# ANALYSIS OF QUALITY CONTROL TO REDUCE THE NUMBER OF PRODUCT DEFECTS WITH THE SIX SIGMA METHOD WITH THE INTEGRATION OF THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ) AND FUZZY-MCDM

**UNDERGRADUATE THESIS**

**Submitted to the International Undergraduate Program in Industrial Engineering in Partial Fulfillment of Requirement for the Degree of Sarjana Teknik at the Faculty of Industrial Technology**
**Universitas Islam Indonesia**


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**UNDERGRADUATE PROGRAM IN INDUSTRIAL ENGINEERING**
**FACULTY OF INDUSTRIAL TECHNOLOGY**
**UNIVERSITAS ISLAM INDONESIA**
**YOGYAKARTA**
**2023**

## AUTHENTICITY STATEMENT

I acknowledge that this thesis is my own work except for quotations and summaries, all of which I have explained the source. If in the future it is proven that my confession is not true and violates legal regulations, I am willing to have the degree I have received withdrawn by Universitas Islam Indonesia.

Yogyakarta, 17 December 2023


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# DEDICATION PAGE

*Alhamdulillahirabbil'alamin*
I dedicate this thesis to my family and friends as a thank you for the prayers and support that have been given so that I can complete this thesis. This thesis would also not be completed without the help of my supervisor, Ir. Muhammad Ridwan Andi Purnomo, ST, MSc, PhD, IPM. Thank you for everything. My prayer and love for all of you can never be quantified.

## MOTTO

"Allah does not require of any soul more than what it can afford."
(Q.S. Al-Baqarah: 286)

"For indeed, with hardship [will be] ease. Indeed, with hardship [will be] ease."
(Q.S. Al-Insyirah: 5-6)

"All it takes, when He wills something ˹to be˺, is simply to say to it: 'Be!' And it is!"
(Q.S. Yasin: 82)

# PREFACE

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Praise be to Allah SWT because thanks to His grace and guidance, researchers can complete research and this thesis report as well as possible entitled "Analysis of Quality Control to Reduce the Number of Product Defects with the Six Sigma Method with the Integration of Theory of Inventive Problem Solving (TRIZ) and Fuzzy-MCDM" in order to fulfil the requirements to achieve a Sarjana Teknik (S1) in the Undergraduate Program in Industrial Engineering, Faculty of Industrial Technology, Universitas Islam Indonesia. Sholawat and greetings always go to our great prophet Muhammad SAW and his family, friends, and followers until the end of time.

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The author hopes that in the future this Final Project report can not only be used as a reference, but can also help add experience and knowledge, especially for the author. The author realizes that the writing of this report is far from perfect. Therefore, constructive criticism and suggestions are needed so that it can be better in the future. Lastly, the author hopes that the objectives of the implementation and preparation of this report can be achieved, and the results can be accepted as expected.

***Wassalamu'alaikum Warahmatullahi Wabarakatuh.***

Yogyakarta, 6 December 2023

Sekar Arum Sari

## ABSTRACT

PT Narmada Awet Muda is one of the companies engaged in the bottled drinking water industry. The products produced are bottled drinking water, cup bottled drinking water, and gallon bottled drinking water. It is known that there are problems related to quality control faced by the company, namely the occurrence of product defects in the production process. This research aims to help the company minimize the occurrence of product defects by using the Six Sigma method with the stages of Define, Measure, Analyze, and Improve, FMEA, TRIZ method, and Fuzzy MCDM method. Based on the company's historical data, it is known that bottled drinking water products are the most produced products and are more in demand by consumers. Based on this, the focus of this research is 600ml bottled drinking water products. There are three types of defects that occur in the production process of drinking water in 600ml bottles, namely bottle cap defects, bottle defects, and water volume defects. Based on data processing, it is obtained that the type of bottle cap defect has the highest defect percentage value, which is 38% of all defective products. Meanwhile, the average DPMO value is 8,621 and the average sigma value is 3,94. In the FMEA calculation, the potential cause with the highest RPN value is obtained, namely the function of the bottle capping machine is not optimal with a value of 270. Based on the method that has been applied and has been calculated, it results that there are 9 potential causes of failure. To get an improvement proposal in the form of optimal mitigation actions, there are 12 actions based on the results of the TRIZ method that have been carried out.

Keywords: Quality Control, Six Sigma, DMAIC, FMEA, TRIZ, FMCDM

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# CHAPTER I
# INTRODUCTION

## 1.1 Background

Water is an essential element for human survival. Water plays an important role in the human body, especially in maintaining fluid levels so that no disturbances occur in the body. Based on the Ministry of Health of the Republic of Indonesia, adults are advised to consume about eight 230 ml glasses of mineral water per day or a total of 2 liters. Based on the Decree of the Minister of Industry and Trade of the Republic of Indonesia No.96/2011, Bottled Drinking Water (AMDK) is water that has been processed without other food ingredients and food additives, packaged, and safe to drink. Public demand for drinking water is very high. This is because population growth and people's need for drinking water are directly proportional. Based on the Central Agency on Statistics (Central Agency on Statistics, 2023) the distribution of bottled water in Indonesia aimed at households has the highest percentage value of 39.52% among other water sources used for drinking. In addition, based on data from the Central Agency on Statistics of Tegal Regency, the number of drinking water consumers in 2020, 2021, and 2022 was 48,665, 51,712, and 54,424 respectively, which shows that the need for drinking water always increases over time. This is used as an opportunity for business actors to gain profits so that the creation of industrial companies in the field of drinking water is increasing rapidly. This is used as an opportunity for business actors to gain profits so that the creation of industrial companies in the field of drinking water is increasingly rapid. There are 1,032 bottled drinking water companies registered with the Indonesian Food and Drug Authority throughout Indonesia.

