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Quality Control Analysis Using Six Sigma Method and Root Cause Analysis on 100ml Bottles at PT. XYZ Pandaan

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Article Info	Abstract

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This study investigates quality control of 100ml bottle products at PT. XYZ Pandaan using the Six Sigma methodology and Root Cause Analysis. The primary concern is a high defect rate, which negatively impacts production efficiency and product quality. Over a 30-day observation period, 9,810 sample units were examined. Five major defect types were identified: black spots, oil stains, uneven bottle mouths, folded mouths, and deformations. Pareto analysis revealed that black spots, uneven mouths, and folded mouths constituted over 80% of total defects. A P-chart analysis indicated an unstable process. The Defects Per Million Opportunities (DPMO) was 5,708, corresponding to a sigma level of 4.03. The process capability index was 1.34, suggesting the process is capable but requires refinement. RCA was employed to develop improvement strategies, including operator training, preventive maintenance, and stricter quality control. The proposed control plan includes SOP implementation, daily checklists, continuous training, and visual management tools.

1. INTRODUCTION

In today's modern industrial era, competition in the manufacturing sector is getting tighter as many companies produce similar types of products. To be able to survive and excel in the competition, companies are required to have a competitive advantage (Santoso et al., 2024; Widodo & Soediantono, 2022), one form of such excellence is superior product quality. Quality plays an important role in the sustainability of the manufacturing industry because it has a direct effect on brand image and consumer loyalty (Hutama & Widyasmara, 2022; Rudiawan, 2021). In fact, product quality is often used as an indicator to assess the extent of an industry's maturity in producing products that meet standards (Astrini & Imran, 2022).

However, maintaining consistent product quality is not easy. Even though the production process has been carried out optimally, there are often still discrepancies between the products produced and the expected specifications (Mahaputra, 2021; Mahardika et al., 2023). Defective or non-standard products can hinder operational efficiency and force companies to take corrective actions to maintain consistent production quality.

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PT. XYZ Pandaan is one of the leading plastic packaging manufacturing companies in Indonesia, with a reputation that has been built since 1967. The company produces various types of plastic packaging for domestic and international needs, including 100ml plastic bottles used as pesticide product packaging. Despite having an established production system, quality problems still occur, especially in 100ml bottle products that show fluctuating levels of defects.

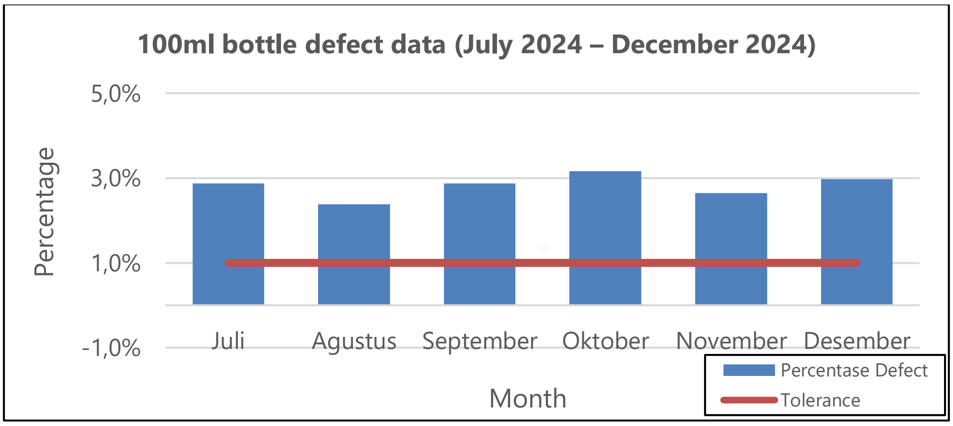

Fig. 1. 100ml bottle defect data (July 2024 – December 2024)

Based on data on the company's rejected products recorded from July 2024 to December 2024, it shows a fluctuating level of defects and tends to exceed the tolerance limit set by the company by 1%. This indicates that there are problems in the production process that need to be handled seriously and systematically. The high level of product defects not only causes financial losses due to rework and disposal costs, but can also reduce customer trust and brand image if defective products reach consumers. If left unchecked, this condition can reduce the company's competitiveness in the market in the long run.

