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Product Quality Control to Minimize Defects Using the Six Sigma Method in Labor Intensive Industries

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ABSTRACT

PAIG is a manufacturing company that produces footwear components, especially the upper part, which receives orders only from one of the world's brands and will not be produced if there is no order from the brand. The problem is that the upper quality produced by PAIG in January - November 2023 has a higher defect than the target set by management. This impacted the high demand for additional materials and became wasteful due to the time-consuming re-production, which ultimately resulted in delays in the delivery of previously agreed orders. This research aims to analyze the quality of products made by PAIG using the Six Sigma method and reduce the number of defective products currently occurring in the company. Six Sigma quality control uses the DMAIC (Define, Measure, Analyze, Improve, and Control) stages to determine the characteristics of product defects, factors that cause product defects, and improvements to the factors that cause product defects. By using the DMAIC stage, it is known that the types of defective products are divided into four categories, with the largest category being defective components, while PAIG's sigma level is 4.19, which states that there are only 323 pairs of defective products for every 1 million pairs of upper produced. The analysis of this research shows that PAIG needs a standard operating procedure (SOP) to minimize defective products in each process.

Key Words: DMAIC, Defective Products, Quality Control, Six Sigma.

1. INTRODUCTION

Competition in the industrial sector has become increasingly fierce lately, especially in labor-intensive industries, causing open competition on a large and global scale. Labor-intensive companies often face complex problems in choosing to achieve goals, especially in addressing customer needs and wants. To be able to fulfill and compete in the market, a company usually tries various ways to be ahead of its competitors by making products with excellent quality and requiring a speedy demand time and by the interests of buyers so that they can compete with comparative products both outside and within the country.

PAIG is one of the companies engaged in footwear components and only produces certain brands through contracts agreed upon by consumers as brand owners. As stated in the contract, one of the indicators of continuing to produce the brand is the product quality based on the provisions and standards provided by consumers. In connection with this, in the order period January 2023 - November 2023, PAIG experienced many defective products, which resulted in delays in delivery and losses due to additional materials that needed to be purchased. In Table 1, it can be seen that the number of defective products at PAIG exceeds the provisions set by the company by a maximum of 0.05% of the total number of products produced.

Table 1. Percentage of PAIG defective products January 2023 - November 2023

Month	Total Production (prs)	Defect		
		Quantity (prs)	% Defects	Target
Jan-23	1,117,469	602	0.054%	0.05%
Feb-23	968,127	355	0.037%	0.05%
Mar-23	1,134,209	218	0.019%	0.05%
Apr-23	589,755	211	0.036%	0.05%
May-23	1,035,568	1,657	0.160%	0.05%
Jun-23	680,143	3,370	0.495%	0.05%
Jul-23	1,180,525	3,510	0.297%	0.05%
Aug-23	1,223,724	2,161	0.177%	0.05%
Sep-23	1,105,650	1,014	0.092%	0.05%
Oct-23	1,169,933	966	0.083%	0.05%
Nov-23	1,131,736	585	0.052%	0.05%

According to the data above, many defective products exceeded the company's target standard starting in May 2023 and continuing until October 2023. The highest percentage of defective products was in June 2023 at 0.495%, July 2023 at 0.297%, August 2023 at 0.117%, and so on until November 2023, which is still above the company's target. If this continues, it can reduce company profits because defective products will require additional materials to replace them.

Looking at the background stated earlier in the industrial world, competition will always be tighter. Therefore, the problems faced by the company are:

1. What is the defect rate and sigma level of the products manufactured by PAIG?
2. What are the factors that cause product defects in PAIG?
3. What are the recommendations for improving the causes of product defects to improve product quality?

2. LITERATURE REVIEW

2.1 Quality Concept

The notion or definition of quality has a broad scope, is relatively different, and changes, so it has many criteria and is very dependent on the context. The concept of quality is often considered conformity, the overall characteristics or characteristics of a product expected by consumers.