The number of drinking water companies makes each company to be able to compete in facing market needs. Companies need to know what consumers want so that consumer loyalty to the products produced by the company does not decrease, which if this happens can affect profits for the company. Therefore, business actors should pay attention to the quality of production control to be able to compete and survive in the long term because quality is a priority for the company. A product is said to have good quality if the product specifications can meet the needs and desires of consumers. So quality can be interpreted as a standard characteristic of a product that aims to meet customer needs and satisfaction (Kusumawati & Fitriyeni, 2017). Therefore, business actors need to maintain quality by controlling quality so that the products produced are in accordance with the standards set by the company and the standards set by local or international bodies related to quality standards that are in accordance with what consumers expect.

There are several industries in the field of bottled drinking water in Mataram City. One of these companies is PT Narmada Awet Muda. This company has two brands of bottled drinking water, namely the Narmada and Rafa brands. Each brand has a different market share. The market share of the Narmada brand covers West Lombok and Central Lombok, while the Rafa brand covers East Lombok and Sumbawa. In addition, Narmada bottled drinking water is distributed to several hotels and modern markets in the Lombok region.

Bottled drinking water products produced by PT Narmada Awet Muda are divided into several packages including cups with sizes 200ml and 220ml, bottles with sizes 330ml, 600ml, and 1500ml, and gallons with a size of 19L. The company is able to produce drinking water in 600ml bottles as many as 25,000 bottles per shift. The company has a commitment to become the market leader of Bottled Drinking Water (AMDK) companies in West Nusa Tenggara by 80% with the implementation of World Class Manufacturing (WCM) by providing good quality products, safe for health, and producing environmentally friendly products. One form of effort in realizing this commitment is to carry out quality control on the entire bottled drinking water production process starting from the preparation of raw materials to the finished product process. The drinking water production process is carried out hygienically by carrying out the ozonation process and three times the feasibility test.

This cannot guarantee overall that the products produced can avoid product defects (zero defects) because many factors can cause product defects, among others, such as in terms of man, method, machine, material, and environment. The object used in this study is drinking water in 600ml bottles. This is because drinking water in 600ml bottles is most in demand by consumers based on the amount of production that is more than drinking water with other types of packaging and sizes in meeting market demand. The product that sells the most in the market will affect the image of a brand and company and will affect consumer perceptions of the product as a consideration in purchasing decisions for a product. In addition, the number of product defects in drinking water in 600ml bottles is quite high. Drinking water products in 600ml bottles experience several defects in the product seen from the presence of damage and non-conformity to specifications determined by the company such as cap defects, bottle defects, and water volume defects caused by several factors during production. The following is data on the number of production and data on the number of defective products in 600ml bottled drinking water products in the period August - December 2022 which shows in Figure 1.1.

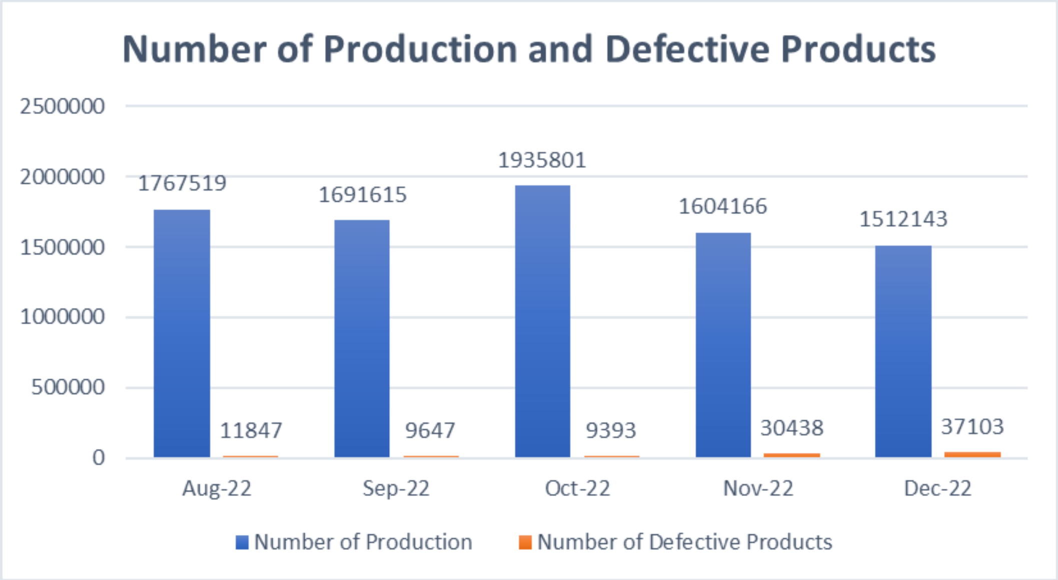


Figure 1. 1 Number of Production and Defective Products Data

Based on Figure 1.1 which is a comparison graph between the number of production data and the number of product defects in the period August - December 2022, it is known that the average number of defects in 600ml bottled drinking water products is 19,685 bottles with an average production of 1,702,249 bottles. Based on this, the company suffered huge losses due to increased defect of 600ml bottled drinking water products. Where, a high number of defects can cause direct effect to financial of company.

By doing quality control, it is hoped that it can help to find the factors that cause defects in products and find improvement solutions to solve these problems so as to minimize the number of defects in products. In order to reduce the defects number of the 600ml bottled drinking water products, it is necessary to determine the factor that cause many defects and mitigate the quality control needed.

To perform quality control and obtain proposed mitigation actions to reduce the number of product defects, researchers combine several methods, namely Six Sigma, Failure Modes and Effects Analysis (FMEA), Theory of Inventive Problem Solving (TRIZ), and Fuzzy Multi Criteria Decision Making (FMCDM).

