Quality Control Analysis of Plastic Product Utilizing Six Sigma with DMAIC Stage: A Case Study

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Abstract. Sigma method with DMAIC is a systematic improvement step to achieve the desired results, which is a flexible and comprehensive system for achieving and maintaining success in business. In this study, this method was implemented to analyze the quality control of trash bag produced by one of the plastic industries. Based on the initial research survey, trash bag in the production period from November 2023 to January 2024 had a defect rate of 5.28%, which did not meet standard, i.e. 5%. This research aims to analyze quality control during the trash bag production process in order to minimize the number of defects production. The Six Sigma DMAIC stage was chosen as a quality control method to analyze defect type, DPMO, sigma level, process capability, and provide some recommendations to improve the production process. The use of the Six Sigma DMAIC stage was combined with Failure Mode and Effect Analysis (FMEA) to determine the failure mode which made the biggest contribution of defects. In addition, Kaizen 5W+1H improvement concept was used to obtain recommendations for minimizing the number of defects. Results showed recommendations for improvement were provided in the form of Standard Operating Procedures (SOP) for machine operation and machine failure check sheets. The SOPs and check sheet was implemented for four days, resulted in a 26% reduction in DPMO. This reduction in DPMO aligned with the increase in sigma level from 3.538 sigma to 3.776 sigma.

Keywords: Six Sigma, DMAIC, Trash Bag, FMEA, Kaizen.

1 Introduction

The industrial sector plays an important role as the main support for the national economy [1]. The rubber products and plastics industries consistently show positive performance and contribute significantly to the Gross Domestic Product on the non-oil and gas processing industry [2]. More specifically, the Ministry of Industry states that the plastics industry is considered a very vital sector and has considerable market opportunities, as the products produced by this sector are needed as raw materials for various types of other industries.

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In Indonesia, the demand for plastics and plastics-based products will continue to grow. The Central Bureau of Statistics has recorded the level of national demand for plastics based on the type of raw material. Polyetyhlene (PE)-based plastics have the highest percentage, reaching 34%, which shows that polyethylene-based plastics are widely used by consumers [3]. Polyethylene can be used to make different types of products, one of which is plastic bags, whose use is very wide and cannot be separated from everyday life [4]. One type of processed plastic bag is trash bag, which is widely used in everyday life due to its strong, flexible, and waterproof characteristics. The quality characteristics of plastic must be taken into consideration by every industry involved in plastic processing.

A product that is able to meet the predetermined standards and in accordance with consumer expectations can be said to be a quality product [5]. Quality is the conformity of the characteristics of a product with the expectations of consumers [6]. Product quality is very important to pay attention to, as it is directly related to consumer satisfaction. The times have changed the way consumers view the selection of a desired product. Ahmad [7] stated that currently, consumers are more selective in choosing products by considering the price and quality offered. Companies must be able to identify the needs and desires of consumers so that the products can compete in the market.

Quality control can be carried out by applying the Six Sigma method of the DMAIC stage which has become one of several product quality control techniques. According to Ahmad [7], Six Sigma method with DMAIC stage is a systematic improvement step to achieve the desired results. The Six Sigma DMAIC stage is carried out to minimize the factors that cause product defects through five stages, namely define, measure, analyze, improve, and control. The Six Sigma method is a flexible and comprehensive system for achieving and maintaining success in business [8]. In this study, the Six Sigma method with the DMAIC stage is used to analyze the quality control of trash bag produced by one of the plastic industries. It is hoped that the results of this study can provide benefits to companies, especially to minimize the number of trash bag defects produced.

2 Literature Review

A detailed review of literature is conducted and research gaps are identified in this section. The literature reviews are divided into four subsections:

2.1 Quality

Quality is a condition related to products, services, processes, people, and the environment that are able to adapt, meet, and even exceed consumer expectations [9]. Quality has dimensions, which are defined as product or service characteristics that can be assessed to provide an evaluation of the level of suitability of the product or service in meeting consumer needs and expectations. By knowing the dimensions of the quality of the product or service produces, companies can understand consumer needs, innovate, increase competitiveness, and increase customer satisfaction. Companies need to conduct quality control on an ongoing basis to ensure that the entire production process

runs well. According to Montgomery [10], quality control and improvement involves a whole series of activities to ensure that the products and services produced meet the requirements and can be continuously improved. With regular quality control, the company is able to quickly identify any deviations that occur so that the company is able to take action to overcome these deviations [11].