To overcome these problems, a data-based and systematic approach is needed. This study applies the Six Sigma and Root Cause Analysis (RCA) methods as the main approach in analyzing and reducing product defects. Six Sigma is a quality management method that focuses on reducing process variations and defects through the DMAIC (Define, Measure, Analyze, Improve, Control) (Nuralisa & Musfiroh, 2022; Qayyum et al., 2021). On the other hand, RCA is a method used to find the root cause of quality problems using tools such as fishbone diagrams and 5 why analysis, so that the solutions applied really target the underlying cause (Haq & Purba, 2020; Khunaifi et al., 2022).

The effectiveness of the application of Six Sigma and RCA methods has been proven in a study by Hizbullah (2023) entitled "Integration of Six Sigma and Root Cause Analysis in Performance Improvement at PT XYZ" showing that the application of Six Sigma has succeeded in improving company performance through efficiency by 7.8%.

Based on this background, this study aims to analyze the quality control process in 100ml bottle products at PT. XYZ Pandaan uses the Six Sigma approach and Root Cause Analysis, to identify the factors causing defects and formulate appropriate improvement recommendations to improve overall production quality.

2. METHODS

Objects and Types of Research

The object of this research is the 100ml plastic bottle product produced by PT. XYZ Pandaan, a plastic packaging manufacturing company that serves the domestic and export markets. This research was conducted during 30 observation activities from March 2025 to April 2025. This research uses a quantitative approach, namely an approach that focuses on numerical data and statistical measurements to explain phenomena that occur objectively (Dawadi et al., 2021; Jailani, 2023; Mohajan, 2020).

Population and Sample Determination Techniques

The population in this study was the total production of 100ml bottles during 30 days of observation. To determine the number of representative samples from daily production, the Slovin formula is used as follows:

$$n = \frac{N}{1+N.e^2}$$

Information:
n = sample size
N = population size
e = margin of error

Data Processing Stage

The data processing stage is carried out using the six sigma method with the DMAIC (Define, Measure, Analyze, Improve, and Control) and RCA (Root Cause Analysis) approaches.

Define

The first stage in six sigma is define, which is defining or identifying related problems found (Nandakumar et al., 2020). The process of identifying problems related to the level of defects in 100ml bottle products is identifying the types of defects that occur in 100ml bottle products and determining the CTQ (Critical To Quality) of the types of defects that have an effect.

Measure

Measure is a stage where measurements are made related to the level of product defects that have been identified (Tsung & Wang, 2023). The stages in measure are as follows:

a. Proportion control chart (P-Chart)
In calculating the control chart, the following steps and formulas can be used:
Determination $\overline{p}$

$$\overline{p}= \frac{\text{Number of defect product}}{\text{Production quantity}}$$

Determining UCL and LCL

$$CL= \frac{\Sigma\text{Number of defect product}}{\Sigma\text{Production quantity}}$$

$$UCL=CL+3\sqrt{\frac{CL\ (1-CL)}{\text{Production quantity}}}$$

$$LCL=CL-3\sqrt{\frac{CL\ (1-CL)}{\text{Production quantity}}}$$

Information:
$\overline{p}$ = value of proportion of defects
CL = Central Limit
UCL = Upper Control Limit
LCL = Lower Control Limit

b. Calculating DPMO Value and Sigma Level

$$DPMO= \frac{\text{Number of defect product}}{\text{Production quantity x CTQ}} \text{ x } 1.000.000$$

Information :
DPMO = Defects per million opportunities
CTQ = Critical to quality

To calculate the sigma value, you can use the following formula in Microsoft Excel:

$$\text{Sigma Level=NORMASINV}\frac{(1000000\text{-DPMO})}{1000000}+1{,}5$$

c. Process Capability Calculation

The process capability value for attribute data is obtained using the following equation.

$$Cp= \frac{\text{Level Sigma}}{3}$$

According to Gaspersz (2002), the Cp assessment criteria are as follows (Gaspersz, 2002).

