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Integrating DMAIC Six Sigma for Systematic Defect Analysis and Quality Improvement in Manufacturing

(Case Study: Rattan Craft Industries)

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ABSTRACT

This study focuses on a rattan-based manufacturing unit producing Base Plant Stand products, where a significant number of defects—2,305 units out of 9,000—were identified, resulting in a current sigma level of 3.14. By employing qualitative and quantitative research approaches, the study aims to identify root causes of product defects and propose process improvements to minimize their occurrence. Using the DMAIC framework of Six Sigma, the most frequent defect types were mold (27.9%), imprecision (22.7%), loose tie (20.9%), and pinhole (15.88%). Key contributing factors included excessive humidity, limited production space, insect infestation, and insufficient operator skills. Based on field research and literature, the proposed improvements include covering products with tarpaulins during rainy conditions, expanding work-in-progress (WIP) space, providing operator training, and developing clear standard operating procedures (SOPs). These recommendations aim to enhance product quality and increase the sigma level through systematic, continuous improvement. The findings are a practical reference for similar small-scale manufacturing operations seeking to optimize their production processes through quality management tools.

Keywords: *Six Sigma, DMAIC, 5W+1H, Product Defects, Rattan*

Introduction

Sumber Sejahtera Rattan uses a made-to-order production system that produces goods only if there is an order. The product that is the focus of discussion in this study is the Base Plant Stand, which can be seen in Figure 1a. The product has a demand for 9,000 units within nine weeks, namely September-October 2024. The demand was resolved by scheduling production of 1,000 units per week, with defects found in 2,305 of the 9,000 units produced. Some defects were mold, pinhole, imprecision, loose tie, and fire spot

a) Base Plant Stand b) Armchair c) Rattan Desk d) Basket

Figure 1. Rattan prosperity source craft products

In Figure 2, it can be seen that there are always defective products with fluctuating quantities every week. Products found to be faulty must be disassembled and reassembled, replaced with raw materials, or cannot be repaired at all. The number of defective products will hamper the company's production schedule. Base Plant Stand product defect data is used to measure the sigma value, and a sigma value of 3.14 is obtained.