2.2 Six Sigma

The term Six Sigma refers to a technique used to reduce defects until the value does not exceed 3.4% DPMO (Defect Per Million Opportunity) or 99.99966 percent focused on achieving customer satisfaction [12]. Six Sigma is an effort to improve quality toward a target value of 3.4 defects per one million opportunities of each production process performed [13]. The implementation of quality improvement with Six Sigma can use the DMAIC concept (define, measure, analyze, improve, and control), which consists of sequential improvement steps and each stage has an important role to achieve the desired results [7]. The define stage is the first step taken to define the quality standard problem, define the action plan to be implemented, and determine the process to be evaluated. The measure stage is the second step taken to determine the quality characteristics, collect data, and measure data related to the defect rate or sigma level that occurs. The analyze stage is performed to analyze the factors that cause defect problems and to identify the root cause of the problem. The improve stage aims to identify corrective actions in solving the problems that occur. This stage also aims as a step to improve quality and provide recommendations for improvement. The control stage is performed as a final stage to monitor the progress of corrective actions and keep them within the specified limits.

2.3 Six Sigma Tools

The tools used in Six Sigma include the project charter, SIPOC diagram, control chart, defects per million opportunities, process capability, Pareto chart, fishbone diagram, Failure Mode and Effect Analysis, and kaizen. Project charter is a short document that contains a series of project descriptions to define the project objectives, the functions of each party involved, and the scope of the project. The project charter is used as the basis for implementing Six Sigma projects so that the team stays in line with the project goals [14]. The SIPOC diagram will define suppliers, inputs, processes, outputs, and customers to show the flow of the production process starting from the material procurement process until the product reaches the consumers [15]. Control chart is a statistical process control technique that is very helpful in seeing the source of variability that occurs [10]. Montgomery [10], stated that control charts can be classified into two types whose use is adjusted to the quality characteristics to be measured, namely variables control charts and attributes control charts. Variables control charts are used to measure the value of variable-shaped characteristics such as volume, height, width, temperature, and other quantitative units. Variables control charts are divided into $\bar{x}$ control chart, s control charts, and R control charts. In addition to variables, there are

quality characteristics that cannot be measured on a quantitative scale, known as attributes. In general, the evaluation of attribute quality characteristics is based on the conforming or nonconforming characteristics of a product. There are types of attributes control charts, namely p charts, c charts, and u charts. According to Rahayu and Supono [16], if the samples taken for each observation are the same, then measurements can be made using a p chart.

Defects per million opportunities is a parameter used to show the failure of one million defect opportunities [17]. Montgomery [10] stated that opportunity is the number of potential opportunities for defects in a unit. Equation 1 shows the measurement of defects per million opportunities (DPMO).

$$DPMO = \frac{Total\ number\ of\ defects}{Number\ of\ units\ \times Number\ of\ opportunities} \tag{1}$$

After obtaining the defects per million opportunities (DPMO) value, the conversion of the parts per million (ppm) value is equivalent to the sigma level. The calculation of the sigma level is shown in Equation 2

$$Sigma\ Level = Normsniv\left(\frac{1.000.000 - DPMO}{1.000.000}\right) + 1{,}5 \tag{2}$$

Process capability is a performance measure that indicates the ability of a process to produce a product according to predetermined specifications [18]. Pareto chart is a statistical method that can be used to identify the most important factors in a system or process [19]. In general, the 80:20 principle can be used when performing Pareto analysis, that is, 80% of the nonconformances that occur are caused by 20% of the causes [20]. Therefore, by focusing on the 20% most relevant causes, the desired goal will be achieved faster. Fishbone diagram is also known as cause and effect diagram, which is one of the seven tools of quality control to see the relationship between causes and effects of problems in a system [21]. In quality control, the identification of potential causes of failure problems can be classified into six categories, namely material, manpower, maintenance, method, machine, and environment [22]. Failure Mode and Effect Analysis (FMEA) is a method used to identify failure patterns and the effects of these failures [23]. FMEA is a tool used in quality control, reliability improvement, and design maintenance as an important component of risk management, FMEA is a technique recommended by international standards such as ISO 9000 to identify, prevent, and eliminate potential failures in systems, manufacturing processes, and services before they are delivered to customers [24]. Risk assessment criteria in FMEA can be divided into three factors, namely severity, occurrence, and detection.