1) $Cp \geq 2.00$. Process capability is very good and able to meet target quality specifications.
2) $1.00 \leq Cp \geq 1.99$. Process capability is at the level of not capable to quite capable.
3) $Cp \leq 1.00$. Low process capability and very incapable of achieving quality targets.

Analyze

Analyze is a stage where analysis is carried out and determining the root cause of the problem of the defect that occurs (Mittal et al., 2023). At this stage, the RCA (Root Cause Analyze) method is used with the aim of analyzing the underlying roots of the cause of the defect. The tools used are fishbone diagrams and 5 whys method.

Improve

Improve is a stage by providing recommendations for improvements to the production process (Yanamandra & Alzoubi, 2022). At this stage, strict supervision is carried out so that errors that have been reduced do not recur.

Control

Control is the final stage in implementing six sigm which aims to ensure that the improvements that have been implemented are sustainable and the production process remains stable and consistent in meeting the established quality standards (Sá et al., 2022).

3. RESULT AND DISCUSSION

The determination of the number of samples in this study aims to obtain representative data on the total population of 100ml bottle production at PT. XYZ Pandaan. The sampling technique uses a simple random sampling method with the Slovin formula approach, considering the large population and the need for efficiency in data collection. Based on the observation that the cycle time of 100ml bottle production is 5.04 seconds per bottle, the daily production capacity is estimated to reach 17,143 bottles. Thus, the total population during 30 days of observation is 514,290 bottles. The margin of error is determined at 0.01, so during 30 observation activities at least 9810 bottle samples are needed to be examined, so the number of samples taken per day is 327 bottles. The observation data is then analyzed using the Six Sigma DMAIC method (Define, Measure, Analyze, Improve, and Control) and root cause analysis. These stages are explained in the following sections.

Define Phase

The define stage is the initial step in the DMAIC cycle which aims to identify the type of defect and determine Critical to Quality (CTQ), which are quality parameters that are considered crucial by customers. Based on the results of observations over 30 days, five types of defects were found that most often occur in 100ml bottle products, namely:

a. Black dirty, which is a type of defect in the form of black spots on the surface of the bottle which comes from combustion residue or foreign particles.
b. Oil dirty, which are a type of defect in the form of oil stains or marks on the surface of the product due to engine leaks or excess lubricant.
c. Uneven mouth, which is a type of defect where the mouth of the bottle is uneven or chipped, resulting in the mouth of the bottle not being able to be closed.
d. Folded mouth , which is a type of defect in the form of a fold in the mouth of the bottle which causes a mismatch in shape and functionality.
e. Deformation, which is a type of defect in the form of a change in the shape or structure of the bottle that does not comply with the mold specifications.

The five types of defects are considered to have a direct impact on the aesthetics, functionality, and feasibility of the product. So the five types of defects are determined as CTQ parameters in this study.

Measure Phase

The Measure stage aims to measure the level of defects in 100ml bottle products that have an impact on quality. All types of defects are categorized as attribute data, so P-charts, Defects Per Million Opportunities (DPMO) calculations, sigma levels, and process capabilities are used to evaluate production performance. Based on the results of observations for 30 days from March 2025 to April 2025, the number of samples was 9,810 units with a total of 280 defects. Details of the distribution of defect types are shown in Table 2.

Table 1. Data on the Number of Defects in 100ml Bottles

Observation of-	Sample	Types of Defects					Total Defects
		Black Dirty	Oil Dirty	Uneven Mouth	Folded Mouth	Deformation	
1	327	4	0	2	3	0	9
2	327	4	1	1	2	0	8