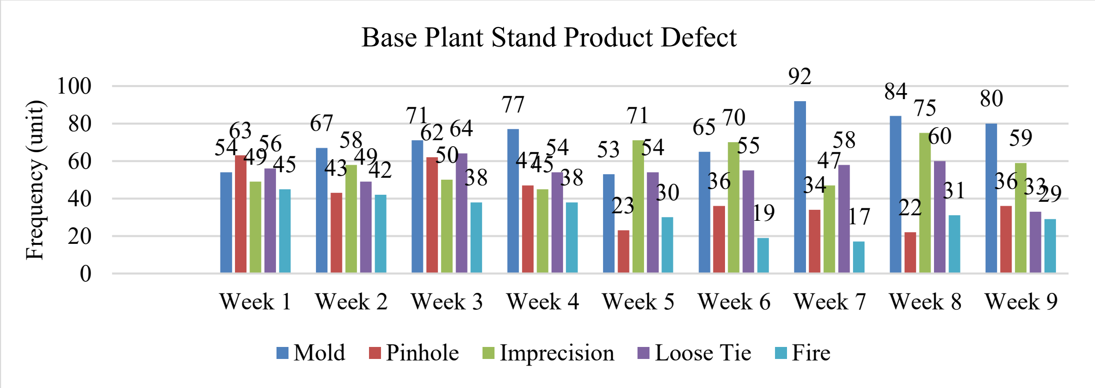

Figure 2. Base Plant Stand Product Defect

Based on several studies in the last five years, the company's sigma value, which is still at level 3, can be increased to approach a sigma value of 5 or 6. According to [1] A rattan chair production craft company with a sigma value of 3.31 can improve with the Six Sigma DMAIC method approach. According to [2] Companies with a sigma value of 3.00 in the production of rattan chairs can improve with the Six Sigma DMAIC approach. According to [3] Handicraft companies that produce rattan chairs with a sigma value of 3.49 can improve production efficiency with the Six Sigma DMAIC method.[4], [5]. In other industries, efforts to minimize product defects with the implementation of Six Sigma DMAIC have also been able to increase the sigma value. Research [6]–[8] Increased the sigma value from 3.47 to 3.62. Based on previous studies, the problems in Sumber Sejahtera Rattan regarding product defects can also be solved using the Six Sigma DMAIC method. The research conducted includes analysis, evaluation of the causes of the problem, proposed improvements, and control according to the Lean Six Sigma method using the concept of the DMAIC phase to minimize defective products and increase the company's sigma value to improve customer quality. DMAIC is a phase carried out in any improvement project, which stands for Define-Measure-Analyze-Improve-Control. DMAIC is a closed-loop process that eliminates unproductive process steps, often focuses on new measurements, and implements technologies for quality improvement towards six sigma targets.

Research Method

Research was conducted at Sumber Sejahtera Rattan to analyze the number, proportion, causes of defects, and proposed improvements to Base Plant Stand products through several stages, namely case studies, problem identification, observation, data collection, data processing, analysis, and conclusions according to the flow chart in Figure 3.

Researchers collected primary and secondary data. Primary data includes data obtained from direct observation and interviews with the operational manager of Sumber Sejahtera Rattan. Secondary data is obtained from existing sources, including company profiles, production data, defective product data, and other supporting data.

The following are some stages carried out in data processing to solve product defect problems using the Six Sigma DMAIC approach.

1. Determine the problems in the company and identify each stage of production. This stage is done using a SIPOC diagram.
2. Calculating the sigma value based on the number of productions, defects, CTQ, and DPMO calculations.

In this stage, problem analysis will be carried out based on data processing results, namely, analyzing dominant defects using Pareto diagrams, identifying things that cause defects using fishbone diagrams, and providing proposals based on the 5W + 1H principle.

Draw conclusions based on the research and analysis conducted to provide solutions to product defect problems. Suggestions contain proposals addressed to companies and other researchers.