While conducting risk assessment using FMEA, an approach is taken to prioritize failures modes using an index called risk priority number (RPN). RPN in FMEA is used to prioritize risks and choose the right corrective action [25]. The value of RPN can be obtained by calculation using Equation 3

$$RPN = Severity \times Occurence \times Detection \tag{3}$$

Kaizen is a philosophy originating in Japan that focuses on continues development and improvement within the organization [26]. Sumiati and Nugraha [27] stated that kaizen is an approach that describes the process of business culture towards continuous improvement with the active participation and commitment of all company employees. One of the Kaizen implementation tools is Kaizen 5W + 1H, which is a tool used by the technique of compiling improvement steps by listing basic questions, namely what, who, why, where, and how. According to Casban and Dewi [28], Kaizen 5W + 1H is able to investigate the causes of failure in more detail.

2.4 Research Gap

This research has similarities in terms of methods used with previous research. Rivaldy [15] used Six Sigma DMAIC stage method supported by the Kaizen improvement concept. In addition, Hanifah and Iftadi [29] also used the Six Sigma DMAIC stage method supported by the FMEA improvement concept. The difference between this research and the previous research is in the subject of research and the methods used. In some previous studies, there has not been a detailed definition of the project and the objectives to be achieved, this research will use a project charter at the define stage to define the project to be implemented along with details of the research scope. In addition, there are differences in the use of research methods, this research will combine the use of FMEA method at the analyze stage to see the causes of defects that are the top priority to be resolved, supported by the Kaizen improvement concept, which will be used at the improvement stage to provide alternative improvement recommendations, meanwhile the study by Parwati [30] used the Poka Yoke method at the improvement stage to determine the causes of defects and Kaizen at the control stage to provide an action plan in quality control. Then, at the control stage, the improvement recommendations proposed by this study are implemented and monitored within a certain period of time in order to minimize the number of defects in the products produced by the company. On the other hand, some previous studies conducted by Rivaldhy [15] have only been carried out up to providing improvement recommendations at the improvement stage without implementing the given improvement recommendations.

The use of FMEA method in this study is based in the advantages of FMEA to identify and prioritize the improvement steps that need to be taken in a process [23]. In addition, the use of the Kaizen improvement concept in this study is based on the advantages of Kaizen, which is able to solve any fundamental problem that occurs [31]. Meanwhile, some previous studies used other methods such as Poka Yoke and FTA to solve the problems that occurred. The use of the Poka Yoke method aims to avoid defective products by preventing and correcting human errors, so this method functions more as a method to prevent errors and is not used to find errors that occur [30]. The FTA method is generally used to examine the reliability of a product using a tree diagram to analyze the causal relationship between one event and another [32]. Therefore, the selection of FMEA and Kaizen methods in this study is based on the suitability of

using the method with the problems that occur, so that it is expected to be able to solve problems and provide optimal solutions for the object under study.

3 Methodology

The sequence of data processing to data analysis follows the DMAIC concept, the define stage is the initial stage of quality control using the Six Sigma method DMAIC stage. At this stage, researchers will identify problems related to quality in the entire series of production processes. At the define stage, the SIPOC diagram is created, types of product defects are identified, and critical to quality (CTQ) is determined. The measure stage is the second stage where product defects are calculated using a control chart, the percentage of product defects is calculated using Pareto chart, the DPMO value is determined, the sigma level is determined, and process capability is measured. The analyze stage is performed by searching and analyzing the causes of product defects obtained from the calculation results performed in the measure stage. In this stage, the root causes of products defects are identified using fishbone diagrams and potential failures are analyzed using FMEA. This stage also includes analysis and verification if the results are not better than before after implementing the improvement recommendations the improvement stage is carried out by providing alternative improvement recommendations to minimize the number of product defects.

