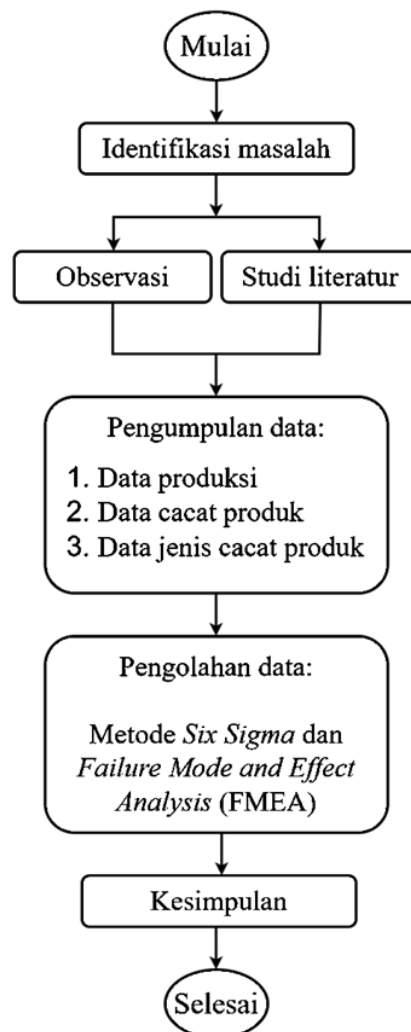


Figure 1. Research Flowchart.

RESULTS AND DISCUSSION

A. Define

In this define stage, the production process will be identified and various types of defects that arise in the product will be analyzed using a SIPOC diagram. The SIPOC diagram will explain the elements that occur in the production process, from suppliers to

the finished product sent to customers. Here is the SIPOC diagram for the outsole production process at CV. Carita Niaga.

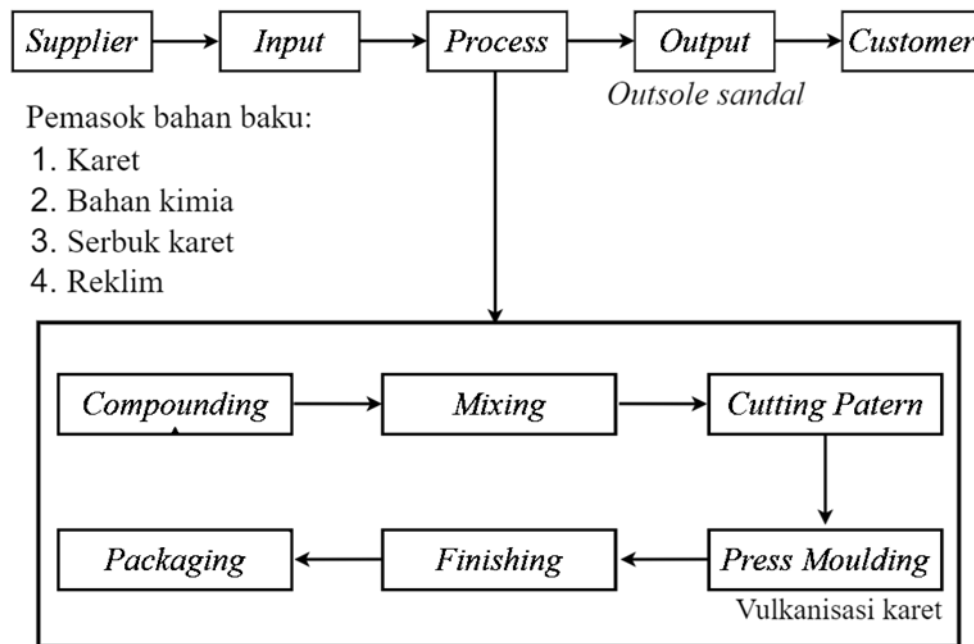


Figure 2. SIPOC Diagram.

Based on Figure 2, it is known that the outsole manufacturing process at CV. Carita Niaga is carried out in several stages. Starting from the raw material purchasing process, carrying out the production process, and finally delivering the product to the customer. As for the products sent to customers, they are of good quality and meet the product specifications determined by the company.

After understanding the production process flow, the types of product defects present in the production process were also identified, along with the number of each defect that occurred during October-December 2023. This data was obtained from prior interviews and observations.

Table 1. Number of Defective Products.