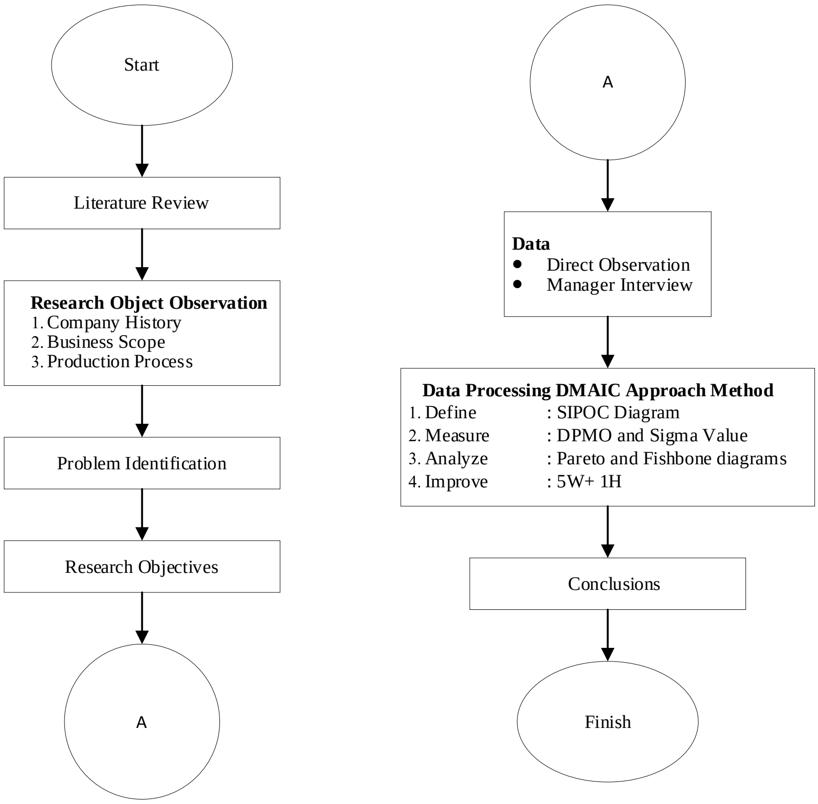

Figure 3. Flowchart of research method

Six Sigma

Six Sigma is a comprehensive and flexible system for achieving, supporting, or optimizing a business process that focuses on customer needs by utilizing data, facts, and statistical analysis and paying continuous attention to setting, improving, and reviewing processes in a business [9]–[12]. Six Sigma is a vision of quality improvement towards a target of 3.4 failures per 1,000,000 (million) opportunities DPMO (defects per million opportunities) for every product transaction (goods and/or services) or an enterprising effort towards excellence (zero defects-zero failures) [13]. According to [14], Six Sigma is a comprehensive approach to solving problems and improving processes through DMAIC.

Table 1. DPMO and sigma level

Limit Specifications (LSL - USL)	The percentage that meets specifications (LSL - USL)	DPMO (failure/defect per million opportunities)
± 1-sigma	68,26%	317.300
± 2-sigma	95,46	45.500
± 3-sigma	99,73%	2.700
± 4-sigma	99,9937%	63
± 5-sigma	99,999943%	0,57
± 6-sigma	99,9999998%	0,002

The classification of sigma values based on DPMO values can be seen in Table 1. The DPMO value obtained depends on the number of defective products, total products produced, and CTQ (Critical to Quality). CTQ identification is developed based on specifications sourced from the voice of the customer and standard specifications in the company[15]. The customer wants a product that meets the specifications but does not have these defect criteria. Here is how to determine the DMPO value.

$$\text{DPMO} = \frac{\text{number of defective product}}{\text{number of products produced x CTQ}} \text{ x } 1{,}000{,}000 \quad (1)$$

After getting the DPMO value, it is converted into a sigma value using the sigma conversion table.

Lean Six Sigma

In the process, Lean Six Sigma can systematically reduce defects with DMAIC. By defining, measuring, analyzing, improving, and controlling. [16]–[18]

1. Define is the initial stage that aims to determine the company's problems and identify the product that needs improvement. This stage is carried out by explaining the production flow and identifying the process flow from supplier to customer using the “Supplier-Input-Process-Output-Customer” (SIPOC) diagrams.
2. Measure is the second stage that aims to calculate the sigma value based on data number of defects, CTQ, and DPMO calculations.
3. The analysis stage is to analyze the dominant defects using a Pareto diagram to determine the largest defects in order and identify the things that cause defects using a fishbone diagram. A fishbone diagram is a tool used to display data about the causal factors of a defect or non-conformity and analyze the root cause of the factors causing the problem. The fishbone diagram is shaped like a fishbone and contains five factors that cause defects: humans, methods, materials, machines, and the environment.
4. The improvement stage is the stage to improve the causes identified through the previous stage. Developing an action plan is expected to eliminate existing problems. The improvement stage is a set of activities to determine, select, and evaluate several alternative improvements to improve company performance. The 5W + 1H principle (what, when, who, where, why, how) is carried out at the improvement stage as a provision of improvement proposals [19]–[22].
5. Control is the last operational stage in Six Sigma quality improvement, and continuous improvement occurs.

Results and Discussion

1. Define

Define is the stage of identifying the Base Plant Stand production process using a SIPOC diagram, as seen in Figure 4. It aims to determine the production process flow in the company. The following is a SIPOC diagram of the Base Plant Stand production process at Sumber Sejahtera Rattan.