4 Case Study

This research was conducted in one of the plastic companies in Indonesia. The company has a vision to become a plastic manufacturer that is able to meet customer needs and build customer trust by producing quality products. In line with this vision, this company is committed to providing the best service by providing quality products. In order to improve the provision of quality products, this company determines that the number of defect products does not exceed the standard of 5%. However, during the implementation of the production process, there will certainly be the potential for discrepancies between the products and the quality standards, which are commonly known as defects products. Based on the initial survey, it was found that the number of defect products during the production period from November 2023 to January 2024 still exceeded the set standard. Therefore, it is necessary to analyze the causes of defects to determine quality control measures.

4.1 Define

Identification of defect types will be carried out at the define stage which is the initial stage of the entire DMAIC stage. The define stage is carried out to define the quality standard problem, define the action plan that must be carried out, and determine the process that will be evaluated. At the define stage, the project definition and research scope will be carried out using a project charter, preparation of a SIPOC diagram, and

definition of quality characteristics using a critical to quality (CTQ). The results of the project charter and SIPOC diagram are shown in Table 1 and Fig.1.

Table 1. Project Charter

Project Charter	
Project Title	Quality Control Analysis on Plastic Product Using Six Sigma Method with DMAIC Stage: A Case Study
Business Case	The research was conducted in one of the companies engaged in plastic production with the main product is trash bag. Based on the initial research survet, it was found that the average percenatge of defect products during the production period of November 2023 to January 2024 still exceeded the set standard, which was 5 percent.
Problem Statement	a. It is necessary to identify the types of defects that occur during the trash bag production process in the company. b. The company does not know the DPMO value, sigma level, and capability value in the trash bag production process. c. The company does not know the cause of defects that has the greatest influence on the problem of defects in the production of trash bag. d. There are no corrective measures to minimize the number of defects in the trash bag production process at the company.
Goal Statement	a. Identify the types of defects that occur in the trash bag production process in the company. b. Analyze the DPMO value, sigma level value, and capability value od the trash bag production process in the company. c. Identifying the causes of defects that have the greatest influence on the problem of defects in the production of trash bag in the company. d. Provide alternative recommendations for improvements that can be made by the company in minimizing the number of trash bag product defects.
Project Scope	a. This research is only focused on quaity issues during the trash bag production process, starting with the processing of plastic ore, plastic molding, and plastic cutting. b. Not analyzeing the cost factors due to defects in trash bag products.pe
Stakeholders	1. Researcher 2. Manager 3. Production Staff 4. Operator
Working Definition	This research is conducted to analyze the quality control of trash bag produced by the company using Six Sigma method with DMAIC stage. The FMEA method will be used in the analyze stage, supported

	by the Kaizen improvement concept in the improve stage. The implementation of the improvement recommendations is carried out for a certain period of time in the control phase.		
Milestone	***Start Date***	***Finish Date***	***Status***
Define	07/04/2024	20/04/2024	*Completed*
Measure	21/04/2024	30/04/2024	*Completed*
Analyze	01/05/2024	07/05/2024	*Completed*
Improve	08/05/2024	12/05/2024	*Completed*
Control	13/05/2024	26/05/2024	*Completed*

