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Reducing Production Defects in Box Products: A Six Sigma DMAIC Approach to Achieving Higher Process Capability

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ABSTRACT

The Six Sigma methodology has been adopted by industries as a business management tool to enhance operational capabilities and reduce defects in any process. This study aims to present a case study on the application of the Six Sigma DMAIC methodology with the objective of reducing the defect rate produced by PT. XYZ. This factory is a company engaged in handcraft-oriented manufacturing, with several machining processes involved. One of the products manufactured is the Gift Box, which has a higher defect rate compared to other products. The analysis identified five main types of defects: length discrepancy, dents, asymmetrical panels, height misalignment, and color inconsistency. The current process shows an average DPMO of 38,925 and a sigma capability of 3.25 out of 6, indicating a significant number of defects and that the goal of Zero Defects has not yet been achieved. The recommended improvements include worker training, time management, and SOP implementation that should align with the production process. Machine maintenance, calibration, and material monitoring are crucial to preventing product defects. These steps are expected to reduce defects, improve efficiency, and enhance process capability.

Keywords: Defect, Quality, Six Sigma, DMAIC.

1. Introduction

In an era of increasingly fierce global competition, the manufacturing industry is required to continuously improve product quality and operational efficiency. Consistency and product quality are important factors that have a direct impact on operational efficiency. Quality can be defined as fitness for use, namely the suitability between product function and consumer needs. Sofijanova (2020) states that quality and reliability are two key elements that are often used together in the context of product performance, and this is very important in customer purchasing decisions. Along with the increasing demands for quality and efficiency, manufacturing companies are trying to find effective approaches to reduce variation in the production process. One approach that has proven effective is the Six Sigma method, which focuses on process improvement and variation reduction. Six Sigma enables companies to identify and eliminate major sources of defects, thereby improving process capabilities, reducing waste, and increasing overall customer satisfaction. The Six Sigma method has been widely applied in quality control and process improvement, as shown in previous studies (Singh et al., 2020; Byrne et al., 2021; Elumalai et al., 2022; Gaikwad et al., 2022).

In addition, the application of Six Sigma can also be used to measure service quality performance (Bloj et al., 2020) where this study applies Lean Six Sigma in the energy sector to increase the level of actualization in the service process, with significant results within three months. Likewise in manufacturing products as studied by Elumalai et al., (2022) who applied Six Sigma to reduce defects in the valve manufacturing process, which can increase the sigma level from 3.0 to 3.5. One of the main methods in Six Sigma is through the application of the DMAIC methodology (Define, Measure, Analyze, Improve, Control). DMAIC is a primary method consisting of five structured stages: Define to identify problems and set project objectives, Measure to measure current process performance, Analyze to find the root cause of defects, Improve to implement appropriate solutions, and Control to ensure improvements can be maintained. DMAIC functions as a closed-loop process that helps eliminate unproductive steps, often focusing on new measurements and the application of quality improvement technologies towards Six Sigma targets (Soundararajan & Reddy, 2020).

PT. XYZ is a manufacturing company that focuses on the production of handmade goods. One of the products produced is a gift box made of Medium-Density Fiberboard wood. Although it has a Quality Assurance (QA) department tasked with monitoring product quality at every stage of the fabrication process, the company still faces major challenges in the form of high levels of defective products (Not Good or NG), especially in woodworking factories. This has an impact on the increase in the number of products that do not pass inspection at the assembly stage.

Based on the analysis of production defect data during the period May to September 2024, it shows fluctuating data on the occurrence of Not Good goods. High product defect rates not only affect the company's profitability but also increase product returns due to poor quality (Singh et al., 2021). These product returns, in turn, have a direct impact on the delay in the payment process from consumers. This delay in payment has a significant chain effect. Including disruption of the company's cash flow, which causes delays in employee salary payments. In addition, this financial problem also triggers increased employee dissatisfaction, which is reflected in the high turnover rate. This situation further worsens the company's operations, where the lack of qualified workers can reduce productivity and increase training costs for new employees. If not addressed immediately, this problem could pose a serious threat to the company's operational stability and business continuity, as well as reduce overall financial performance. This study aims to identify the types of defects that most affect total product defects and find the main causes of the high defect rate using the Six Sigma DMAIC approach.