No	Month	Number of Products (Pairs)	Number of Defective Products Based on CTQ			Total Defect
			Cracked	Chipped	Error Cut	
1	October	12240	120	40	10	170
2	November	4600	68	0	17	85
3	December	13340	132	65	25	222
Total		30180	320	105	52	477

In Table 1, the classification of defects in sandal outsole products shows 3 types of defects: cracks, chips, and cutting errors. These results are data obtained from October to

December 2023. The classification data in Table 2 is used to identify the sigma value, Pareto diagram, and P-chart for this production.

B. Measure

In this measure stage, process capability will be calculated to determine whether a product meets its quality standards. In this stage, CL, UCL, and LCL will be calculated to determine whether the defects occurring in the production of this outsole are still within control limits or outside of control limits. After that, a performance baseline calculation will also be performed using the unit of Defects per Million Opportunities (DPMO), which is useful for determining the sigma level.

Calculation of UCL and LCL

In this calculation of UCL and LCL, a P-Chart is used to determine whether or not there are factors outside the control limits.

$$\begin{aligned}
 1. \quad P &= \frac{\text{Number of Defects}}{\text{Number of Samples}} = \frac{170}{12.240} = 0,0139 \\
 2. \quad \text{CL or Average (p)} &= \frac{\text{Total defect}}{\text{Total Samples}} \\
 &= \frac{477}{30.180} = 0,0158 \\
 3. \quad \text{UCL} &= p + 3 \sqrt{\frac{p(1-p)}{\text{Samples}}} \\
 &= 0,0158 + 3 \sqrt{\frac{0,0158(1-0,0158)}{12.240}} = 0,0192 \\
 4. \quad \text{LCL} &= p - 3 \sqrt{\frac{p(1-p)}{n}} \\
 &= 0,0158 - 3 \sqrt{\frac{0,0158(1-0,0158)}{12.240}} = 0,0124
 \end{aligned}$$

Next are all the results of calculating the Control Limit (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) values, which can be seen in the following Table 2:

Table 2. Calculation of CL, UCL, and LCL.

No	Month	Number of Products (Pairs)	Total Defect	Defect Proportion	CL	UCL	LCL
1	October	12240	170	0.0139	0.0158	0.0192	0.0124
2	November	4600	85	0.0185	0.0158	0.0213	0.0103
3	December	13340	268	0.0201	0.0158	0.0190	0.0126
Total		30180	477	0.0525			

Based on Table 2 above, it can be seen that the CL value from October to December is 0.0158. The UCL value in October is 0.0192, in November it is 0.0213, and in December

it is 0.0190. The LCL value in October is 0.0124, in November it is 0.0103, and in December it is 0.0126.

The next step is to present the data on a control chart (p-chart) to determine whether the analyzed data falls within the established control limits [16].

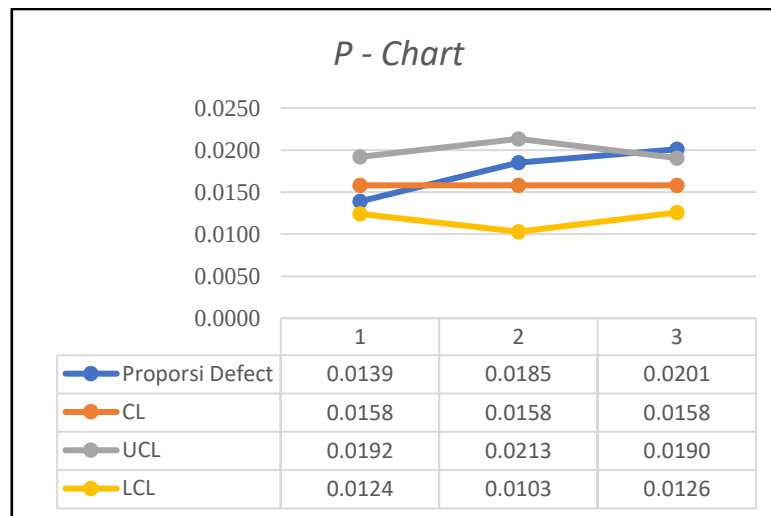


Figure 3. P-Chart Diagram.

From the calculations above, it can be concluded from Figure 3 that in December, the proportion of defects was outside the control limits (Out of Control), so an analysis of the causes needs to be conducted and data outside the control limits discarded. Then, recalculation should be performed until the data falls within the control limits (in control). The following is a recalculation of the CL, UCL, and LCL, excluding the data from December.