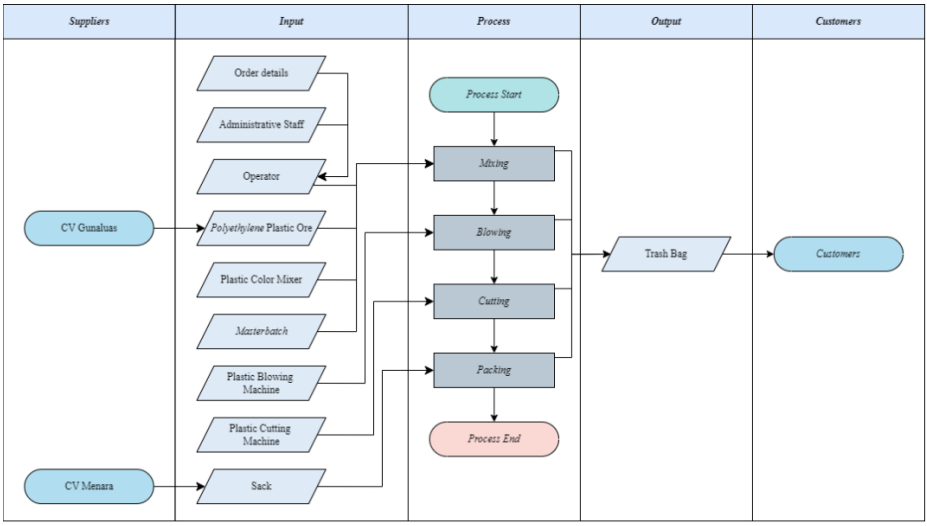

Fig. 1. SIPOC Diagram

In this research, the process of determining CTQ is based on the needs of product specifications according to product quality standards set by the company. Based on the results of interviews and discussions with the company, information was obtained that CTQ from trash bag refers to the defect types that occurs during the production process. The defect types are divided into two, namely hollow plastic, and melted plastic. The results of determining CTQ which have been obtained through interviews and discussions with the company will then be used as a reference for determining the CTQ trees as shown in the Fig. 2.

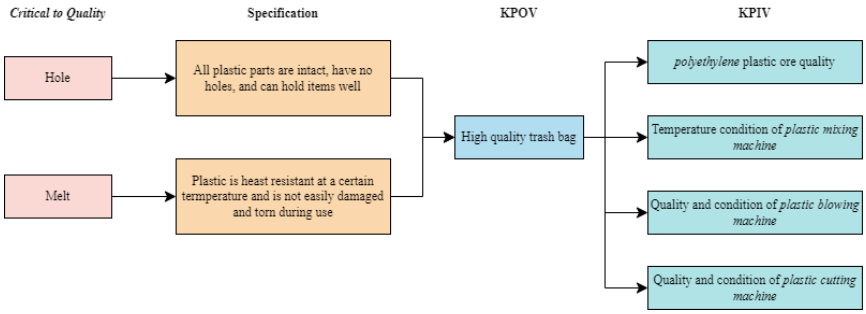

Fig. 2. CTQ Tree

4.2 Measure

Sigma level analysis is carried out at the measure stage which is the second stage of the entire DMAIC stage. The measure stage is carried out to measure data related to the defect level or sigma level that occurs. The data measured is trash bag production defect data in the period November 2023 to January 2024. In the measure stage, data measurement will be carried out using control chart (see, Fig. 3), Pareto chart (see, Fig. 4), determining DPMO, determining sigma level, and measuring process capabilities.

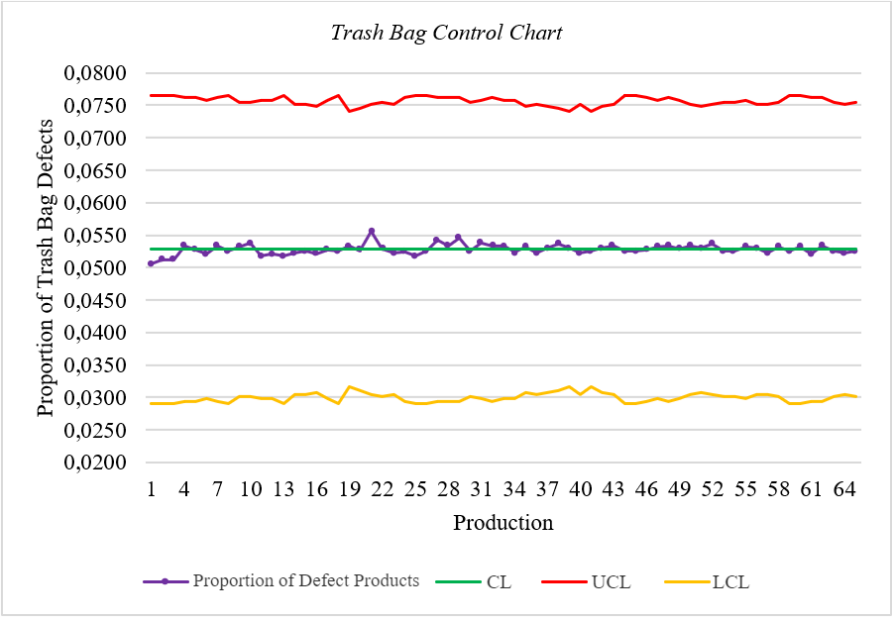

Fig. 3. Control Chart

All sample points plotted are within the control limits (see, in Fig. 3). This means that the average process that occurs does not deviate from the target and the process results are relatively in accordance with the specifications set by the company. However, even though the overall process is within control limits, this does not always indicate that the resulting product meets all expected specifications. Therefore, it is necessary to consider improvement measures to improve the current process.