2. Literature Review

2.1 Quality

Quality control (QC) is an important aspect in the production process that aims to ensure that the products or services produced are in accordance with the specifications and requirements that have been set. QC functions as a mechanism to monitor quality throughout the production process and prevent defective products or inadequate services from reaching consumers. Quality control is the operational techniques and activities used to fulfill requirements for quality. Quality control is an important process in production that ensures that the products produced are in accordance with the company's specifications and requirements, including through the use of Pareto diagrams and Six Sigma methods to reduce production defects (Gozali et al., 2020). Product quality is a key factor that influences consumer emotions, resulting in satisfaction that continues to loyalty, where the consumer experience reflects the fulfillment of physical and psychological needs (Rodiah, 2022). Based on several previous opinions, it can be concluded that quality control is a technique and planned action carried out to achieve, maintain and improve quality.

2.2 Six Sigma

Six Sigma is a methodology that aims to improve the quality of products and processes by reducing variation and defects in production. Vhankade (2017) defines Six Sigma as a complex and flexible system for achieving, maintaining, and maximizing business success, based on understanding customer needs and expectations, and the disciplined use of facts and statistical analysis (Vhankade, 2017). Six Sigma not only includes statistical techniques to measure and reduce defects, but also creates an organizational structure that supports continuous quality improvement (Schroeder et al., 2008). With the concept of zero defects, which refers to errors caused by lack of knowledge, can be overcome by using modern techniques. In addition, a survey of factories in Nigeria emphasized the importance of regular facility inspections to prevent major damage and ensure timely repairs, which ultimately increases organizational effectiveness (Bagshaw & Peters, 2015).

2.3 DMAIC

DMAIC is a data-driven methodology designed to improve quality and efficiency in various business processes. DMAIC consists of five phases: Define, Measure, Analyze, Improve, and Control. This methodology is widely used in various industries to solve problems and improve the quality of products or services. Research by Mast and Lokkerbol (2012) examines DMAIC as a problem-solving approach in the context of Six Sigma. This study highlights the strength of DMAIC in using powerful statistical techniques for fact-based problem solving, but also finds weaknesses in the methodology's ability to diagnose problems efficiently. The use of less structured tools in the analysis phase can limit the efficiency of identifying the cause of the problem. Although initially used in the manufacturing industry, DMAIC has been successfully applied in the service industry. Subagyo et al. (2020) examined the challenges and benefits of implementing DMAIC in five service companies in Indonesia. The results showed increased customer satisfaction, reduced delivery errors, and shorter lead times after implementing DMAIC, despite challenges such as the lack of transparency from the company in the implementation process. The DMAIC methodology is the key to Six Sigma problem solving, which includes sequential improvement steps, each of which is critical to achieving the desired results. The methods used in Six Sigma have lasting value, even if they are marketed under a new name in the future. These ideas can be integrated with other productivity improvement methods and will continue to demonstrate the existence of a product in global competition.

3. Research Methodology

The study was conducted from May to September 2024. Data collection includes primary and secondary data, where primary data is information related to the research object collected directly from original sources such as the number of production and the number of defective products. Meanwhile, secondary data is obtained indirectly in the form of files, documents, archives, or company records, such as factors causing defects and production processes. The product analyzed in this study is a gift box. The data processing process is carried out using the Six Sigma method which consists of five stages of DMAIC (Define, Measure, Analyze, Improve, Control):

Define

The define stage is the initial stage carried out in improving six sigma, the quality tools used in the define stage are as follows:

a. CTQ (Critical To Quality)

The CTQ diagram presents the characteristics of the most critical defects according to customers. Observations are made on the characteristics of defects in gift box products that are of concern to customers.

b. Pareto Diagram

A diagram that presents data based on the order of the number of occurrences. Data with the highest number of occurrences is sorted from right to left to identify potential problems to be fixed.

Measure

The Measurement stage is the identification stage of data collected by checking the stability of the production process using a control chart such as a P-Chart and measuring the current sigma level of the gift box production process (conditions before repair). In calculating the sigma level using Microsoft Excel software with the following formula:

Sigma= NORMSINV ((1000000-DPMO) / 1000000) + 1.5 ……(1)

Analyze
Conduct analysis on the problems found by finding the cause of product defects using Fishbone Diagram. The causes presented in Fishbone Diagram are material, machine, man, method, and environment factors.

Improve
Proposed actions that must be taken in improving six sigma quality using 5W + 1H (What, Where, When, Who, Why and How).