Six Sigma is a method that can be used in quality control with a statistical concept that measures a process related to defects at the 6 (six) sigma level, which is only 3.4 defects out of a million opportunities (Manan et al., 2018). Six Sigma analysis is carried out based on analysis of facts and data so as to reduce the risk of making wrong decisions because it is supported by empirical evidence. There are 5 cycles in the Six Sigma method, namely DMAIC (Define, Measure, Analyze, Improve, and Control). The DMAIC cycle is a key in making continuous improvements in achieving Six Sigma targets (Widiyawati & Assyahlafi, 2017). The DMAIC cycle provides a systematic approach to problem solving and continuous process improvement. In analyzing the potential factors that cause product defects, the Failure Mode and Effect Analysis (FMEA) method is used. FMEA can help in identifying the priority of potential causes of failure in a product based on the Risk Priority Number (RPN) value so that the potential causes of product defects can be known from the highest to the lowest level. To get an improvement proposal, researchers combine the Six Sigma method with the TRIZ (Theory of Inventive Problem Solving) method at the improve stage. TRIZ is a logic and data-based problem-solving method that accelerates the ability to solve problems creatively (Anwar, 2018). TRIZ has a systematic and structural framework in identifying a solution so that it can help solve a problem effectively. In addition, this method can also overcome uncertainty and contradictions to the problems faced based on previous experience in order to produce an optimal solution. In addition, this research also uses the Fuzzy Multi Criteria Decision Making (FMCDM) method. This method is used to assist researchers in making decisions on several alternatives so that researchers can get the best alternative to be used as a proposed improvement based on certain criteria.

With this study, it is hoped that it can help companies in carrying out quality control in the production process of bottled drinking water in 600ml bottles and be able to design proposals related to priority improvements that can be carried out by companies and can produce optimal solutions so that companies can minimize the risk of defective products with high numbers.

## 1.2 Problem Formulation

After describing the problems that occur and the main focus to be studied, several problem formulations are obtained, namely as follows:

1. What is the DPMO value and sigma level of 600 ml bottled drinking water products at PT. Narmada Awet Muda?
2. What are the most potential factors that cause defects in 600 ml bottled drinking water products at PT. Narmada Awet Muda?

3. What improvement solutions can be provided to minimize the occurrence of product defects in 600 ml bottled drinking water products at PT. Narmada Awet Muda?

**1.3 Research Objectives**

Based on the problem formulation above, the following are the objectives of this research:

1. Get the DPMO value and sigma level on 600 ml bottled drinking water products at PT. Narmada Awet Muda.
2. Knowing the most potential factors that cause defects in 600 ml bottled drinking water products at PT. Narmada Awet Muda.
3. Obtain improvement solutions to minimize the occurrence of product defects in 600 ml bottled drinking water products at PT. Narmada Awet Muda.

**1.4 Research Benefits**

The benefits that can be expected from doing this research are as follows:

1. For the Company

   The results of this study are expected to be taken into consideration for companies in making decisions related to product quality control so as to minimize the number of defects in products.
2. For Researchers

   The results of this study are expected to provide knowledge to researchers in analyzing a problem and finding solutions to solve problems, especially in quality control to minimize the number of product defects.
3. For Further Researchers

   The results of this study are expected to be a reference for those who will conduct similar research in the future.

**1.5 Scope of Problem**

Research limitations are needed so that research can be done in focus and not deviate. The research limitations in this study are as follows:

1. The research was conducted at PT Narmada Awet Muda.
2. Research is only conducted on bottled drinking water products 600 ml brand Narmada.
3. The data used is data on the amount of production and the number of defects obtained from company documents for the period November - December 2022.

4. The research uses the Six Sigma method with the DMAIC stage without using the control stage, FMEA, TRIZ, and FMCDM.
5. The improvement actions proposed by the researcher are not implemented directly but are only limited to the recommendation of the proposal in quality control to reduce the number of defects in products.

### 1.6 Systematical Writing

The systematical writing in this thesis is organized as follows:

**CHAPTER I** **INTRODUCTION**

This chapter contains the background, problem formulation, research objectives, research benefits, scope of problem, and systematical writing.

**CHAPTER II** **LITERATURE REVIEW**

This chapter contains a literature review and theoretical basis that can prove that the research topic raised meets the requirements and criteria that have been described.

**CHAPTER III** **RESEARCH METHODOLOGY**

This chapter contains the object of research, data collection methods which include the types and sources of data used, techniques used in data collection, and research flow.

**CHAPTER IV** **DATA COLLECTION AND PROCESSING**

This chapter contains the data processing process with the methods used. Data collection and processing are represented using images, tables, and graphs. The results of the data processing will be further analyzed in the next chapter.

**CHAPTER V** **DISCUSSION**

This chapter contains a critical discussion related to the results of data processing that has been carried out in the study. The results of the discussion are expected to be the basis for determining to produce a recommendation.

**CHAPTER VI** **CONCLUSION**

This chapter contains conclusions that contain brief statements that answer research questions and objectives. In addition, this chapter contains recommendations addressed to companies and similar future research that will be developed based on the limitations or obstacles found during the research.

# CHAPTER II
# LITERATURE REVIEW

## 2.1 Literature Review

This section contains scientific journals regarding similar research that has been conducted previously related to the research topic to be discussed, especially research using Six Sigma, DMAIC, FMEA, TRIZ, and FMCDM methods. Thus, researchers get an overview of the research to be carried out.