Table 3. Recalculation of CL, UCL, and LCL.

No	Month	Number of Products (Pairs)	Total Defect	Defect Proportion	CL	UCL	LCL
1	Oktober	12240	170	0.0139	0.0146	0.0179	0.0114
2	November	4600	85	0.0185	0.0146	0.0200	0.0093
3	Desember	8080	110	0.0136	0.0146	0.0187	0.0106
Total		24920	365	0.0460			

Based on Table 3 above, it can be seen that for improvements to be made, data points outside the control limits are eliminated during the data processing stage, resulting in new data as shown in Table 4 above. Therefore, it can be determined that the CL value from October to December is 0.0146. The UCL value for October is 0.0179, for November is 0.0200, and for December is 0.0187. The LCL value for October is 0.0114, for November is 0.0093, and for December is 0.0106.

The next step is to present the data on a control chart (p-chart) to determine whether the analyzed data falls within the established control limits [16].

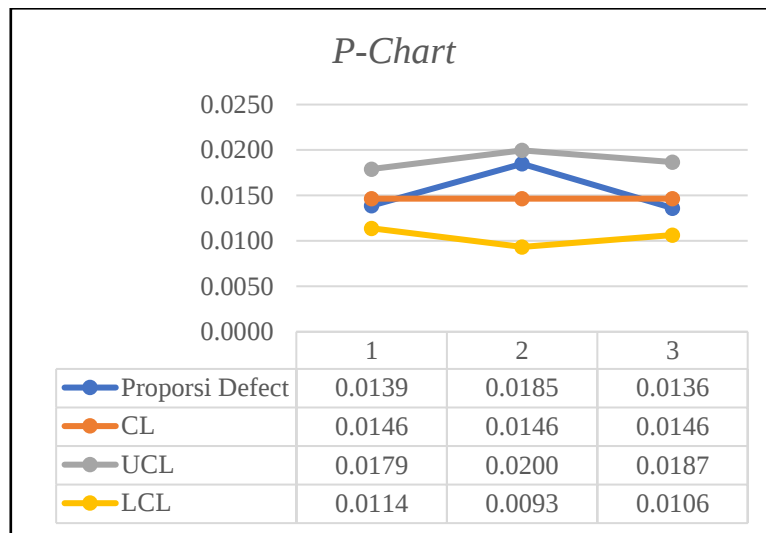


Figure 4. P-Chart Map Graph Diagram.

After the recalculation above, it can be seen in Figure 4 that all the data on the proportion of defects are within the control limits (in control).

Calculation of DPMO and Sigma Level Values

This calculation describes the number of defects per one million opportunities. When the DPMO value of a defect increases, it means that the control measures taken are still not optimal, and the sigma level will be further from the six sigma standard.

1. DPO (Defect per Opportunity) = $\frac{\text{Number of Defects Found}}{\text{Number of Units Inspected} \times \text{CTQ}}$
 $= \frac{170}{12.240 \times 3} = 0,00463$
2. DPMO (Defect per Million Opportunities) = $\text{DPO} \times 1.000.000$
 $= 0,00463 \times 1.000.000$
 $= 4692,62963$
3. Level Sigma = $\text{NORMSINV}(1 - \text{DPMO}/1000000) + 1,5$
 $= 4,10$

Table 4. Sigma Level.

No	Month	Number of Products (Pairs)	Defect	CTQ	DPO	DPMO	Level Sigma
1	October	12240	170	3	0.00463	4629.63	4.10
2	November	4600	85	3	0.00616	6159.42	4.00
3	December	8080	110	3	0.00454	4537.95	4.11
Average						5109	4.07

Based on the data calculations in Table 4, varying sigma levels were obtained. The sigma value itself can be used to interpret how often defects are likely to occur. The lower the sigma level, the higher the defect rate, which means the lower the process capability, and vice versa [17]. In November, the sigma value is 4.00, which is the lowest sigma level among the other months. Therefore, it can be interpreted that the occurrence of defects is

higher in that month compared to other months, so November needs attention in the production process because it has the lowest sigma level.

Next is to find the potential Critical to Quality (CTQ) that most affects the total defects each month. The following is the percentage of defects out of the total number of defects produced over a 3-month period, as shown in Table 5 below:

Table 5. Percentage of Defects.