Control
Analysis of results and discussion are carried out to draw conclusions in research and suggestions are the final stage of research.

4. Results

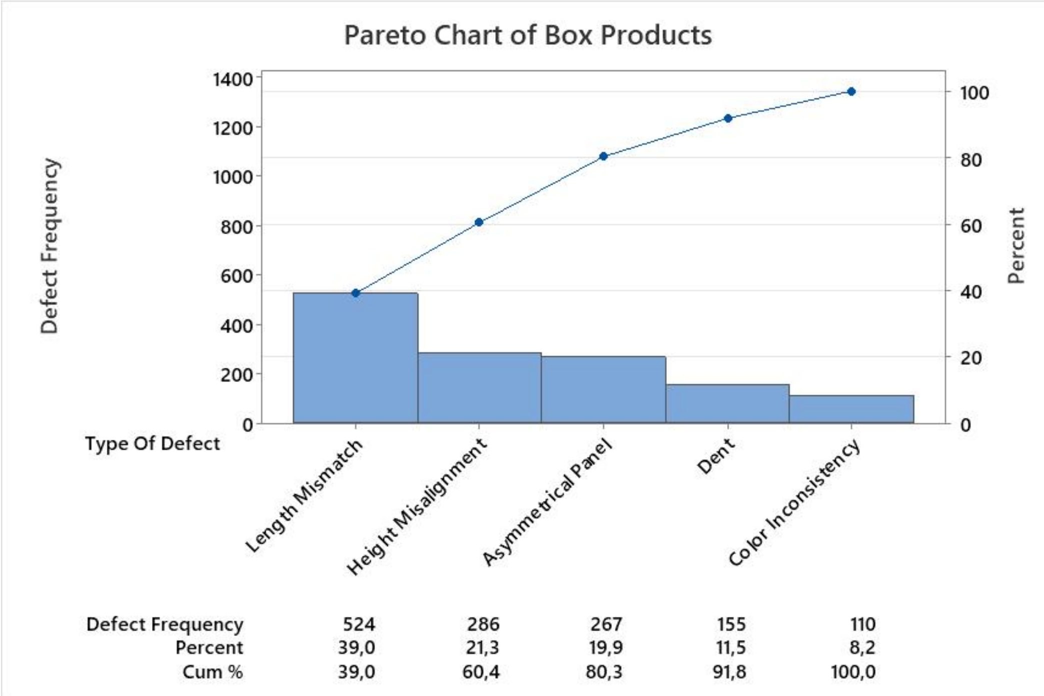
Define
Define is the first stage to identify problems in this research. The define stage is carried out by determining the highest proportion of defects using a Pareto diagram and will be qualified as Critical To Quality (CTQ).

Table 1 Critical to Quality

No	Defect Type	Definition Operational
1	Length mismatch	The box cover panel is misaligned with the body panel, where the cover panel is either longer or shorter along the edges of the box
2	Dent	Damage to the wood caused by impact during handling or production.
3	Asymmetrical panel	A defect that causes the cover panel to be uneven in the gap between the right and left sides in relation to the body panel.
4	Height misalignment	The product has a cover panel that is misaligned in height with the body panel used.
5	Color inconsistency	It occurs when the color application is not uniform, leading to variations across different areas of the product.

Diagram Pareto

Pareto diagram is used to determine potential defects that occur in the gift box production process. Pareto diagram is presented in the image below.



Pic. 1 Pareto Chart of Box Products

The Pareto graph illustrates the distribution of defect types that occur in gift box products. There are five types of defects identified, namely Length Mismatch, Height Misalignment, Asymmetrical Panel, Dent, and Color Inconsistency. Of the five types of defects, Length Mismatch is the most dominant defect, occurring 524 times or around 39% of the total defects detected. This type of defect is a major problem that must be addressed immediately to significantly improve product quality. After that, Height Misalignment is the second most common type of defect with 286 occurrences (21.3%), followed by Asymmetrical Panel with 267 occurrences (19.9%).

If these three main defects, namely Length Mismatch, Height Misalignment, and Asymmetrical Panel, are resolved, the company can reduce 80.3% of the total defects that occur in gift box products. This shows that the main focus should be given to these three types of defects, because improvements in this area will have the greatest impact on improving quality. In addition, Dent or dents contributed 11.5% of the total defects with 155 occurrences, and Color Inconsistency or color mismatch occurred 110 times (8.2%). Although these two types of defects are lower in frequency, they are important to note after the main defects have been successfully repaired.