Research related to quality control using the Six Sigma method with the stages of Define, Measure, Analyze, Improve, and Control (DMAIC) has been widely conducted. Widyarto et al. (2019) researched drinking water products in gallon packaging which aims to determine the company's performance measurement baseline based on the Defect Per Million Opportunities (DPMO) value and sigma value to identify the causes of product defects. The results showed that the most dominant types of defects were leaking and broken gallons. The proposed improvements that can be made are to mark gallons that have patches so that they are not confused and pay more attention to the gallon's service life to ensure that the gallon is still suitable for use. Similar research was conducted by Achmad et al. (2023) in the sportswear industry with the aim of minimizing defects in polyester technical sportswear products in the sewing process. In this study using the Six Sigma method DMAIC stages and Reverse Engineering method. The results showed that the defect was caused by the use of blunt needles. Therefore, the proposed improvements that can be made are programming a timer alarm system that is integrated with the sewing machine to replace the needle. Other research related to quality control with the Six Sigma method with the DMAIC stage was also conducted by Sumasto et al. (2022) in the railroad manufacturing industry to achieve cost reduction and improve company quality. Anggraini et al. (2019) conducted research in the batik industry which aims to identify the causes of defects. The largest defect rate is 45% in the color produced is not suitable. Proposed improvements that can be made are improving employee work in the coloring line, giving time labels on the fabric, and adding processes in the form of blocking the fabric. The application of these proposals can increase the sigma level which was originally level 3.375 to level 4.

Prasetya et al. (2021) conducted research on the TL-5 production process which is a car component that aims to analyze failures that cause a problem. The method used is Failure Mode and Effect Analysis (FMEA). The results showed that there were 7 failure modes with the highest RPN value of 168 which occurred in the overproduction time factor. The proposed improvements that can be made are by implementing the LSS program. Similar research was also conducted by Aiman & Nuruddin (2023) in different industries, namely the aquarium and glass cabinet manufacturing industry, and Nurdyansyah & Ningrum (2023) in the bottled mineral water industry.

Putri & Primananda (2021) conducted research on the textile manufacturing industry with the aim of minimizing product defects and recommending improvements in yarn production. The methods used are Six Sigma and Kaizen methods with 5W + 1H. The results showed that the over doffing defect had the highest percentage of 54.8%. Proposed improvements that can be made are repairing PCBs and scheduling for spare part replacement.

Trenggonowati et al. (2020) conducted research in the steel industry which aims to determine product quality and factors causing product defects. The method used is the Six Sigma method using Failure Mode and Effect Analysis (FMEA) in identifying the most potential causes of defects. The results showed that the roll entry guide stand finishing wear had the highest RPN value of 448. Proposed improvements that can be made are providing proper work instructions and SOPs, ensuring billet size conformity, conducting roll inspections, and supervising production. Hanifah & Iftadi (2022) conducted a similar study in the sugar industry with the aim of providing improvement suggestions and minimizing product defects. The results showed that the type of defect in the form of inappropriate sugar color had the highest percentage of 42%. The quality of sugar cane is not in accordance with the standard and has the highest RPN value of 168. Proposed improvements that can be made are to increase checking the quality of sugar cane and increase accuracy in cleaning sugar cane. This can increase the sigma value to 4.48. Similar research was conducted by Adawiyah & Donoriyanto (2022) in the rice industry. The highest percentage of defects is 41.7% which occurs in the defect of sticking rice skin. Proposed improvements that can be made are recalibrating and checking husker machine settings regularly. Matajang & Muslim (2022) conducted research on the coffee bean industry with the aim of reducing the number of defects in coffee beans. The highest defect occurred in pixel defect with a percentage of 84%. The highest RPN value is 186 which is caused by raw materials are stored too long in collectors. Improvements that can be made are checking the purchase time from farmers before buying coffee beans from collectors. Another similar study was also conducted by Montororing et al. (2022) in pharmaceutical manufacturing industries who successfully implemented proposed improvements to defective products, thereby increasing the sigma value from 4.18 to 4.46. Similar research using Six Sigma and FMEA methods was also conducted by Untoro & Iftadi (2020), Wijaya & Ekawati (2021), and Wicaksono et al. (2023).

Munawar et al. (2023) conducted research on the fashion accessories manufacturing industry which aims to analyze and minimize product defects. The method used is Six Sigma with the stages of Define, Measure, Analyze, Improve, and Control (DMAIC), Material Requirement Planning (MRP), and Failure Mode and Effect Analysis (FMEA). The results showed that the factor of less disciplined and conscientious operators had the highest RPN value of 140. Proposed improvements that can be made are monitoring operator work and giving detailed explanations to operators regarding the product manufacturing process.

Boangmanalu et al. (2020) conducted research on manufactures of solid drugs which aims to minimize the number of defective products and identify the risk of failure that occurs. The method used in this research is Six Sigma with DMAIC stages and Theory of Inventive Problem Solving (TRIZ). The results showed that the operator is the most potential cause of product defects with an RPN of 162. Proposed improvements that can be made are conducting worker training, periodic machine maintenance, and giving sanctions to operators if they violate work rules. By implementing the proposed improvements, it can increase the sigma value from 3.61 to 4.06. Similar research was also conducted by Purnomo & Lukman (2020) in the wood manufacturing industry with the aim of reducing waste and increasing productivity. The results showed that the most dominant type of waste was waiting during the process with a percentage of 30%. Proposed improvements that can be made are changing the assembly operational conditions into balanced workstations and checking inventory in the warehouse regularly.

Muangman et al. (2020) conducted research that aims to assist rubber farmers in choosing suitable plants for cultivation. The method used is Fuzzy Multicriteria Decision Making (FMCDM). In this study there are 3 criteria with 25 sub criteria and 6 alternatives. The results showed that the suitable plant for cultivation is Baegu because it has more advantages in commercial terms. Similar research was also conducted by Irianto & Sudarmin (2020) which aims to help farmers in choosing banana fruit plants that are suitable for cultivation. In this study there were 9 criteria and 6 alternatives. The results showed that Barangan banana is a type of plant that is suitable for cultivation. Wang & Han (2019) also conducted similar research with the same method which aims to evaluate retailer financial performance for supply chain management. In this study there were 4 criteria with 15 sub criteria and 3 alternatives. The results showed that retailer 2 has the best financial performance among other retailers. Research related to decision selection using the FMCDM method was also conducted by Bernardo & Promentilla (2022) which aims to select materials for optimal solid-state hydrogen storage. In this study there are 4 criteria and 4 alternatives. Based on the results of the study, metal-organic frameworks are the best material to be used as an alternative.