In general, quality dimensions, according to Vincent Gazpersz (2007), identify eight quality dimensions that can be used to analyze the quality characteristics of goods, which are as follows:

1. Performance relates to the functional aspects of the product and is the main characteristic that customers consider when buying a product.
2. Features are the second aspect of performance that adds to essential functions relating to options and development.
3. Reliability relates to the likelihood of a product performing its function successfully within a specified period under specified conditions.
4. Serviceability is a characteristic of speed, friendliness/politeness, competence, ease, and accuracy in repair.
5. Conformance relates to the level of conformity of the product to the specifications previously set based on customer desires.
6. Durability measures a product's lifetime. This characteristic relates to the durability of the product.
7. Aesthetics is a subjective characteristic that relates to personal judgment and reflects individual preference or choice.
8. Perceived quality, which is subjective, is related to the customer's feelings when consuming the product.

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2.2 Quality Control Concept

Quality control is an activity (company management) that maintains and ensures that the quality of company products and services can be maintained as planned. Quality control is a preventive effort before product quality is damaged (Ahyari, 2000). The primary purpose of quality control is to obtain assurance that the quality of the product or service is by predetermined quality standards at an economical or lowest possible cost. The objectives of quality control, according to Sofjan Assauri (1998), are:

1. So that the manufactured goods can achieve the predetermined quality standards.
2. Strive to keep inspection costs as small as possible.
3. Strive for the design cost of products and processes using a specific production quality to be as small as possible.
4. Seeking to keep production costs as low as possible

2.3 Six Sigma Concept

Motorola developed the Six Sigma methodology, which large international companies use in this competitive business era (cost-sensitive and quality demand). The Six Sigma method has become a necessity for large and medium-sized companies.

Six Sigma methodology is a well-structured tool (DMAIC Stages) that can help solve technical problems, especially in manufacturing companies, which are related to the product development process (optimization) and production management process (efficiency) (Saludin, 2016). The results are in reducing production costs (reducing waste) or increasing productivity (optimizing results expressed in units of monetary value). In addition, the Six Sigma method can form a work culture that values product quality and consistency, fosters customer trust and satisfaction, and sustains increased product competitiveness in the market.

Six Sigma is a technologically advanced method engineers and statisticians use to improve or develop processes or products (Hidayat, 2008).

Six Sigma aims to help people and processes achieve high aspirations of defect-free products and services. The term zero defects does not apply here. Six Sigma recognizes that there is always the potential for defects, even in well-run processes or well-made products.

The benefits of Six Sigma are different for each company, depending on the business it runs. Usually, there are improvements in the following things:

a. Productivity improvement
b. Market share growth
c. Cycle time reduction
d. Reduction of defective products

After we know the position of business and industry performance at present (baseline measurement), for example, at 3 Sigma capability, which produces errors or failures of 66,807 DPMO (defects per million opportunities), we must make various improvement efforts towards the Six Sigma target (Six Sigma), which will only produce 3.4 DPMO.

According to Gaspersz (2011), an increase from 3 sigmas to a four sigma process capability requires about ten times improvement, an increase from 4 sigmas to a five sigma process capability requires about 30 times improvement, while an increase from 5 sigmas to 6 sigma capability requires about 70 times improvement. Thus, if we assume that Indonesia's business and industry performance is still at the three sigma capability level, it will take about 21,000 (= 10 x 30 x 70) times of improvement to reach the 6 Sigma target. This means that the higher the sigma capability, the higher the improvement effort to achieve excellence and perfection. The improvement effort from 5 sigma to 6 sigma will be higher than the improvement effort from 4 sigma to 5 sigma and also higher than the improvement effort from 3 sigma to 4 sigma.

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2.4 DMAIC (Define, Measure, Analyze, Improve, Control)

DMAIC is a methodology used in Six Sigma to solve problems that arise. This method is carried out repeatedly so that the improvement process occurs continuously. DMAIC is a structured method to solve problems and improve processes through stages. The stages are as follows:

1. Define (D); this stage is the first operational step in the Six Sigma quality control program. Things that need to be defined are:

a. Six Sigma project selection criteria.
b. Roles and responsibilities of the people who will be involved in the project
c. Six Sigma.
d. Training needs for the people involved.
e. Key processes in Six Sigma projects and their customers.
f. Specific needs of the customer.
g. Six Sigma project goal statement.