Measure

Based on the Pareto diagram, it is found that the dominant defect contributes more than 10% of all defects that occur. Then the DPMO value and sigma value of all types of defects are calculated as follows:

Table 2 DPMO

PERIOD	Total Production	Total Defect	DPU	TOP	DPO	DPMO	Sigma Value
Mei'24	1.051	303	29%	5.255	5,8%	57.659	3,07
Juny'24	1.524	259	17%	7.620	3,4%	33.990	3,33
July'24	1.448	289	20%	7.240	4,0%	39.917	3,25
August'24	1.588	264	17%	7.940	3,3%	33.249	3,34

September'24	1523	227	15%	7.615	3,0%	29.810	3,38
		Average				38.925	**3,25**

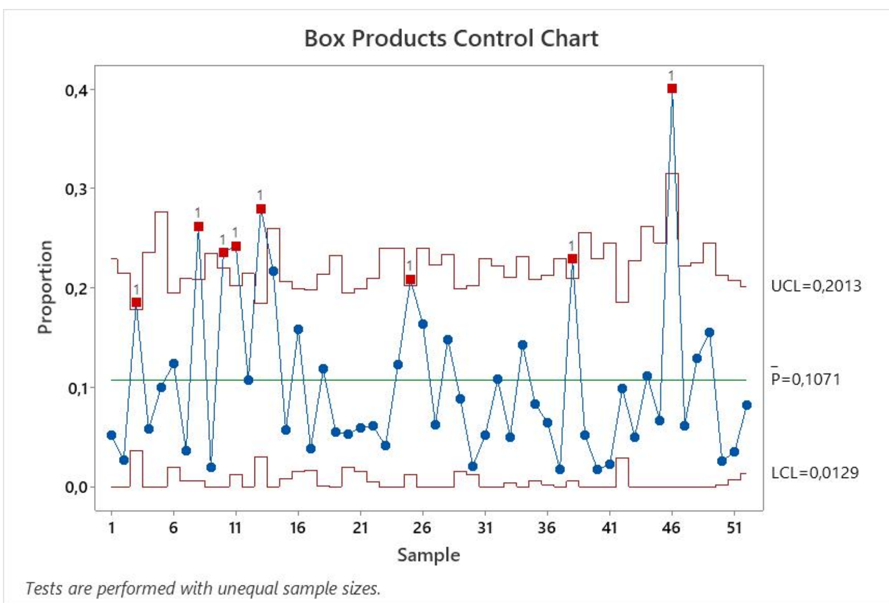
$$\text{DPU} = \frac{\textbf{Total Defect}}{\textbf{Total Production}} \text{ x } 100\% \quad \text{.........(2)}$$

Total Opportunities (Top) = Number of Opportunities x Total Production ....(3)

$$\text{DPO} = \frac{\textbf{Total Defect}}{\textbf{ToP}} \quad \text{.........(4)}$$

$$\text{DPMO} = \frac{\textbf{Total Defect}}{\textbf{ToP}} \text{x } 1.000.000 \quad \text{.........(5)}$$

With a sigma value of 3.25 produced, the production process can produce a fairly consistent product, but further steps need to be taken to approach the ideal Six Sigma standard, which is 6 sigma, which only allows 3.4 defects per million opportunities. Improvements in more critical aspects of the process and reduction of variation will help improve overall product quality.