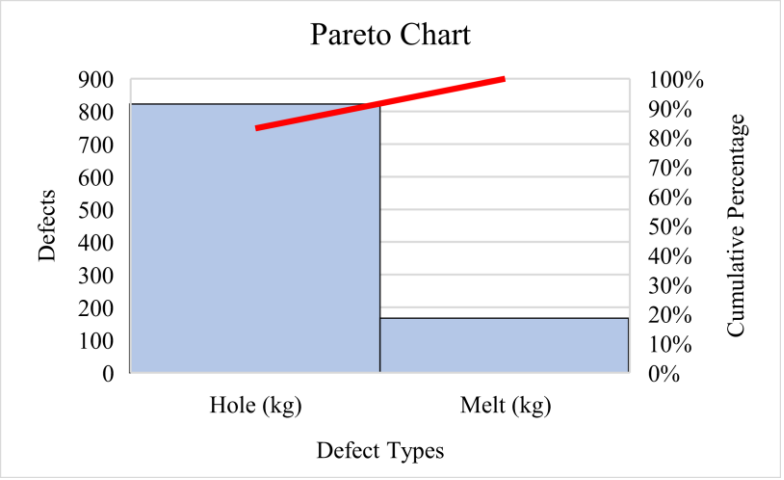

Fig. 4. Pareto Chart

Table 2 shows the results of measuring process capability, which is 1.069, which means that the process capability is in sufficient condition to meet quality specifications. In this condition the company also has the opportunity to make efforts to improve quality. Therefore, even though the process capability value is in a fairly good condition, the company can still make efforts to improve quality by focusing on repairing hole defects which are the biggest cause of trash bag quality problems.

Table 2. Trash Bag Process Capability

Defect Types	Total Production (kg)	Total Defect	DPMO	Sigma Level	Process Capability
Hole	56,200	2466.211	43,907.137	3.207	1.069
Melt	56,200	500.989	8,880.438	3.873	1.291
Average			**26,396.797**	**3.538**	**1.180**

4.3 Analyze

Identification of the causes of defects and failure modes will be carried out at the analyze stage which is the third stage of the entire DMAIC stage. The analysis stage is

carried out with the aim of identifying the factors causing defects using a fishbone diagram. Fishbone diagrams are used as a tool to see the cause and effect relationships of defects that occur (see, Fig. 5). At this stage, failure mode analysis is also carried out using FMEA, Table 3, to provide an assessment of each failure mode for the defects that occur.

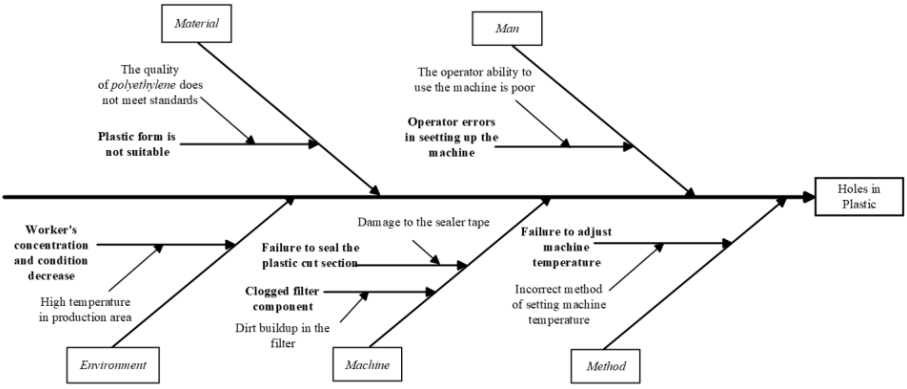

Fig. 5. Fishbone Diagram

Table 3. Failure Mode and Effect Analysis (FMEA)