Type of Defect	Quantity	Defect Percentage	Cumulative Percentage
Cracked	223	61,10%	61,10%
Chipped	105	28,77%	89,86%
Error cut	37	10,14%	100%
TOTAL	523	100%	

In Table 5, the percentage of defects for each CTQ was obtained to generate a Pareto diagram from the results of that table. The percentage of disabilities has a cumulative percentage used to determine which level of disability occurs most frequently, indicated by a significant percentage of disability. After calculating the percentage of defects, the dominant Critical to Quality (CTQ) is determined with the help of a Pareto chart. Here are the results of the Pareto diagram, which can be seen in Figure 4 below:

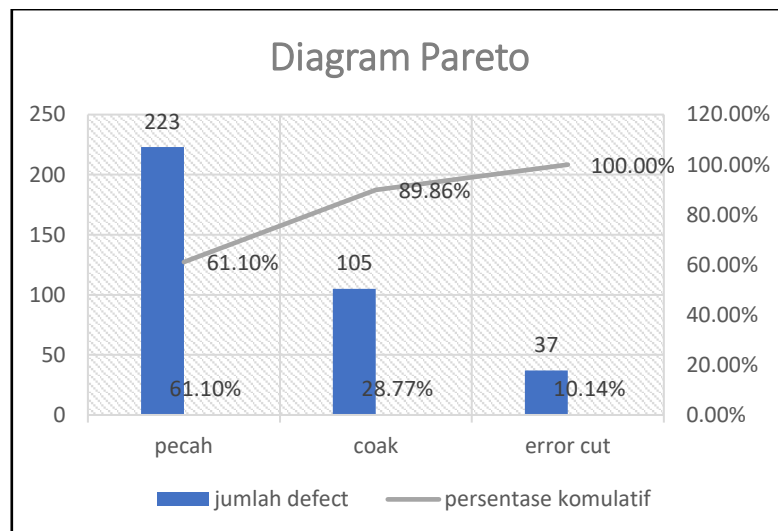


Figure 5. Pareto Diagram.

In Figure 5, the Pareto diagram shows that the dominant defect is breakage, as this defect type has the largest scale, with 223 pairs. The next dominant defect is notching, with a scale of 105 pairs, and finally, error cuts, with a defect scale of 37 pairs.

C. Analyze

In the analyze stage, the causes of product defects are identified and analyzed according to the dominant CTQ using a cause-and-effect diagram or fishbone diagram. The analysis using a fishbone diagram will be based on human factors (man), machines

(machine), raw materials (material), and methods (method) [15]. The fishbone diagram can be seen in the following image:

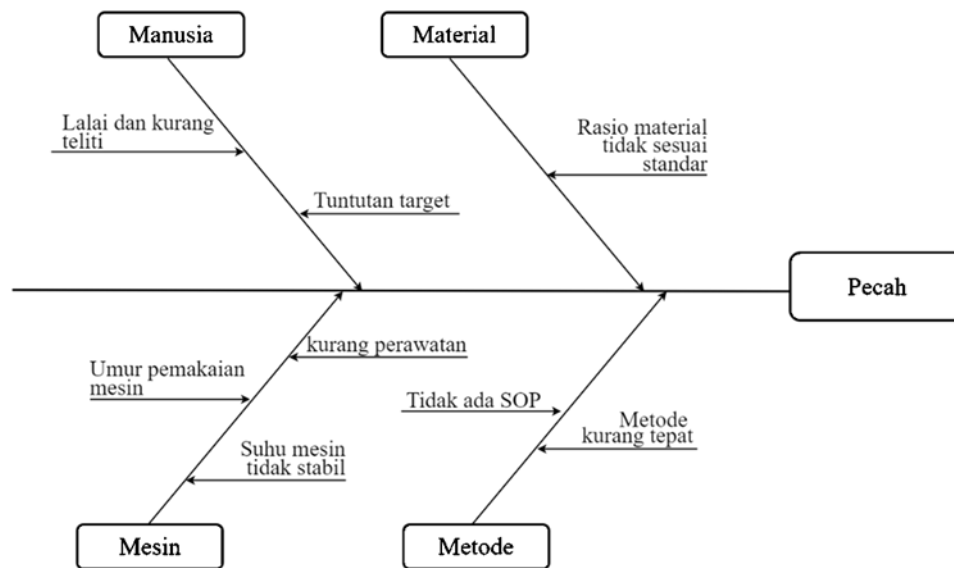


Figure 6. Fishbone Diagram.