The tools used are usually Critical to Quality (CTQ) and used to brainstorm and validate customer needs and expectations of the processes targeted for development.

2. Measure (M): At this stage, three main things must be done beforehand, namely:

a. Select or define key quality characteristics (CTQs) that relate directly to the customer's needs.
b. Develop a plan for data collection through measurements that can be taken at post-process, output, or outcome levels.
c. Measure current performance at the post-process, output, or outcome level to establish a performance baseline after the start of the Six Sigma project.
d. Then, we can determine the SQL (Sigma Quality Level) value based on the Six Sigma conversion table, find the value of DPO (defects per opportunity), DPMO (defects per million opportunities), DPU (defects per unit), and calculate Yield.

3. Analyze (A) is the third stage in Six Sigma quality control where things need to be done, among others:

a. Establish performance targets of the quality characteristics (CTQs) to be improved in the Six Sigma project.
b. Identify sources and root causes of defects or failures.
c. Convert multiple failures into quality failure costs.

The tools used are usually Pareto Diagrams or bar charts that show problems based on the order of the number of occurrences. Cause and Effect diagrams show the relationship between cause and effect. Cause and effect diagrams show causal factors (causes) and the quality characteristics (effects) caused by these factors.

4. Improve (I): Plan development is one of the essential activities in the Six Sigma quality improvement program. In this stage, the Six Sigma improvement team must decide what must be achieved, why the action plan must be carried out, where the action plan will be implemented or carried out, how the action plan will be carried out, who is responsible for the action plan, how to implement the action plan, and how much it costs to implement the action plan and the positive benefits received from the implementation of the action plan.

A commonly used tool is FMEA (Failure Mode and Effect Analysis), which is used to identify the sources and root causes of a quality problem. FMEA is a structured procedure that identifies and prevents as many failure modes as possible. A failure mode is anything included in the defect, a condition outside the set specifications, or changes in the product that disrupt the product's function.

5. Control (C) is the last operational stage in a Six Sigma quality control project. This is the stage where the results of the control carried out are documented and disseminated, successful best practices in improving the process are standardized and disseminated; procedures are documented and made into standard work guidelines, and ownership or responsibility of the process, which means the Six Sigma project ends at this stage.

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3. METHOD

3.1 Ttype of Research

This type of descriptive research is carried out to identify a problem from the company, evaluate the problem, and suggest appropriate solutions or proposals for the company.

3.2 Data Collection Methods

The data collection required in the study is the stock data of material inventory of bedside table assembly products of furniture manufacturing companies, which is done in the following way:

1. Literature Study Library research leads to data collection obtained from research journals similar to current research and actual data within the scope of furniture manufacturing companies.
2. Field research
   a. Interview: Conduct interviews by asking questions directly with related parties to obtain data on problems and improvements needed to reduce or prevent inefficient material availability.
   b. Observations are made by directly observing the location in the work group working on bedside table assembly products to obtain the necessary data and information.

3.3 Data Processing and Analysis Methods

The method used refers to the principles contained in the Six Sigma method. This method anticipates errors or defects by using measurable and structured steps. Based on existing data, continuous improvement can be carried out using the Six Sigma methodology, which includes DMAIC (Gaspersz, 2002).

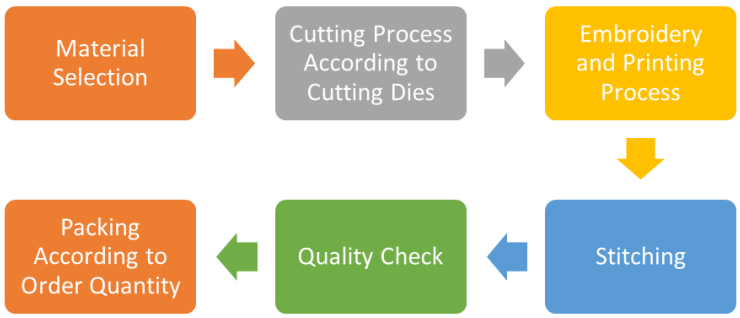

Figure 1. Research steps

4. RESULT AND DISCUSSION

PAIG is a manufacturing company that produces footwear components, especially uppers, that accepts orders only from one of the world's brands and will not produce if there is no order from the brand. The upper manufacturing process can be explained as follows:

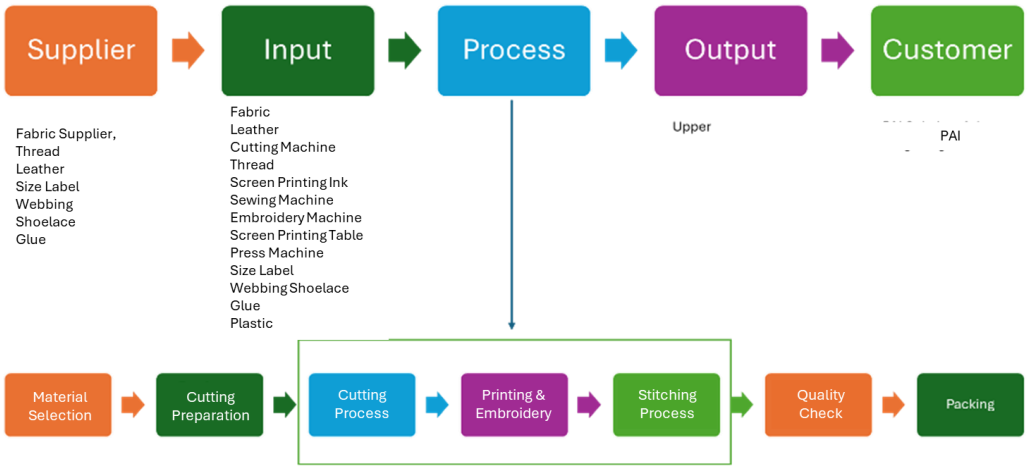

Figure 2. Upper Product SIPOC Diagram

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4.1 Define (D)

The earliest stage in improving quality with the Six Sigma method is the Define stage. The tools used are CTQ (Critical et al.). CTQ is a crucial characteristic directly related to consumer desires. To identify CTQ, VOC (Voice of Customer) or the voice of the customer is needed to determine what the customer needs.

In the research conducted, CTQ was obtained from discussions with the Head of Production and the Head of Quality so that consumers could understand what is needed. The following is CTQ (Critical et al.) based on the inspection results of related parts.

Table 2. CTQ of PAIG Products

No	CTQ	Description	Objective
1	Broken Components	There are some parts of the product that have damaged components, such as cuts or peeling.	Komponen harus sempurna, tidak ada yang rusak, tidak ada yang terpotong ataupun tidak ada yang terkelupas
2	Poor Stitching	The stitches are wrinkled, the stitch step is not according to the standard, the stitch distance from the edge of the component is too small, the stitches jump, and the stitches break.	Seams must be in accordance with specifications, including sewing steps, seam allowances and all seams must be perfectly stitched.
3	Cleanliness	There are dirty products with glue marks, sewing guide marks, pen marks and other stains.	The product must be free of glue marks, sewing guides, pens or other stains.
4	Others	Incomplete components, different colors of components, and not in pairs.	Must be in pairs and the same color

4.2 Measure (M)

The next stage is calculating or measuring the sigma value, DPMO (Defect Per Million Opportunity), and the probability of products that are not defective (Yield). This stage has a vital role in improving a product's quality because, with this calculation, the company's current performance can be known as a basis for further analysis and improvement.

Table 3. Calculation of DPMO, Yield, and Sigma values of Upper PAIG products

Month	Total Production (prs)	Defect Quantity (prs)	Sigma Calculation				
			DPU	DPO	DOPMO	Yield	Sigma
Jan-23	1,117,469	602	0.000539	0.000135	135	99.95%	5.14
Feb-23	968,127	355	0.000367	0.000092	92	99.96%	5.24
Mar-23	1,134,209	218	0.000192	0.000048	48	99.98%	5.40
Apr-23	589,755	211	0.000358	0.000089	89	99.96%	5.25
May-23	1,035,568	1,657	0.001600	0.000400	400	99.84%	4.85
Jun-23	680,143	3,370	0.004955	0.001239	1239	99.51%	4.53
Jul-23	1,180,525	3,510	0.002973	0.000743	743	99.70%	4.68
Aug-23	1,223,724	2,161	0.001766	0.000441	441	99.82%	4.83
Sep-23	1,105,650	1,014	0.000917	0.000229	229	99.91%	5.00
Oct-23	1,169,933	966	0.000826	0.000206	206	99.92%	5.03
Nov-23	1,131,736	585	0.000517	0.000129	129	99.95%	5.15
Total	11,336,839	14,649					
Avg	1,030,622	1,332	0.001292	0.000323	323	99.87%	4.91