Observation of-	Sample	Types of Defects					Total Defects
		Black Dirty	Oil Dirty	Uneven Mouth	Folded Mouth	Deformation	
3	327	5	0	3	3	1	12
4	327	2	0	4	3	1	10
5	327	3	2	2	1	0	8
6	327	4	2	2	2	0	10
7	327	2	0	3	1	0	6
8	327	2	0	2	3	0	7
9	327	4	0	3	2	0	9
10	327	3	1	1	2	1	8
11	327	5	0	2	1	1	9
12	327	3	1	2	3	0	9
13	327	2	0	4	1	0	7
14	327	4	0	3	2	0	9
15	327	2	1	1	1	1	6
16	327	5	1	2	3	0	11
17	327	3	0	4	4	0	11
18	327	2	0	2	7	1	12
19	327	1	1	3	2	0	7
20	327	3	1	3	2	0	9
21	327	2	0	2	3	0	7
22	327	3	2	3	1	0	9
23	327	5	0	5	2	0	12
24	327	3	1	2	3	1	10
25	327	9	0	8	1	1	19
26	327	2	0	2	3	0	7
27	327	6	1	3	2	0	12
28	327	3	2	2	3	0	10
29	327	2	0	2	2	1	7
30	327	5	0	3	2	0	10
Total	9810	103	17	81	70	9	280

Creating a P-Chart

The creation of a proportion control chart (P-chart) is used to evaluate the stability of the production process. The following is a picture of the results of calculating the defect rate control chart on a 100ml bottle product during 30 observation activities.

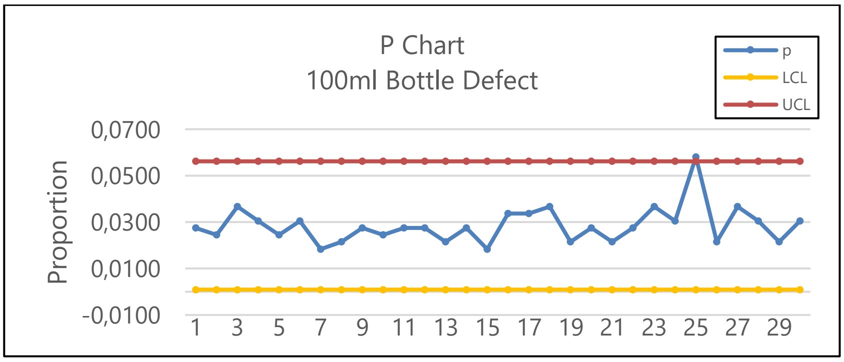

Fig. 2. Control chart of 100ml bottle defects

Based on the image, it is known that there is a proportion point that is outside the control limit, so it can be stated that the level of 100ml bottle defects is unstable, this is due to several factors that cause uncontrolled defects. Therefore, it is necessary to search for the root cause in order to find out the cause of the black dirty defect using Root Cause Analysis (RCA) in the next stage.

DPMO and Sigma Level Calculation

There are 5 known CTQs, namely black dirty, uneven mouth, folded mouth, oil dirty, and deformation. The following is the calculation of DPMO based on the total defect data and the total samples examined.

$$DPMO=\frac{\text{Number of defect product}}{\text{Production quantity x CTQ}} \text{ x } 1.000.000=\frac{280}{9810 \text{ x } 5} \text{ x } 1000000=5708$$

Based on the DPMO Value above, the next step is to calculate the sigma level, in order to determine the sigma level of the defect rate of the 100ml bottle product. The following is the calculation of the sigma level based on the DPMO value.

$$\text{Sigma Level}=\text{NORMASINV}\ \frac{(1000000)\text{-}5708}{1000000}+1{,}5=4{,}03$$

From the calculation, it is known that the production process of 100ml bottles tends to be low. This is based on the DPMO value of 5708, which means that per million opportunities there are 5708 possibilities of producing defective products. Furthermore, the DPMO value is converted into a sigma level, so the sigma level is 4.03. This value can still be categorized as quite good, but the value of the sigma level is considered not yet able to compete in the world class which has a quality standard at the 6 sigma level.

Process Capability Calculation

Process capability is calculated to determine the extent to which the process is able to produce products according to specifications. The following is a calculation to determine the value of the process capability of producing 100ml bottles.

$$Cp = \frac{\text{Level Sigma}}{3} = \frac{4{,}03}{3} = 1{,}34$$

The Cp value of 1.34 indicates that the 100ml bottle production process is said to be quite capable of producing products according to specification standards, but still needs to be improved to achieve the zero defect target.