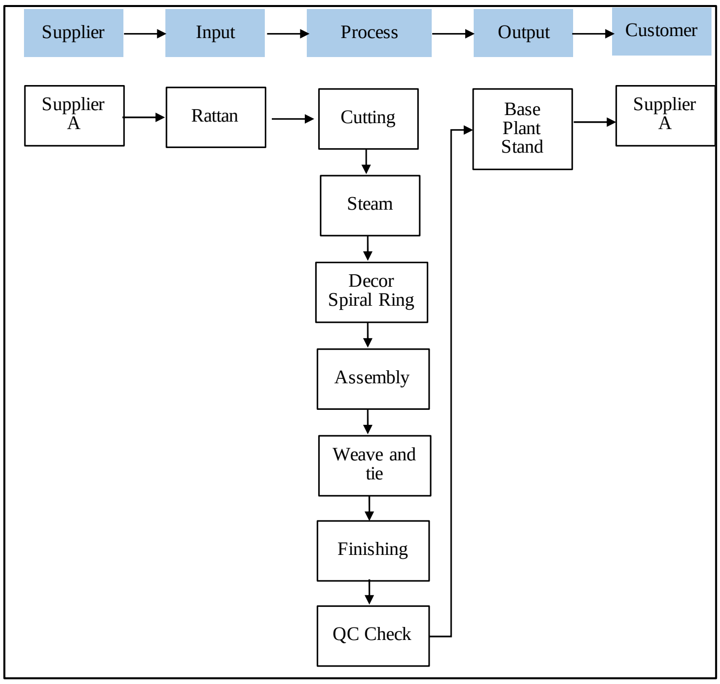

Figure 4. SIPOC diagram

Figure 4 explains the production process flow at Sumber Sejahtera Rattan starting from the supplier's request to make 9,000 units of Base Plant Stand pot products, which must be completed in nine weeks, namely the September-October 2024 period. Supplier A also provides rattan raw materials, which are input for Sumber Sejahtera Rattan to make products. The first processing stage is cutting after the raw materials enter and are received at the company. At this stage, the raw material is cut according to a predetermined size, then proceeds with the steam stage, which is the process of softening the rattan to make it more flexible and easier to shape, then proceeds with the spiral ring assembly stage, which is the benchmark for assembling the body. The body is constructed by making the upper and lower circles, elbows, and pot legs, then continuing with the plaiting and tying stage. The sanding process is carried out as a finishing stage. After the product is finished, it is continued with checking by the QC team, where products that meet specifications will pass QC and be stored in the finished goods area, while products that do not pass QC or defective goods will be reworked. The final stage, after the product passes QC, is when the product is sent to supplier A.

During the production process from the cutting to the finishing stage, several defects occur, especially in the decoration process, body assembly, and weaving process. Defects were found in mold, pinholes, imprecision, fire spots, and loose ties at these stages. At this stage, the objectives and targets of improvement that are the object of research are determined, namely, the number of defective products in the production of Base Plant Stands. The condition that can be provided to consumers is a product that meets standard specifications and is free from defects.

The types of Base Plant Stand product defects are as follows.

a. Mold Defects

This type of mold defect can be found in faintly visible mold and mold that is visible and black. Dye fungi cause bluish, brown, red, and purple spots. Dye fungi not only stain the surface of the rattan but also penetrate the rattan tissue. The higher the moisture content and humid conditions, the more active the dye fungus attack. There is also an attack by weathering fungi, which causes the rattan to become regas or weathered. This fungus attacks rattan that has been dried but often experiences wetness due to poor storage, such as long stacking and humid conditions. The shape of this mold defect can be seen in Figure 5.

b. Imprecision Defects

Imprecision defects can be found when the pot legs are not aligned and the product tilts to the right or left. The shape of this type of defect can be seen in Figure 5.

c. Fire Spot Defects

Fire spot defects are blackish, like burning. This type of defect is difficult to remove because it is not only on the surface of the rattan skin, which can certainly reduce the rattan's quality. The shape of the fire spot defect can be seen in Figure 5.