Based on the calculations above, the average sigma level of Upper PAIG products from Jan - Nov 2023 is 4.91. The average DPMO is 323 pairs per one million opportunities, with a reasonable product probability of 99.87%.

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4.3 Analyze (A)

After obtaining the calculation, the next step is to create a Pareto diagram based on the number of defects and their cumulative percentage, which can be seen in the figure. The diagram shows that the dominant type of defect in PAIG upper products is the type of defective component defect, with a total defect of 8474 pairs or 57.85% of the total defect. Therefore, special handling is needed for repair.

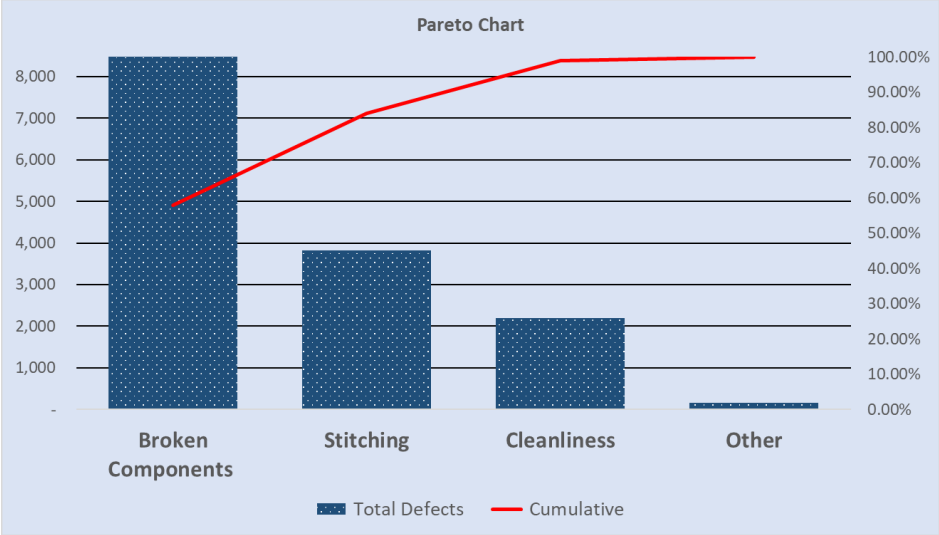

Figure 3. Pareto diagram of Upper PAIG's Janis Rijek Products

After making a Pareto diagram, defective components are the most significant cause of defects, with a percentage of 57.85%. This defect often occurs due to factors such as man, machine, material, method, or the environment. So, it is necessary to analyze the defect using cause-and-effect diagrams to determine its cause.