Table 2. 1 Literature Review

| No | Author and Year | Method | | | | | Research Focus |
|---|---|---|---|---|---|---|---|
| | | Six Sigma | FMEA | TRIZ | FMCDM | Other | |
| 1 | Widyarto et al. (2019) | √ | | | | | Identify the causes of gallon defects |
| 2 | Achmad et al. (2023) | √ | | | | √ | Minimizing polyester technical sportswear product defects in tailoring |
| 3 | Sumasto et al. (2022) | √ | | | | | Reduce costs incurred and improve company quality |
| 4 | Anggraini et al. (2019) | √ | | | | | Identify the causes of defects in batik cloth |
| 5 | Prasetya et al. (2021) | | √ | | | | Analyze the failures that cause problems in the TL-5 production process |
| 6 | Aiman & Nuruddin (2023) | | √ | | | | Reduce product defects, increase customer satisfaction, and enhance competitiveness through improvement |
| 7 | Nurdyansyah & Ningrum (2023) | | √ | | | | Knowing the dominant types of defects in bottled drinking water |
| 8 | Putri & Primananda (2021) | √ | | | | √ | Knowing the product quality and factors that cause defects in 20 open end yarns |
| 9 | Trenggonowati et al. (2020) | √ | √ | | | | Knowing the quality of steel and the factors that cause |

| No | Author and Year | Method | | | | | Research Focus |
|---|---|---|---|---|---|---|---|
| | | Six Sigma | FMEA | TRIZ | FMCDM | Other | |
| | | | | | | | non-conformity of specifications in steel |
| 10 | Hanifah & Iftadi (2022) | √ | √ | | | | Provide suggestions for improvement and minimize defects in sugar products |
| 11 | Adawiyah & Donoriyanto (2022) | | √ | | | √ | Analyze the causes of defects and suggest improvements to improve quality. |
| 12 | Matajang & Muslim (2022) | √ | √ | | | | Reduce the number of defects in coffee beans |
| 13 | Montororing et al. (2022) | √ | √ | | | | Solve the causes of drug quality problems |
| 14 | Untoro & Iftadi (2020) | √ | √ | | | | Analyze the factors causing defects at each workstation and make improvements |
| 15 | Wijaya & Ekawati (2021) | √ | √ | | | | Reduce the defect rate of cigarettes and identify the dominant defect factor |
| 16 | Wicaksono et al. (2023). | | √ | | | | Identify the causes of problems and minimize the occurrence of production defects in centrifugal pumps. |
| 17 | Munawar et al. (2023) | √ | √ | | | √ | Analyze and minimize product defects |
| 18 | Boangmanalu et al. (2020) | √ | √ | √ | | | Minimize the number of product defects and identify the risk of failure in medicine |
| 19 | Purnomo & Lukman (2020) | √ | | √ | | √ | Reduce wastage and increase productivity |
| 20 | Muangman et al. (2020) | | | | √ | | Selection of rubber plants suitable for cultivation |

| No | Author and Year | Method | | | | | Research Focus |
|---|---|---|---|---|---|---|---|
| | | Six Sigma | FMEA | TRIZ | FMCDM | Other | |
| 21 | Irianto & Sudarmin (2020) | | | | √ | | Selection of suitable banana fruit plants for cultivation |
| 22 | Wang & Han (2019) | | | | √ | | Evaluating retailer financial performance for supply chain management |
| 23 | Bernardo & Promentilla (2022) | | | | √ | | Selection of optimal material for solid-state hydrogen storage |
| 24 | Sari (2023) | √ | √ | √ | √ | | This thesis determines the selection of the best alternative in the form of priority mitigation actions that can be applied in minimizing defects in drinking water products in 600 ml bottles. |

## 2.2 Fundamental Theory

The fundamental theory contains general theories related to the research topic. The following is the theoretical basis used in this study:

### *2.2.1 Quality concept.*

According to ISO 8402, the definition of quality is a product performance to meet the needs and satisfaction of consumers as specified based on the overall characteristics of a product. Quality is also the requirements or specifications of a product that have been determined by the company where these specifications are used as product advantages (Razak, 2019). Meanwhile, according to Sari (2021), quality is a characteristic that has been determined by the company where these characteristics differentiate between the company's products and competitors' products offered to consumers so that consumers see that the company's products have added value according to consumer expectations where it aims to increase competitiveness in the market. One of the basic factors that influence consumer decisions on a product or service is quality (Rachman, 2019). So that quality has a very important role both for producers in determining specifications and for consumers in choosing a product.

According to Garvin (1987), there are eight dimensions of product quality, which are as follows:

1. Performance refers to the main characteristics of a product.
2. Features refers to additional characteristics that complement the main characteristics of a product.
3. Reliability refers to the likelihood of a product to fail within a certain period of time.
4. Conformance refers to the related characteristics in accordance with predetermined specifications.
5. Durability refers to the life and durability of the product.
6. Serviceability refers to the speed, courtesy, competence, and ease of repair in service.
7. Aesthetics refers to the visuals of the product which includes appearance, taste, and smell.
8. Perceived quality refers to consumer perceptions of the quality of a brand.