d. Pinhole Defect

Insects cause pinholes. There are two pinhole borers: the pinhole borer and the powder post beetle. Pinhole borer or wet rattan powder is caused by beetles that attack fresh rattan from the time the rattan is still growing until the rattan is harvested and causes the rattan to have small holes (0.5-2.0 mm in diameter) and a blackish color that will reduce the quality of the appearance and strength of the rattan. Powder post beetle or powder dried rattan is characterized by holes filled with fine powder. Attacks can occur in rattan raw materials and semi-finished goods. The flame defect type can be seen in Figure 5

e. Loose Tie Defect

Plaited and ikat variations are usually wrapped with glue, hot nails, or staples. These variations may come loose because the winding is not strong enough, making the product look bad. This defect is also included for loose nails and missed staples. This is because a firing nail has a different resistance from a drill nail or screw which has a spiral side on its surface so that it can withstand shear in the formed rattan connection. The shape of the firing defect type can be seen in Figure 5.


Mold defect


Imprecision defects


Fire spot defect


Pinhole defect


Loose tie defect

Figure 5. Types Of Defects

2. Measure

DPMO and Sigma Value

CTQ can be interpreted as part of the process or activity that directly affects achieving the expected quality. After brainstorming between the company and the supplier, it was found that there were 5 CTQ characteristics from the production of Base Plant Stands: mold defects, imprecision, fire spot, pinhole, and loose tie. So, the CTQ value used to calculate DPMO and sigma values is 5.

Table 2 DPMO and sigma values of Base Plant Stand

No.	Frequency	Production Quantity	Total Defects	CTQ	DPMO	Sigma
1	Week 1	1,000	267	5	53,400	3.11
2	Week 2	1,000	259	5	51,800	3.13
3	Week 3	1,000	285	5	57,000	3.08
4	Week 4	1,000	261	5	52,200	3.13
5	Week 5	1,000	231	5	46,200	3.18
6	Week 6	1,000	245	5	49,000	3.16
7	Week 7	1,000	248	5	49,600	3.15
8	Week 8	1,000	272	5	54,400	3.10
9	Week 9	1,000	237	5	47,400	3.17
Average			256			**3.14**

Week 1 Calculation

$$\text{DPMO} = \frac{267}{1{,}000 \text{ x } 5} \text{ x } 1{,}000{,}000 = 53{,}400$$

The DPMO value was obtained as 53,400, and then the sigma value was determined based on the sigma conversion table. The calculation is as follows:

$$y = y1 + (x - x1)\ \frac{y2 - y1}{x2 - x1}$$
$$y = 3.2 + (53{,}400 - 44{,}600)\ \frac{3.1 - 3.2}{54{,}800 - 44{,}600}$$
$$y = 3.2 + (8{,}800)\ \frac{-0.1}{10{,}200}$$
$$y = 3.2 + (-0.08627451)$$
$$y = 3.11$$

The recap data for calculating DPMO and sigma values for Base Plant Stand production is obtained using the same calculation formula, as shown in Table 2. The data shows that the average product defect during the nine weeks of production is 256 products, and a sigma value of 3.14 is obtained. Referring to Table 1, the sigma value of 3.14 is included in the classification of 99.73% of production that meets the specifications, meaning that the sigma value can still be improved with continuous improvement.

3. Analyze

Pareto Diagram

A Pareto diagram is a bar graph that shows a problem based on the order of the problem, starting from the most common to the least common [23]–[26] Calculating the dominant defect is useful for identifying the most common defects in the product and sorting them from most to least. The sequence of defects with the highest frequency in the production of Base Plant Stands at Sumber Sejahtera Rattan is as follows.

Table 3. Dominant defect types

No.	Defect Type	Frequency (Unit)	Percentage	Cumulative Percentage
1	Mold	643	27.90%	27.90%
2	Imprecision	524	22.73%	50.63%
3	Loose Tie	483	20.95%	71.58%
4	Pinhole	366	15.88%	87.46%
5	Fire Spot	289	12.54%	100.00%
	Total	**2,305**	**100%**	