Analyze Phase

The analyze stage is an analysis process that aims to determine the most dominant type of defect in the 100ml bottle production process, as well as identifying potential causes of the defect. To find out the type of defect that has the most influence on product quality, an analysis is carried out using the Pareto diagram. This diagram helps in identifying the type of defect with the largest contribution to the total number of defects.

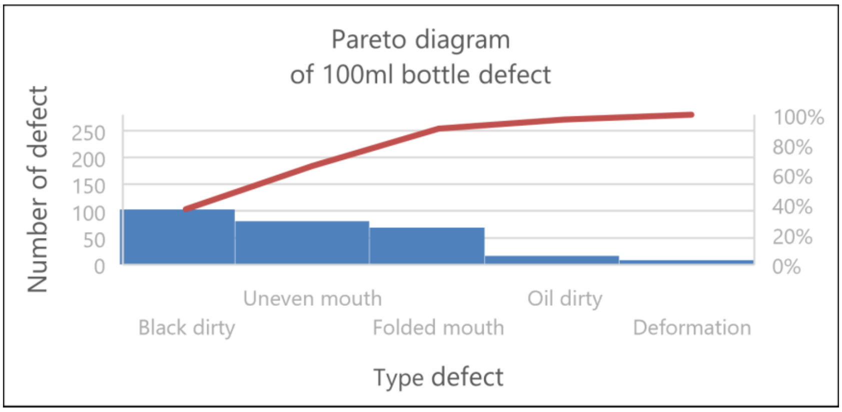

Fig. 3. Pareto diagram of 100ml bottle defects

In accordance with the principle of the Pareto diagram, namely the 80:20 rule, which means that the type of defect whose cumulative value reaches 80% is considered to represent all types of defects that occur. In the Pareto diagram, it is known that there are 3 types of defects that have a cumulative value of more than 80% which are considered to have critical value and require corrective action, namely the type of black dirty defect, uneven mouth, and folded mouth. Root Cause analysis with fishbone diagram and 5 why analysis is used to determine the cause of defects that occur in 100ml bottles. The following is a fishbone diagram of the three types of defects.

a. Fishbone diagram black dirty defect

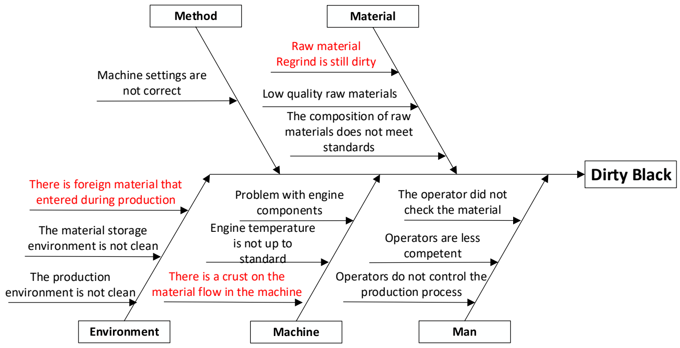

Fig. 4. Fishbone diagram of black dirty

Based on initial identification through fishbone diagram, various factors were obtained that have the potential to cause the emergence of black dirty defects in 100ml bottle products. These potentials include: the use of dirty regrind (aval) raw materials, low-quality raw materials and raw material compositions that do not meet standards, the presence of components of the machine that experience problems, the machine temperature that does not meet standards or is inconsistent, and there is crust on the material flow in the machine, the setting method on the machine is not right, there is foreign material entering the production area because the production environment is open, the material storage environment is not clean, and the production environment is not clean (lots of dust in the production machine area).