From the fishbone diagram in Figure 6, it can be seen that the causes of defects, particularly breakage, are due to several factors: human operators (negligent and inattentive due to company target demands), materials (material ratio not meeting standards), machines (unstable machine temperature due to the machine's age and lack of maintenance), and methods (inappropriate methods because the company does not have established SOPs). From these factors, the process will move on to the improvement stage with the aim of determining the appropriate improvements for the defect so that productivity can be increased.

D. Improve

The improve stage is the effort used to make improvements based on the identification of failure modes and causes in the production process. At this stage, FMEA (Failure Mode and Effect Analysis) will be used. The data for this improvement stage is the result of observations and interviews with parties responsible for the production process of these sandal outsoles, including Mrs. Ninik Wijayanti, the business owner, Mr. Widodo, the person in charge of sandal outsole production, and the employees of this sandal outsole production.

Table 6. Failure Mode and Effects Analysis.

Type of Failure (Defect)	Potential Failure	S	Failure Causes	O	D	RPN	Rating
Reject	Outsole Cracking	5	Operator negligence and lack of attentiveness	2	2	20	3

Improper pulling and release of the outsole from the molding	3	3	45	2
Incorrect pressing time	3	1	15	5
Incorrect mold positioning	1	1	5	6
Unstable machine heating temperature	4	4	80	1
Material ratio does not match the specified measurement	2	1	10	4

Table 6 explains that the product defect of a cracked outsole is caused by several factors. The most influential causes are unstable engine heat with an RPN value of 80, inaccurate removal and release of the outsole from the molding with an RPN value of 45, and finally, operator negligence and lack of thoroughness with an RPN value of 20. Next is to analyze the root causes of the problems from the activities with the highest RPN values and determine the corrective actions that can be taken using the 5W + 1H method.

Table 7. Outsole Crack Defect Improvement.

Potential Failure	What	Why	Where	When	Who	How
Outsole Cracking	The machine heating temperature is unstable	The machine has been used for a long period and lacks proper maintenance	CV. Carita Niaga	During the production process	Operator	Performing regular machine maintenance and using a blower to stabilize the temperature
	Improper pulling and release of the outsole from the molding	Insufficient operator training	CV. Carita Niaga	During the production process	Operator	Providing training to improve operator skills
	Operator negligence and lack of attentiveness	Production targets pressure	CV. Carita Niaga	During the production process	Operator	Conducting evaluations and advising operators to be more attentive

E. Control

The control stage is the final stage of the DMAIC cycle in the Six Sigma method. This stage emphasizes the documentation and dissemination of corrective actions that will be and have been taken, including: 1. Regularly checking and maintaining production machines. 2. Monitoring employee performance to minimize outsole product defects and increase company productivity. 3. Creating company SOPs as a guide for workers in carrying out the production process.

CONCLUSION

Fundamental Finding : Based on the results and discussion, it can be concluded that: In the production of sandal outsoles, there are three types of defects, namely cracked defects, chipped defects, and error cut defects. Cracked defects refer to the condition where the surface of the sandal outsole is not smooth, caused by parts of the outsole sticking to the molding. Chipped defects are outsole defects where there are numerous small holes in the outsole. Error cut defects occur when scratches appear on the sides of the outsole, caused by a dull trimming machine used in the finishing process. Among the three types of defects, the most dominant defect is cracked defects, with a total of 223 pairs or 61.10% of all defects identified. Sigma level can be used to interpret how often the possibility of defects occurs. The lower the sigma value, the lower the capability of the production process and the higher the possibility of defects. November is considered the period with the worst capability because it has the lowest sigma value among other periods, which is 4.00. Cracked defects are the dominant defects in sandal outsole production; therefore, this defect becomes the focus for determining solutions to reduce its occurrence. **Implication :** To determine the appropriate improvements, it is necessary to identify the failure modes and causes in the production process by determining the RPN (Risk Priority Number) value using the FMEA method. The results obtained indicate that the highest RPN value is 80, caused by machine-related factors, specifically unstable machine temperature. **Limitation :** The analysis only emphasizes the dominant defect in sandal outsole production and focuses on machine-related factors, specifically unstable machine temperature, as the highest RPN cause, without further exploring additional sources of variation or broader environmental influences. **Future Research :** The recommended improvement for the dominant defect with the highest RPN value is to carry out regular machine maintenance and use a blower in the production area.

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