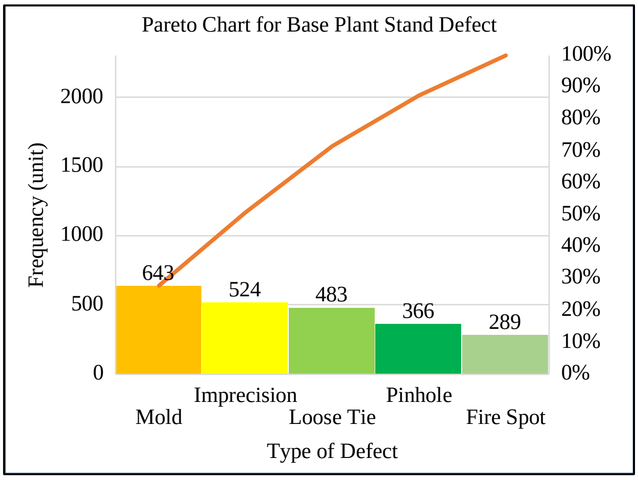

Figure 6. Cumulative pareto diagram

From the data and cumulative percentage calculations in Table 3, a Pareto diagram is obtained as in Figure 10, where the determination of defect types follows the 20:80 rule in the Pareto diagram principle. The highest defect type data is sorted from right to left to identify potential problems to be fixed. Based on the pareto principle, that 80% of issues are caused by 20% of causes, the pareto analysis of this problem is that the issues with a cumulative percentage of 80% are mold defects (27.9%), imprecision (22.7%), and loose tie (20.9%), and pinhole (15.88%). These problems are prioritized for further analysis using the Six Sigma method. Furthermore, the causes of the defects were analyzed using fishbone diagrams to identify the root cause of each CTQ.

Fishbone Diagram

The dominant defects determined based on the Pareto diagram were further analyzed using a fishbone diagram. After brainstorming with the operational manager, the factors that cause defects are as follows.

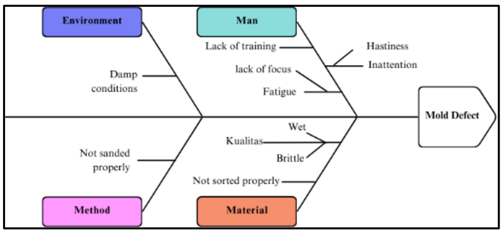

Figure 7. Mold defect fishbone diagram

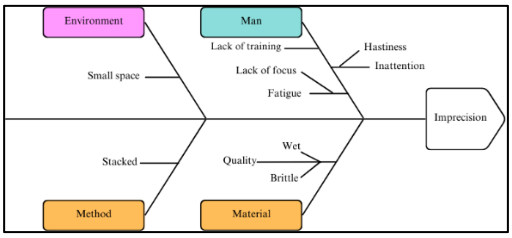

Figure 8. Imprecision defect fishbone diagram

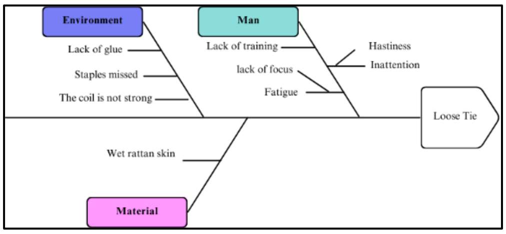

Figure 9. Loose tie defect fishbone diagram

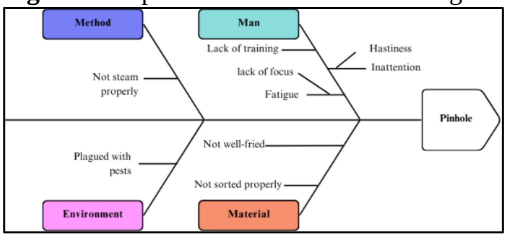

Figure 10. Pinhole defect fishbone diagram

Fungus on rattan causes the rattan to become regas or weathered, and reduces the quality of the rattan because of the coloring caused in the form of dark and brownish black colors. Based on Figure 8, several factors cause mold defects. The main factors causing mold defects are humid conditions and less than optimal oven performance. Humid conditions can be caused by weather factors, namely rattan exposed to rainwater, which can be found when it is still raw material or work in process (WIP). For raw materials, excess moisture content can be removed during the drying process with an oven. Still, the condition of the oven, which is not well maintained, causes the temperature to be unstable, so that the drying process is not optimal. Currently, there is no stage of measuring the moisture content of rattan.