### *2.2.2 Quality control.*

Quality control is a planned action carried out by companies such as meeting, maintaining, and improving the quality of a product to meet consumer needs (Shiyamy et al., 2021). Quality control is also a supervisory activity carried out by the company so that there are no quality failures in the production process so that the production results are in accordance with predetermined standards (Damayant et al., 2022). According to Immanuel Sihombing et al. (2017), quality control can improve performance and the company's superiority in competing with competitors, it can also provide benefits for the company. Quality control can be carried out by conducting continuous inspections so that information is obtained that can be used in controlling and improving product quality (Lestari & Purwatmini, 2021).

Based on this definition, quality control is an activity carried out by the company by monitoring the characteristics of a product so that there are no quality deviations that cause losses to the company, besides that it also aims to maintain and improve product quality so that product specifications are in accordance with consumer expectations so that the company can excel in competing in the market. The purpose of quality control is to minimize costs incurred in carrying out the production process according to a predetermined time and increase consumer satisfaction with the product (Syarif et al., 2017).

*2.2.3 Six Sigma.*

Six Sigma is a method in which the measurement process uses several statistical tools to reduce a failure with a Defect per Million Opportunities (DPMO) value of no more than 3.4 so that it can meet customer satisfaction (Harahap et al., 2018). A value of 3.4 DPMO is equivalent to a sigma achievement level of 6 sigma. Six Sigma has a principle of continuous improvement in which quality improvement uses statistical tools and problem-solving tools (Arif & Wahid, 2019).

In implementing the Six Sigma method, the DMAIC concept is used starting from the define stage, measure stage, analyze stage, improve stage, and control stage in mapping a process and problem (Somadi, 2020). Six Sigma focuses on minimizing failure by emphasizing understanding, measurement, and process improvement (Rozi & Nugroho, 2022). The sigma value can measure an achievement towards success in implementing the Six Sigma concept. The following is the level of sigma achievement based on the DPMO value which can be seen in table 1.2 below:

Table 2. 2 Sigma Achievement Level

| **Sigma Achievement Level** | **DPMO (Defect Per Million Opportunities)** | **Information** | **Cost of Poor Quality** |
|---|---|---|---|
| 1-sigma | 691.462 | Not very competitive | Not calculable |
| 2-sigma | 308.538 | Indonesia industry | Not calculable |
| 3-sigma | 66.807 | average | 25-40% of sales |
| 4-sigma | 6.210 | USA industry average | 15-25% of sales |
| 5-sigma | 233 | Japan industry average | 5-15% of sales |
| 6-sigma | 3,4 | World-class industry | <1% of sales |
| Every 1-sigma increase, or shift will give an increase in profit of about 10% | | | |

Source: Gasperz, 2007

In the application of Six Sigma, process performance can be measured based on DPMO values and sigma values. Based on this, in implementing quality control using the Six Sigma method, the concepts of Define, Measure, Analyze, Improve, and Control (DMAIC) are used.

### *2.2.4 DMAIC concept.*

DMAIC (Define, Measure, Analyze, Improve, and Control) is a basic element in the Six Sigma method in identifying defects that aim to improve the performance of a process (Lestari & Purwatmini, 2021). The DMAIC method also has an important role in Six Sigma, namely as a key in solving a problem which consists of several stages in order to get the desired results (Ahmad, 2019). According to (Terawati & Wiguna, 2021), in conducting quality control, the DMAIC method is a complete approach because this method starts with identifying problems to controlling and recommending proposals for improvement. The following are the DMAIC stages and tools used in this study:

1. Define

   The define stage is the first stage in quality improvement efforts. This stage aims to identify problems that occur related to quality standards that cause product defects. At this stage, SIPOC diagrams are made and CTQ (Critical to Quality) is defined.

   a. SIPOC Diagram

      SIPOC diagram is a diagram that describes a process or sub-process in general in a business process to help determine the boundaries and important elements of a process (A. Rahman & Perdana, 2021). SIPOC stands for 5 elements which include Suppliers, Inputs, Processes, Outputs, and Customers. The following is an image of the SIPOC diagram which can be seen in Figure 2.1.

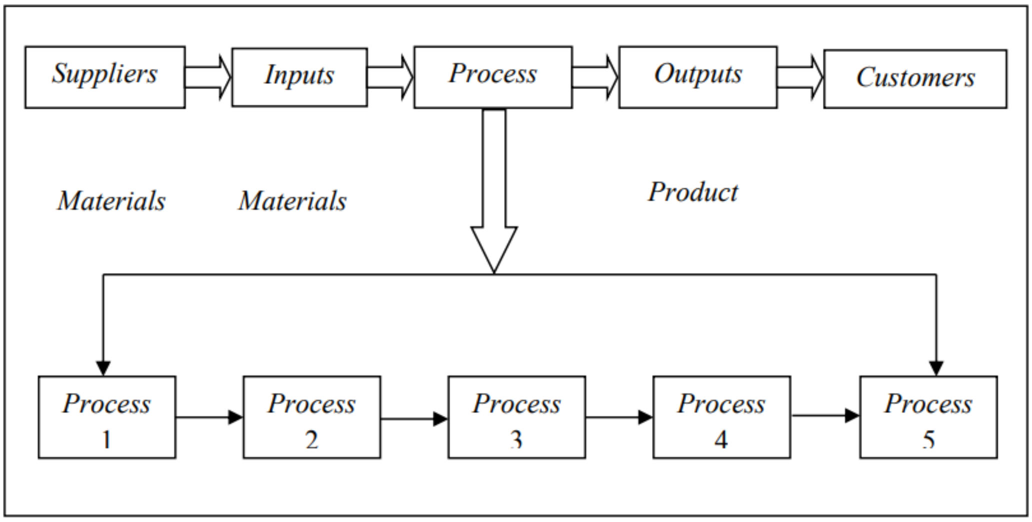


Figure 2. 1 SIPOC Diagram

Source: Ekoanindiyo, 2014

Based on Figure 2.1, there are 5 elements in the SIPOC diagram, including:

1) Suppliers

   Suppliers are parties that supply goods or services resources to a business to be inputted at the process stage.