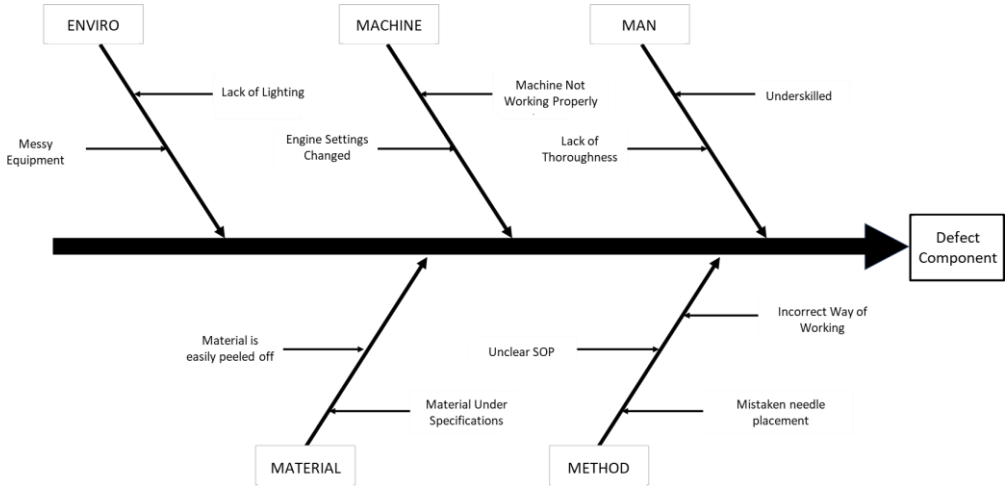

Figure 4 Faulty Component Cause and Effect Diagram

From the cause and effect diagram, it can be seen that several factors caused the rejection, including:

1. Human factor: Employees lack conscientiousness and expertise.
2. Machine factors: The machine settings changed, and the machine was not operating correctly.
3. Material factor: Material is easily peeled off and not according to specifications
4. Method factors: Unclear SOP, needle insertion error, and wrong working method.
5. Environmental factors: Lack of lighting and cluttered condition of equipment.

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4.4 Improve (I)

The next stage is the Improve stage, which helps improve problems previously known at the Analysis stage so that improvement proposals can be given according to problems prioritized to be fixed. At the improvement stage, the tools used are FMEA, which functions to find the most prioritized problems to be improved according to the largest RPN (Risk Priority Number) value.

Based on the cause of failure table from RPN with a value range of 1-99, among others, from human factors, namely lack of expertise (84), from environmental factors, namely messy equipment conditions (84) and poor lighting (70). So that the action to overcome the cause of failure/defect is to monitor without action.

Table 4. Causes of Defects Judging from the RPN Value

No	Component	*Modes of Failure*	*Effect of Failure*	*S*	*Cause of Failure*	*O*	*Current Control*	*D*	*RPN*	*Recommendation*
1	Upper PAIG	Broken Component	Perforated Products, Different Color Products, Product Peeling, Broken Products	7	Underskilled	4	Reprimand, Retrain	3	84	1. Improve Skill with Practice 2. Increase awareness of quality 3. Reward employees who have quality awareness
2					Lack of Thoroughness	5	Remind and reprimand employees, increase supervision	3	105	1. Increase Motivation 2. Add Skill 3. Reward conscientious employees
3					Engine Settings Changed	7	Machine inspection before the production process	3	147	1. Perform Periodic Maintenance 2. Supervision of frequently broken machines 3. Provide employee training to perform AM
4					Machine Not Working Properly	5	Repair the machine if it is damaged	3	105	1. Implement Preventive Maintenance 2. Supervision of Aged Machines
5					Incorrect Way of Working	5	Provide direction and explanation of the correct method	4	140	1. Provide Direction and Supervision 2. Provide Training on system operating instructions and work standards
6					Mistaken needle placement	5	Replacing the needle with the thread	3	105	1. Briefing on work standards 2. Check all machines and settings according to the type of material. 3. Supervision
7					Unclear SOP	7	Supervision and explanation	4	196	1. Improve the SOP to make it easy to understand 2. Socialization and Training on SOP 3. Supervision of the SOP in its application
8					Material Under Specifications	6	Separating and returning materials	3	126	Provide training to understand which materials cannot be used and which are good to use
9					Material is easily peeled off	5	Repairing by re-pressing	3	105	1. Returns to the previous process 2. Standardize what is good and what is not
10					Lack of Lighting	5	Adding lights to the machine	2	70	Provide and measure good lamp spacing for work according to the level of accuracy
11					Messy Equipment	6	Periodic arrangement of equipment	2	84	Improvement of work area conditions with 5S implementation

For the cause of failure with an RPN value range of 100-199, among others, from the human factor, namely less thorough (105), from the machine factor, namely the machine settings change (147), the machine does not operate (105), while from the method factor, namely needle installation errors (105), work method errors (140), and unclear SOPs (196). Because the RPN value is above 100, improvement action is needed. However, the recommended

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improvement action as a priority for prioritizing improvements to the cause of the failure mode is in the method factor with the highest RPN value, namely unclear SOP with an RPN value of 196. Improvement is only prioritized on the method factor, namely the unclear Standard Operating Procedure (SOP). SOP is an essential reference in doing a job, so if the SOP is not clear, it can result in the system not running correctly. So, by prioritizing improvements to the method factor, namely SOP improvement, it is hoped that the operation of the production process will be better and that other factors that cause failure can also be overcome.