Products produced with imprecision are the second most common defect in Base Plant Stand production. Based on Figure 9, the main factor causing imprecision defects is the small space that causes operators to store WIP by piling up. If there are many products, then the pile is getting higher, causing the product below to get high pressure, so that the product becomes imprecise.

Figure 10 explains that three factors caused the detachment defect. The main factors are that the operator missed firing the staples during the framing process, there was a lack of glue, and weaker winding during the plaiting process.

The Pinhole is a condition where the rattan stem is blackish and has small holes (0.5-2.0 mm in diameter). The causes of defects in the pinhole condition are several factors, namely human factors, methods, raw materials, and the environment, as shown in Figure 11. The raw material factor dominates the cause of pinhole defects. In the initial process of rattan processing, there is a frying stage where the rattan is fried in oil to reduce the water content and dissolve the sap. The beetle eggs inside the rattan die and are unable to reproduce. However, the frying stage is not optimal, which will result in the rattan still having a high-water content, so that the eggs of the beetles are still alive and can hatch. In addition, the steam process also needs to be done well to ensure that the eggs and beetles contained in the rattan die.

4. Improve

After analyzing and obtaining the factors that cause defects, the following are suggestions for improvements that can be made at Sumber Sejahtera Rattan to optimize the Base Plant Stand production process.

What

What is the main target of quality improvement?

1. Reduce mold product defects due to moisture and oven performance factors

2. Reduce imprecision defects due to narrow space, only measuring (5x1) m
3. Reduced loose tie defects due to a lack of operator skills
4. Optimizing the production process

Improvement:

1. Create a detailed and easy-to-understand Standard Operating Procedure (SOP) for the production process, including an SOP for production equipment.
2. Ensure that the work environment, especially raw material and product storage areas, is not damp. In rainy weather, this can be done by covering the product with a tarp.

Products splashed with rainwater will become wet and moist, as the moisture content becomes high. This condition causes the product to become moldy. The following is the form of improvement made:

Figure 11. Condition before being covered with a tarpaulin

Figure 12. Condition after being covered with a tarpaulin

Figure 12 shows that there are still open parts not covered by tarpaulins, so that raw materials may be exposed to rainwater splashes. In contrast, in Figure 13, the open part has a tarpaulin that can be opened when it is sunny, so there is no need to use lights, and closed when it rains.

3. Provide rest instructions so that operators are not overtired while working

Operators do not have a scheduled break time; operators can rest as they wish for 30 minutes. This is because operators will be ambitious to work to increase their daily income, but these conditions can cause fatigue, so they are not focused on working. According to the Job Creation Law Number 11 of 2020, workers are entitled to a rest period of at least 30 minutes after 4 hours of work. Sumber Sejahtera Rattan operators start working at 08.00 WIB, so there is a need for rest instructions at 12.00 WIB.

4. Train operators according to their division to improve their abilities and provide the same standards between operators, from handling raw materials to finishing.

Based on research [27] regarding improving product quality, the improvement stage for the human factor is to provide an understanding of the SOP and provide training to work by work rules is one form of effective improvement to reduce product defects, as evidenced by his research, which was able to increase the sigma level from 3.474 to 3.717. Training that can be done for Sumber Sejahtera Rattan operators is training on operating production support tools such as ovens and flame gun torches, training on the ikat and plaiting process, training on finishing sandpaper techniques, and training on occupational health and safety environment.

5. Conduct regular evaluations with operators regarding product defects so that no repetitive errors occur.

Figure 14 shows the evaluation process, which is carried out by the owner of Sumber Sejahtera Rattan together with all operators. There is also a discussion session to provide suggestions for improvement.