b. Fishbone diagram of uneven mouth deformity

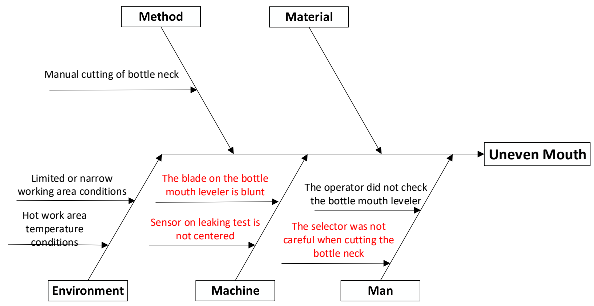

Fig. 5. Fishbone diagram of uneven mouth

Based on initial identification through fishbone diagram, various factors were obtained that have the potential to cause uneven mouth defects in 100ml bottle products. These potential factors include: production operators do not check the bottle mouth leveling tool before the production process, the selector is not careful when cutting the bottle neck, the blade on the bottle mouth cutting machine is blunt or not sharp, the accuracy of the sensor on the leaking test machine is not centered, the cutting method by the selector is still carried out manually, the condition of the worker area is very limited or too narrow and the temperature conditions on the hot blow molding production floor.

c. Fishbone diagram of mouth fold deformity

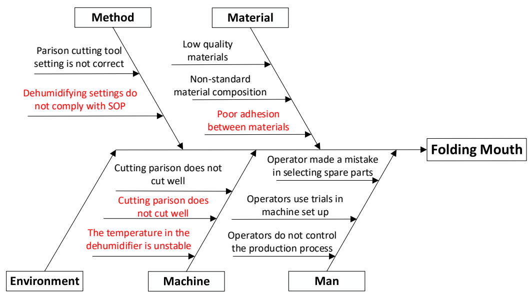

Fig. 6. Fishbone diagram of the mouth fold defect

Based on initial identification through fishbone diagram, various factors were obtained that have the potential to cause the appearance of mouth folding defects in 100ml bottle products. These potentials include: inaccurate use of the type of machine spare parts caused by operator negligence, the operator uses a trial system so that the SOP on the machine setting is not carried out, the operator does not control during the production process, low-quality material characteristics, material composition that does not meet standards, lack of adhesion between materials, the parison cutting system on the machine does not work properly, the blow pin used to blow air on the bottle is not centered, the temperature on the dehumidyfer machine is unstable, the parison cutting knife setting is not right and the dehumidyfer machine setting does not comply with the SOP.

The identification results are the basis for further discussions with the Quality Control team of PT. XYZ Pandaan, with the aim of filtering the causes that are considered the most crucial and contribute greatly to the occurrence of defects in the 100ml bottle production process. Furthermore, based on the results of the discussion, it is known that there are several potentials that are categorized as critical causes of defects in 100ml bottle products, these potentials are marked in red on the fishbone diagram. The potentials that are considered critical will then be further analyzed to explore the underlying root causes using the 5 Why Analysis approach. The analysis related to the critical potential causes of defects using 5 why analysis is as follows.

Table 3. Root cause analysis of defects using the 5 why analysis approach

Types of defects	5 why analysis				
	Why 1	Why 2	Why 3	Why 4	Why 5
Black dirty	Regrind raw materials are still dirty	The recycling process for rejected products that will be used as raw materials is less than optimal	There is no sorting process between contaminated rejects and non-contaminated rejects.		
	The presence of engine crust that accompanies the flow of material in the engine	There are gaps between machine component connections, so that at high temperatures the material flow becomes crusty.	Worn engine components cause small gaps in the joints.	The service life of machine components that have exceeded their service life limit	
	Foreign materials introduced during production	Uncovered raw material storage tank	The operator was negligent in ensuring that the cover of the raw material storage tank was closed.		
Uneven mouth	The selector was not careful when cutting the bottle neck	Selectors have little understanding of cutting quality standards	The training program for selectors is not well scheduled		
	The mouth leveler blade is blunt	Replacement and maintenance of blades is not carried out routinely	Focus maintenance on the knife only when the damage is severe	There is no periodic preventive maintenance schedule on the cutting blades.	
	The sensor in the leaking test is not centered enough	There is a loose sensor part so the sensor does not point to the center of the product.	The operator was not careful when installing the sensor part		
Mouth folded	Poor adhesion between materials	The heating process time for raw materials in the dehumidyfer machine is less than the standard, namely 4 hours.	Operator does not run the dehumidyfing process according to standards		

Blow pin on blow molding machine is not centered	The presence of a loose bolt part causes the pin to be less centered	Lack of preventive maintenance on blow molding machines	
The temperature on the dehumidifier machine is unstable	The temperature control system on the dehumidifier is not working	Maintenance is only carried out when the machine experiences serious damage.	Lack of preventive maintenance on dehumidifier machines
Dehumidifier machine settings do not comply with SOP	The operator did not run the dehumidyfing process time setting according to the standard, namely 4 hours.	The operator is incompetent and in a hurry	

Improve Phase

At this stage, recommendations will be given regarding improvements to the quality problems being studied. The following are suggestions for improvements based on the root cause of each type of defect.