2) Inputs

   Inputs are resources in the form of materials, services, people, and information that will be processed into an output.

3) Process

   A set of activities in managing inputs to become the final result or output.

4) Outputs

   Output is the final result of a process that will be given to customers.

5) Customers

   Customers are parties who use the results of outputs.

b. Identification of Critical to Quality (CTQ)

   Critical to Quality (CTQ) is an important characteristic or measurable quality standard of a product that must be maintained in order to achieve a standard product specification because it is related to customer needs and satisfaction.

2. Measure

   The measure stage is the second stage in quality improvement efforts. At this stage, sample collection is carried out at the company which will be used as data to be processed before making improvements. This stage aims to determine the condition of the process that occurs in a company by calculating DPMO, sigma value, and control chart.

a. Calculation of Defect Per Million Opportunity (DPMO) and Sigma Value

Defect Per Million Opportunity (DPMO) is a measure of a failure that indicates the occurrence of failures or defects in a product in one million products produced during the production process (Saputri et al., 2022). To calculate the DPMO value, you can use the formula that can be seen in equation 2.1 below.

$$\text{DPMO} = \frac{\text{Total number of defects found in sample}}{\text{Sample size} \times \text{Number of defect opportunities}} \times 1.000.000 \qquad (2.1)$$

After getting the DPMO value, the next step is to calculate the sigma level. According to Wahyuningtyas & Prahutama, 2016), the sigma level is a measure of a company's performance that describes the company's ability to minimize the number of product defects. The higher the sigma level, the smaller the tolerance for defects, causing the higher the level of process capability, which means it is getting better (Fithri, 2019). To calculate the sigma level, it is done by converting the DPMO value to the sigma value with the help of the Ms. Excel formula. The formula used can be seen in equation 2.2 below.

$$\text{Sigma Value} = \text{NORMSINV}\left(1 - \frac{\text{DPMO}}{1.000.000}\right) + 1{,}5 \qquad (2.2)$$

b. Control Chart

The control chart was first introduced in 1924 by Dr. Walter Andrew Stewart of the American Bell Telephone Laboratories which is used to determine and separate variations that are general and special in nature and determine whether a process is under control or not (Sulistiyo & Vitasarari, 2023). According to (Khikmawati et al., 2021), basically every control chart has a limit line, namely the center line called the Control Line (CL), the upper line called the Upper Control Limit (UCL), and the lower line called the Lower Control Limit (LCL). The following is an overview of the control chart which can be seen in Figure 2.2.

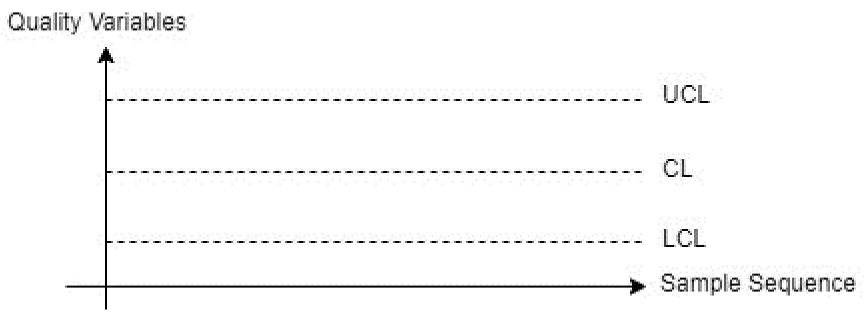


Table 2. 3 Control Chart

Source: Abdullah, 2015

The control chart that will be used in this study is the p control chart. The p control chart is used to measure the proportion of failure or non-conformity of several products during production. Based on Khomah dan Rahayu (2015), the steps for making a p control chart include the following:

1) Calculating the Proportion of Damage (P)

$$P = \frac{\text{Number of defective products}}{\text{Number of samples examined}} \quad (2.3)$$

2) Calculating the Center Line (CL)

$$\overline{P} = \frac{\text{Total number of defective products}}{\text{Total number of samples examined}} \quad (2.4)$$

3) Calculating UCL (Upper Control Limit)

$$UCL = \overline{P} + 3\sqrt{\frac{\overline{P}(1-\overline{P})}{n_i}} \quad (2.5)$$

4) Calculating LCL (Lower Control Limit)

$$LCL = \overline{P} - 3\sqrt{\frac{\overline{P}(1-\overline{P})}{n_i}} \quad (2.6)$$

3. Analyze

The analyze stage is the third stage in quality improvement efforts. This stage aims to analyze the root causes of a problem with CTQ in the form of defective products. At this stage, bar chart and fishbone diagrams are made.

a. Bar Chart

Bar chart is a graph presented in bar form that includes a number of data (Putri, 2010). Bar chart is used to present relative values against other data (Prasetiya et al., 2016). Thus, a bar chart is a graph that aims to see the comparison of data between variables and determine the frequency or quantity of these variables. The following is an overview of the bar chart which can be seen in Figure 2.2.

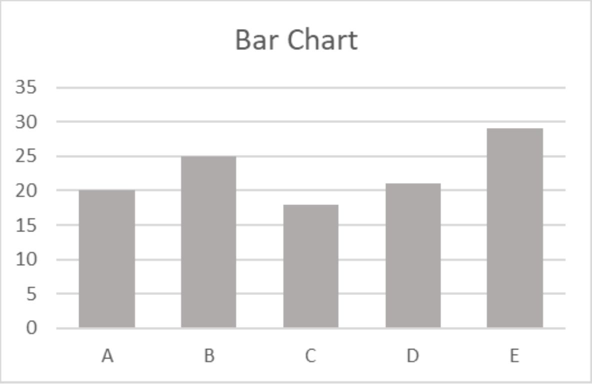


Figure 2. 2 Bar Chart

b. Fishbone Diagram

A cause-and-effect diagram is commonly referred to as a fishbone diagram. According to Fajaranie et al. (2022), a fishbone diagram is a diagram that shows the impact or effect of a problem that occurs along with its causes. In the fishbone diagram, the head is defined as the effect or result of a problem, while the fishbone is defined as the cause of the problem. The following is an overview of the fishbone diagram which can be seen in Figure 2.3.