Product	Failure Effect	Key Input Categories	Failure Mode	Potential Causes of Failure Mode	Current Process Control	SEV	OCC	DET	RPN
Trash Bag	Holes in Plastic	*Material*	Plastic form is not suitable	The quality of *polyethylene* does not meet standards	Raw material testing before production process starts	3	2	2	12
		Man	Operator errors in setting up the machine	The operator ability to use the machine is poor	Mentoring for new operators for 1 week	6	3	1	18
		Method	Failure to adjust machine temperature	Incorrect method of setting machine temperature	Machine temperature reset	6	2	2	**24**
		Machine	Clogged filter component	Dirt buildup in the filter	Replacement of filter component	7	2	2	**28**
			Failure to seal the plastic cut section	Damage to the sealer tape	Replacement of sealer tape on plastic cutting machine	6	2	2	**24**
		Environment	Worker's concentration and condition decrease	High temperature in production area	Installation of two turbine ventilators in the production area	1	5	1	5

4.4 Improve

Determining recommendations for improvement will be carried out at the improve stage which is the fourth stage of the entire DMAIC stage. The improvement stage of the entire DMAIC stage. The improvement stage is carried out with the aim of providing alternative recommendations for improvement to minimize the number of product defects. Alternative repair recommendations will focus on repairing the most critical failure modes based on the results of the highest RPN value in FMEA. The search for alternative recommendations for improvement on the most critical failure modes obtained through FMEA will use the Kaizen 5W + 1H improvement concept. Table 4

shows the results of Kaizen 5W + 1H and it was found that recommendations for improvement to minimize the number of hollow plastic defects due to the failure mode that occurred were through the creation of written SOPs and failure check sheets on machines.

Table 4. Kaizen 5W + 1H

Factor	What	Why	Where	When	Who	How
Machine	Clogged filter component	The machine is not functioning properly due to dirt buildup in the filter	Plastic blowing machine work station	Before and after production process begins	Plastic blowing machine operator	Create SOP and check sheet for machine failures
Machine	Failure to seal the plastic cut section	The machine is not functioning properly due to damage to the sealer	Plastic cutting machine work station	Before and after production process begins	Plastic cutting machine operator	Create SOP and check sheet for machine failures
Method	Failure to adjust machine temperature	Failure occurs due to an incorrect machine temperature control method	Plastic cutting machine work station	Before and after production process begins	Plastic cutting machine operator	Create SOP and check sheet for machine failures

4.5 Control

Implementation of recommended improvements will be carried out at the control stage which is the last stage of the entire DMAIC stage. At this stage, recommendations for improvement will be implemented within a certain period of time. the results of implementing the improvement recommendations will be evaluated to see the sigma level changes that occur. The table below contains a comparison of the results of DPMO calculations, sigma levels, and process capabilities before and after implementing recommendations for improvements during the trash bag production process at the company.

Table 5. Sigma Level Comparison Before and After Using SOP and Check sheet

	Before using SOP and Check Sheet	After using SOP and Check Sheet

Defect Types	DPMO	Sigma Level	Process Capability	DPMO	Sigma Level	Process Capability
Hole	43,907.137	3.207	1.069	35,946.561	3.300	1.100
Melt	8,880.438	3.873	1.291	2,956.225	4.253	1.417
Average	26,396.797	3.538	1.180	19,451.393	3.776	1.258

Based on Table 5 it is known that after implementing SOPs and check sheets, there was a decrease in DPMO to 19,451.393 defect products from one million trash bag produced. The decrease in DPMO is in line with the increase in sigma level from 3.538 sigma to 3.776 sigma. The increase in sigma level also has an impact on increasing process capability at the company. The implementation of the use of SOPs and check sheets has proven to be able to increase the sigma level and minimize the number of defects during the trash bag production process at the company. The increase in sigma level obtained during the control stage in this research means that the research has reached the final stage in the entire DMAIC stage so that conclusions can be drawn from the results obtained.

5 Conclusion

This research implements the Six Sigma method to solve quality problems in one of the plastic industries in Indonesia. The implementation of Six Sigma is carried out by following the DMAIC stage with the aim of minimizing the number of defects in products produced by the company. Through this study, it was obtained that trash bag CTQ refers to two types of defects that occur during production process, namely hollow plastic and melted plastic. Identification of the factors causing defects was carried out using a fishbone diagram and FMEA and it was obtained that the most influential causes of defects came from machine and method factors. This study also used Kaizen 5W + 1H to formulate recommendations for improvement. The recommendations for improvement provided were SOP and machine failure check sheet. The implementation of improvement recommendations was carried out within a certain period of time and obtained an increase in the sigma level from 3.5 sigma to 3.7 sigma.

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