Pic. 2 Box Products Control Chart

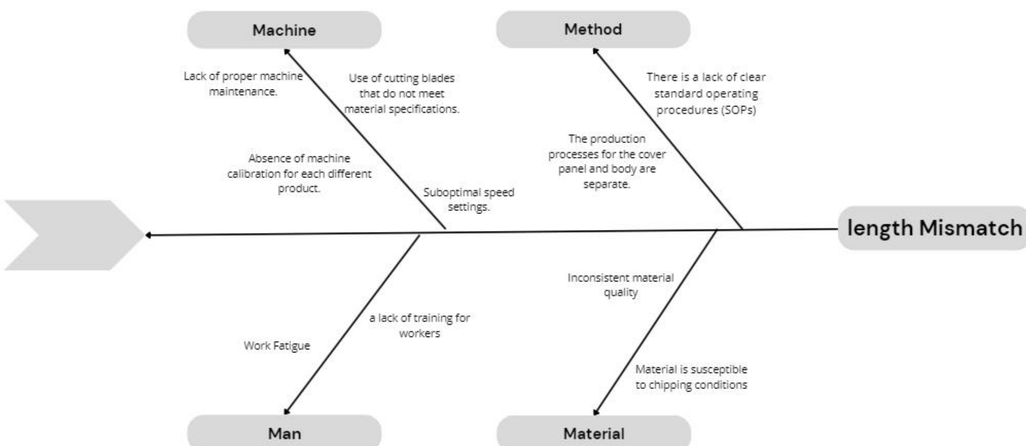
The control chart for the gift box product shown shows how the proportion of defects varies across samples taken during the production process. This chart is used to identify whether the production process is in statistical control or not, with reference to predetermined control limits. The green line in the middle of the chart represents the average proportion of defects, which in this case is about 10.71% ($\bar{P}$ = 0.1071). This means that, on average, about 10.71% of the box products in each sample have defects.

In addition, there are two control limits: the UCL (Upper Control Limit) is at 0.2013, which is the upper limit of variation considered reasonable in the process. If the proportion of defects exceeds this value, the process is considered out of control. The LCL (Lower Control Limit) is at 0.0129, which is the lower limit of variation considered reasonable. If the proportion of defects falls below this limit, the process is also considered out of control, although this is rare.

In this graph, you can see that several points (marked with red boxes and the number "1") are outside the upper control limit (UCL). This indicates that there are a number of samples with a much higher defect rate than expected. The presence of these points indicates that the process is out of control at these points and may be caused by specific problems in production, such as changes in raw materials, machines, or work procedures. Most of the other points are within the control limits, indicating that most of the time, the production process is still running as expected. However, significant fluctuations between different samples also indicate that there is considerable variation in the quality of the resulting product.

Analyze

Based on the results of the measure stage, it is known that the most dominant CTQ is Length Mismatch. Then an evaluation is carried out to find out the causes of the types of defects that often occur using a fishbone diagram which is a structured approach that allows for more detailed analysis in finding the causes of a problem, inconsistencies and gaps that exist (Nasution, 2005) and is evaluated as follows.



Pic. 3 Fishbone Diagram

The diagram above is a Fishbone Diagram used to analyze the potential causes of Length Mismatch problems in the production process. This diagram groups the main causes into four categories: Machine, Method, Human, and Material, each of which contributes to the problem. In the Machine category, the problems identified include lack of proper machine maintenance, lack of machine calibration for each different product, use of cutting blades that do not match material specifications, and suboptimal machine speed settings. All of these factors can cause length mismatches in products. In the Method aspect, it was found that the absence of clear standard operating procedures (SOPs) was one of the main causes. In addition, the production process of the cover panel and the product body which is carried out separately can trigger differences in length in the final result. Meanwhile, in the Human category, work fatigue and lack of adequate training for workers are significant factors. Fatigue can cause workers to make mistakes, while lack of training makes workers not understand best practices in the production process. Finally, in the Material category, inconsistent material quality and material susceptibility to breakage or peeling are also contributing factors. Materials that are easily damaged during the production process can result in products with inappropriate lengths.

Improvement

Based on the root of the problem that has been found in the Analyze stage, a proposal for improvement can be made to prevent similar problems from occurring. The formulation of the proposed improvement refers to the root of the problem of the production size mismatch defect. The analysis of the problem and the proposed improvement for the size mismatch defect are shown in the following table.

Type	5W-1H	Description	
The main purpose	What	The purpose of fixing the Cap misalignment defect is to reduce the number of defective products, improve product quality, and increase customer satisfaction. By reducing these defects, the company can also increase production efficiency, reduce raw material waste, and improve overall process capabilities.	
Reason for Use	Why	Factor	Causes of defects
		Man	1. Lack of training for workers 2. Work Fatigue
		Method	1. Lack of clear standard operating procedures (SOP) 2. The production process of the cover panel and body is carried out separately
		Mechine	1. Lack of machine maintenance 2. No machine calibration for each different product. Use of blades that do not match material specifications. 3. Speed Setting is not Optimal
		Material	1. Inconsistent material quality 2. Material is prone to chipping conditions
Lokasi	Where	The repair process will be carried out in the factory area where product production and assembly takes place, especially in the woodworking and assembly production lines, where the problem of the Cap misalignment defect occurs most often.	
Squence	When	During the production process	
People	Who	Production Manager, Foreman, and workers responsible for its implementation.	
Methode	How	Factor	Suggested Improvements
		Man	1. Conduct regular training programs for workers that focus on operating procedures, machine usage, and best practices in production. 2. Implement good work time management. By rotating tasks to reduce boredom and physical or mental fatigue.
		Method	1. Create and document clear and detailed SOPs for each stage of the production process