Table 4. Proposed improvements based on root cause results

Types of defects	Root cause	Proposed improvements
Black dirty	There is no sorting process between contaminated reject products and non-contaminated reject products in reject products that will be used as raw materials for recycling.	Sorting and making separate tubs for contaminated and non-contaminated reject products is carried out by the selector.
	Lack of manpower in the process of sorting rejected products to be used as raw materials for recycling	Addition of manpower in the recycling process of rejected products which will be used as raw materials again
	The service life of machine components that have exceeded their service life limit	Replacing machine components that exceed their service life or performing preventive maintenance consistently
	The operator was negligent in ensuring that the cover of the raw material storage tank was closed so that foreign objects entered.	Selective in recruiting operators and providing regular training related to SOPs for filling materials and providing visual symbols on raw material storage tanks which are useful as reminders for operators.
Uneven mouth	The training program for selectors was not well scheduled, which resulted in a lack of precision when cutting bottle necks.	Selective in recruiting bottle selectors and providing regular training related to quality standards in the neck cutting process.
	There is no regular preventive maintenance schedule for cutting knives, resulting in blunt blades.	Creating a preventive maintenance schedule for cutting knives to avoid potential blunting of the blade.
	The operator was not careful when installing the leaking test sensor part, which resulted in the sensor not being pointed at the center of the product.	Selective in recruiting operators and providing regular training related to leaking test machines
Mouth folded	Operator does not run the dehumidyfing process according to standards	Selective in recruiting operators and providing regular training related to dehumidyfer machines
	Lack of preventive maintenance on blow molding machines	Perform preventive maintenance on blow molding machines periodically to ensure the condition of the machine.
	Lack of preventive maintenance on the dehumidifier machine results in the machine's temperature often being unstable.	Perform preventive maintenance on the dehumidifier machine periodically and replace parts when they exceed their service life.
	The operator was incompetent and rushed by cutting the dehumidyfing process time.	Selective in recruiting operators and providing regular training related to dehumidifier machines

Control Phase

Control is the final stage in the Six Sigma approach that aims to maintain the sustainability of the results of improvements that have been made. In order for quality to be maintained and defects to not reappear, a consistent and structured monitoring system is needed. Some suggestions in this stage include: the creation of SOP (Standard Operating Procedures) that include new work processes resulting from improvement recommendations, the implementation of daily checklists for operators in running the production process to be more controlled, continued training and periodic refreshers for operators and technicians to be consistent in carrying out work procedures, the implementation of a scheduled preventive maintenance system for production tools and machines, and the use of visual aids (visual management) such as labels, warning symbols, or colors as reminders of SOP in the work area.

4. CONCLUSION

This study concluded that the 100ml bottle production process at PT. XYZ Pandaan is affected by five main defect types: black dirt, oil stains, uneven mouths, folded mouths, and deformations. Among them, black dirt, uneven mouths, and folded mouths contribute to over 80% of total defects and were identified as the primary focus for improvement. Through Six Sigma and Root Cause Analysis, supported by fishbone diagrams and the 5 Whys method, the process was found to have a DPMO of 5,708, a sigma level of 4.03, and a process capability (Cp) of 1.34. This indicates a moderately capable process that still needs enhancement to meet global standards. Recommended improvements include periodic operator training, stricter work procedures, scheduled preventive maintenance, and stronger quality control. Future control measures involve implementing SOP, conducting regular QC assessments, and utilizing visual aids in the production area. Reflecting on this research, ongoing process evaluation and operator awareness are essential for sustaining product quality.

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