Figure 13. Employee evaluation activity

6. Provide a wider work in process and finish good area, measuring (5x2) m, so that products are not stacked too high.

Finish good was previously placed in the front area close to the car parking area, and the space is minimal, so the products must be arranged into 10 stacks as shown in Figure 18. This can cause the product at the bottom to get high pressure, so that it will be imprecise. Figure 19 shows the condition after improvement, the space becomes (5x2) m, and the products are only stacked 5, which can reduce the risk of imprecise products.

Figure 14. Product placement condition before improvement

Figure 15. Product placement condition after improvement

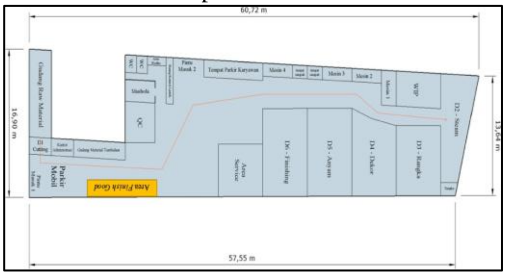

Figure 16. Layout before improvement

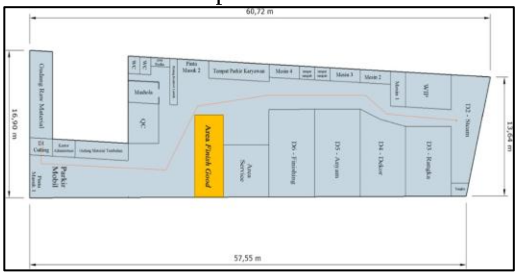

Figure 17. Layout after improvement

The finish goods area was previously located in the front area close to the car park, as can be seen in Figure 17. There is still a large area that can be used as a storage place for finish goods, so repairs can be carried out by moving the finish goods area closer to the service area, as seen in Figure 18. Placing the service area and the finish goods area close together also minimizes the mobility of employees to move repaired products.

Why

The finish goods area was previously located in the front area close to the car park, as seen in Figure 17. There is still a large area, and it is possible to become a storage area for finish goods, so that improvements are made by moving the location of the finish goods area near the service area, as seen in Figure 18. The service area and finish good area placed close together can also minimize employee mobility to move products that have been repaired.

Why is the action plan necessary?

Answer:

1. To increase the level of customer satisfaction
2. To reduce product defects because product defects can increase production costs and time.

3. Increase the company's sigma value

Improvement:
1. Conduct repeated supervision and checking
2. Be more thorough when performing all stages of production

Where
Where the action plan will be carried out
Answer: in each division of Sumber Sejahtera Rattan.
Improvement: Training to check raw materials and finished products, from receiving raw materials to finishing, by checking the color, shape, webbing, nails, and neatness of joints.

When
When will the action plan activities be implemented
Answer: Improvements are made as soon as possible.
Improvement: improvements are made faster so that the problem will be resolved faster, accompanied by periodic audits.

Who
Who will carry out the activities of the action plan
Answer: applied to all production operators and policyholders as policy makers.
Improvement: If something goes wrong during production, all company employees remind each other, evaluate, and provide suggestions for improvement.

How
The description is how to do the activity of the action plan.
Answer: Improvements are continuously carried out by all employees of Sumber Sejahtera Rattan. Improvement: Periodic monitoring is carried out, accompanied by good documentation. If an error is found, an evaluation is immediately carried out, followed by all employees, so that information is evenly distributed in the hope that the same and repeated errors do not occur.

Conclusion

Based on research conducted at Sumber Sejahtera Rattan, it can be concluded that the types of defects found in the production of Base Plant Stands are mold defects, imprecision, loose tie, pinholes, and fire spots. The main factor causing mold defects is humid conditions, the cause of imprecision is stacking the product too high, the factor causing loose ties is missing staples when shooting, winding is not strong enough, and a lack of glue, the factor causing pinhole defects is insect infestation. The factor causing the fire spot is rattan stems burned due to the heat. There are suggestions for improvement in covering products with tarpaulins during rainy weather, adding space for WIP so that products are not stacked too high, and making SOPs for tools and production processes in detail and easy to understand.

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