Type	5W-1H	Description
		2. Combine or synchronize the production process of the cover panel and body so that there is no significant difference in the final result. This can be done by combining the processes in one production line
	Machine	1. Implement preventive and predictive maintenance programs for machines. Routine maintenance schedules should be set and implemented consistently, with regular recording of machine performance. 2. Establish specific calibration procedures for each type of product being manufactured. These calibrations should be performed before product changes, ensuring that the machine is set to suit the needs of different products. 3. Re-evaluate the use of cutting blades to ensure that they are appropriate for the type of material being processed. Replace any blades that are not within specifications and perform periodic test runs. 4. Set the machine speed optimally based on the type of product and material being processed. This can be achieved by re-testing production speeds and applying more precise settings.
	Material	1. Evaluate material suppliers and ensure they meet established quality standards. Implement material quality testing before production begins. 2. Improve the quality of the materials used or replace them with materials that are more resistant to chipping conditions. Also, adjust processing methods and tools used for more sensitive materials.

5. Discussion

Improvements to length Mismatch defect problem aim to reduce the number of defective products, improve product quality, and increase customer satisfaction. A study conducted by (Imaroh & Mustofa, 2022) stated that the use of the Lean Six Sigma method and statistical process control (SPC) can significantly reduce product defects and improve product quality, which leads to increased customer satisfaction. A study at PT Muliaglass Container showed a 10% reduction in production defects after implementing this method. In addition, by overcoming these defects, the company can increase the efficiency of the production process, reduce waste of raw materials, and increase the overall capability of the production process. These improvements have direct implications for reducing time and costs, as well as increasing the company's reputation in meeting high quality standards. In line with research, the application of Six Sigma and Lean Production in the manufacturing industry can improve the performance of the production system by reducing defective products and activities that do not have added value. The results of the study showed that reducing defective products and saving costs can increase customer satisfaction (Aggogeri & Mazzola, 2008).

The causes of the Non-Straight Cap defect in this study were greatly influenced by various factors in the production process, including labor, method, machine, and material factors. In the labor factor, lack of training for workers and work fatigue are the main issues. When workers do not have adequate skills or experience fatigue, this can lead to an inability to operate the machine properly, which ultimately triggers inaccurate production results. Vishnevskaya et al (2021) explained that operators in high-tech industries often experience fatigue caused by monotonous work, static muscle tension, and closed work environment factors. This fatigue reduces work capacity and increases the risk of operational errors, which ultimately affects production accuracy. Method factors are related to the absence of clear Standard Operating Procedures (SOPs), as well as separate production processes between the lid panel and the body, which can cause misalignment in the final results. Meanwhile, machine factors include lack of machine maintenance, improper calibration, use of inappropriate blades, and suboptimal speed settings. Material factors also play a role in quality inconsistencies, including susceptibility to chipping conditions.

The improvement process is focused on the factory area, especially in the woodworking and assembly production lines, where the Misaligned Cap defect occurs most often. This area is a critical point in production, because the woodworking and assembly stages involve many mechanical processes that affect the dimensions and alignment of the final product. By making improvements in this area, it is expected that the reduction in defects can be directly seen in the production results.