Furthermore, the second tool at the improvement stage is the 5W + 1H tool, which accurately determines what actions must be taken to overcome existing problems.

Table 5. Corrective action plan using 5W + 1H

Type	5W+1H	Action
Main Objective	What	1. Creation of SOPs and Work Instructions if there is a change in process
		2. Socialization of SOPs and Work Instructions made to related employees
		3. Supervision of the implementation of the SOP so that it can be implemented properly
Reason	Why	1. SOPs are established to make the production process and system operation carried out in accordance with specifications
		2. SOPs are also intended to reduce defective products.
Location	Where	Implementation must be done in the entire production area
Time	When	SOPs are carried out during the production process, even before and after.
Person	Who	The person in charge of this application is the head of production
Detail Step to Implement	How	1. Create SOPs in accordance with specifications and work standards consisting of: a. The purpose of the Work Instruction is to make adjustments to the machine before work and to ensure that adjustments are made appropriately. b. Work Instructions aim to ensure that the work steps performed in the production area are precise and the steps performed are uniform. c. The SOP for inspection at each stage of the production process aims to simplify and improve accuracy in the inspection of the production process.
		2. Provide direction and briefing on the SOPs made
		3. Control the way employees work during the production process.

A standard operating procedure (SOP) consisting of machine setting SOP, work step SOP, and inspection SOP is to be socialized to all employees by providing explanations and directions on the production system operation to standardize the process. With the explanation of the SOP, employees can understand the machine setting instructions and work standards regarding how to check the accuracy of thread tension, repair if the machine is jammed or the looper shifts, adjust the sewing needle according to the fabric, and replace the needle regularly, and other issues related to machine settings and work steps. In addition, inspections need to be carried out regarding the inspection of materials coming from suppliers, whether the raw materials and supporting materials are according to specifications, inspection of the cutting machine to ensure the sharpness of the cutting knife, then inspection at the final stage of packing to ensure there are no defects in the product. In addition, controlling and supervising how employees work during production is necessary. Supervisory actions can also be taken by re-inspecting each machine used during each product type change. Following compliance with and implementing the SOP is expected to reduce defects and minimize work errors.

4.5 Control (C)

At this final stage are proposals and recommendations to maintain consistency in the quality of products made so that it is hoped that there will be no repeated mistakes in the future. Some of the suggestions are:

1. Supervision and mapping of workers means evaluating each worker's abilities for their work and creating a skill matrix.
2. Re-examine the production process by doing 3M: Receiving, Making, and Sending quality goods. This means only accepting quality goods from the previous process and returning them to the previous process if a defective product is found. Perform the process well according to the SOP and specifications so that if there is a flawed process, it will immediately replace it with a good product. Next, only send quality goods, meaning checking the processed goods before sending them to the following process.
3. Conduct regular training for workers with below-average skills to help them better understand the SOP and the quality of the products they make.

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5. CONCLUSION

Based on the calculations and data processing that have been carried out previously, the conclusions can be drawn as below:

1. PAIG Company has achieved a 4.91-sigma level, with 323 product defects for every 1 million product pairs. The highest defect is the number of damaged components due to the production process not being up to standard.
2. Methods that do not have standard operating procedures (SOPs) cause damaged products or components, resulting in changed machine settings, errors in work stages, and product quality checks that are not by the standards made and requested by the buyer.
3. The corrective action to reduce or eliminate defective products at PAIG is to make SOPs by the specifications set by the buyer and provide examples of the types of defects in each process so that workers can directly determine whether or not the products they make are defective. After that, supervision must be carried out using the 3M inspection method (Receiving, making, and sending quality goods) throughout the production process. So that workers can carry out inspections independently.

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