These improvements must be made during the production cycle, where each step in the production process is optimized to avoid the same defects from occurring repeatedly. Improvements during the production process allow for the implementation of improvement proposals in real time, as well as providing the right time to evaluate the results of the improvements in the final product. Implementation of improvements involves the role of several key parties, including production managers, foremen, and workers who are directly involved in the production process and machine maintenance. Collaboration between these parties is very important to ensure that each improvement proposal is implemented effectively and consistently. Management involvement also plays a role in developing long-term strategies to maintain production quality and efficiency. Several improvements proposed based on the factors causing defects include various aspects of the production process. In the labor factor, regular training programs must be held to improve workers' skills in using machines and implementing good operating procedures. In accordance with previous research stating that a training framework combined with a designed training program can improve workers' technical skills in carrying out operational tasks. The implementation of this framework increases work effectiveness and machine efficiency in the industry (Pinto et al, 2020). In addition, better work time management with the implementation of task rotation can help reduce physical and mental fatigue of workers, which are often the main causes of errors in the production process. In terms of methods, the creation and documentation of clear and detailed SOPs for each stage of production are essential. Good SOPs can provide definite guidance for workers and ensure that the production process is carried out consistently. Combining or synchronizing the production process between the cover panel and the body will also reduce the risk of non-conformity in the final results.

In machines, the implementation of preventive and predictive maintenance programs is highly recommended. Regular routine maintenance schedules and disciplined recording of machine performance can prevent machine damage that can cause product defects. Balaraj & Swamy (2017) showed that regular predictive and preventive maintenance can reduce machine damage and minimize production defects in the splicing process in the tube manufacturing industry. This maintenance ensures the availability and reliability of the machine, thereby reducing damage and product defect rates. Specific calibrations for each type of product are also very important to ensure that the machine is set according to the specifications of the product being produced. In addition, evaluation of the use of the blade and optimal machine speed settings must be carried out periodically. Finally, for material factors, evaluation of material suppliers must be carried out strictly to ensure that the quality of the material is in accordance with the established standards. Testing of materials before the production process begins can reduce the risk of defects caused by non-compliant materials. Materials that are more resistant to chipping conditions should also be considered, as well as processing methods that are adjusted for sensitive materials.

6. Conclusion

This study shows that the Non-Straight Cap defect in the production process can be caused by various factors related to labor, methods, machines, and materials. Lack of worker training, work fatigue, the absence of clear Standard Operating Procedures (SOPs), and separate production processes between the cap panel and the body are significant factors that affect the quality of production results. In addition, lack of machine maintenance, lack of proper calibration for each product, use of inappropriate blades, and suboptimal machine speed settings also increase the risk of product defects. Inconsistent material quality and materials that are prone to chipping conditions further exacerbate the problem.

Through the 5W-1H analysis, this study proposes several improvements, including worker training programs, better work time management, the preparation and implementation of detailed SOPs, and synchronization of the production process. In addition, preventive and predictive maintenance of machines, specific calibration procedures, and monitoring of material quality before production are important steps to overcome the causes of this defect. With the implementation of these improvements, it is expected that there will be a significant reduction in the number of defective products, increased production efficiency, and increased customer satisfaction. This study also emphasizes the importance of a systematic and comprehensive approach in dealing with product quality issues, involving various parties and factors in the production process..

This study yields significant practical and theoretical implications for Company, stakeholders, and researchers in the fields of operational management.

Practical Implications:

1. Implementation of worker training, better work time management, clear SOP implementation, and synchronization of production processes are expected to reduce product defects and improve overall quality.
2. Preventive and predictive machine maintenance and more specific calibration will reduce the possibility of product damage, such as Non-Straight Cap defects, by ensuring that each tool and machine is operating at optimal standards.
3. The production process becomes smoother and more efficient with improved machine management and material quality monitoring, which ultimately reduces operational costs and production time.
4. Reducing the number of defective products will increase customer trust and increase satisfaction due to better product consistency.

Theoretical Implications:

1. This study adds to the understanding of the factors that influence production defects in the manufacturing industry, especially in the context of labor, methods, machines, and materials. Predictive Maintenance Framework Development: The results of this study provide a foundation for better understanding the importance of predictive maintenance of machines and specific calibrations in reducing product defects, and how this can impact quality management theory.
2. Using the 5W-1H analysis, this study integrates a systematic approach to analyzing problems in the production process, which can strengthen theories related to continuous improvement and Six Sigma.

Directions for Future Research:

1. Future research could further explore the impact of worker training on reducing production defects quantitatively, by comparing different training methods.
2. Future research could examine how the application of IoT technology for real-time machine

monitoring can improve the effectiveness of predictive maintenance in reducing production defects.
3. Further research is needed on the impact of material quality on production defects and how to minimize the risk with materials that are more resistant to defects such as chipping.
4. Research could also be directed at developing more dynamic, data-driven SOPs to adapt to changing operational conditions, especially in the manufacturing industry.

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