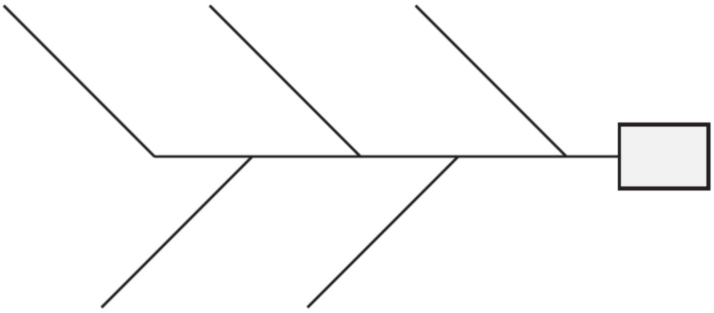

Figure 2. 3 Fishbone Diagram

Source: Borror, 2008

4. Improve

   The improve stage is the fourth stage in quality improvement efforts. After identifying at the analyze stage, the next step is to develop and select the optimal solution to get a quality improvement proposal to minimize the defect rate.

5. Control

   The control stage is the last stage in quality improvement efforts. At this stage, supervision is carried out on the cause of a problem. This stage aims to control each activity so that optimal results are obtained and can reduce unnecessary time, problems, and costs (Rinjani et al., 2021).

#### *2.2.5 Failure mode and effect analysis (FMEA).*

The FMEA method was first developed in 1949 by the United States military as a reliability evaluation technique in evaluating the consequences of failures in equipment systems. FMEA is a method used in defining, identifying, prioritizing, and eliminating a problem both known and potential problems that occur in the system that cause system failure (Budiarto, 2017). FMEA is also a technique that is carried out by examining the impact of each component from the lowest level to the highest level (Arifin et al., 2015).

FMEA is used to identify the priority of potential failures in the product. In determining the priority of improvement, an assessment is carried out based on three components, namely the severity (S), the frequency level of the cause of failure (Occurrence - O), and the level of detection of the cause of failure (Detection - D). Furthermore, the calculation of Risk Priority Number (RPN) is carried out.

The determination of the value category based on the Severity, Occurrence, and Detection components is as follows:

1. Severity

   Severity is the first step to analyzing risk, which calculates how much the impact or intensity of the event affects the end result of the process. The impact is rated on a scale of 1-10, where 10 is the worst impact. The determination of the severity value can be seen in table 2.3 below.

Table 2. 4 Severity Rating and Criteria

| Rating | Criteria |
|---|---|
| 1 | Negligible severity. The failure has no impact on product performance. Consumers may not notice the defect. |
| 2<br>3 | Mild severity. The consequences are only mild. Consumers will not notice a change in product performance. Repairs can be made during regular maintenance. |
| 4<br>5<br>6 | Moderate severity. Consumers will feel a decrease in performance but still within tolerance limits. Repairs are not costly and can be completed in a short time. |
| 7<br>8 | High severity. Consumers will feel a decrease in product performance that is unacceptable and is beyond tolerance. Repairs are very costly. |
| 9<br>10 | Potential safety problems. The consequences are very dangerous and affect the safety of consumers. This condition is against the law. |

Source: (Aiman & Nuruddin., 2023)

2. Occurrence

Occurrence is the likelihood that the cause of the failure will occur and result in some form of failure during the production of the product. Occurance is a rating value that is adjusted to the expected frequency and or cumulative number of failures that can occur. The determination of the occurrence value can be seen in table 2.4 below.

Table 2. 5 Occurrence Rating and Criteria

| Rating | Failure Probability | Criteria |
|---|---|---|
| 1 | Remote | 0,01 per 1000 item |
| 2 | Low | 0,1 per 1000 item |
| 3 | | 0,5 per 1000 item |
| 4 | Moderate | 1 per 1000 item |
| 5 | | 2 per 1000 item |
| 6 | | 5 per 1000 item |
| 7 | High | 10 per 1000 item |

| Rating | Failure Probability | Criteria |
|---|---|---|
| 8 | | 20 per 1000 item |
| 9 | Very High | 50 per 1000 item |
| 10 | | 100 per 1000 item |

Source: (Aiman & Nuruddin., 2023)

3. Detection

Detection serves to prevent the production process and reduce the failure rate in the production process. The determination of the detection value can be seen in table 2.5 below.

Table 2. 6 Rating and Detection Criteria

| Rating | Possibility of Detection | Frequency of Occurrence |
|---|---|---|
| 1 | Failures in the process cannot occur because they have been prevented through solution design. | 0,01 per 1000 item |
| 2 | The probability of the controller detecting the failure is very high. | 0,1 per 1000 item |
| 3 | The probability of the controller to detect the failure is high. | 0,5 per 1000 item |
| 4 | The controller's probability of detecting failure is somewhat high. | 1 per 1000 item |
| 5 | The controller's probability of detecting failure is medium. | 2 per 1000 item |
| 6 | Controller probability of detecting failure is low. | 5 per 1000 item |
| 7 | The controller's probability of detecting a failure is very low. | 10 per 1000 item |

| Rating | Possibility of Detection | Frequency of Occurrence |
|---|---|---|
| 8 | Rare the probability that the controller will discover a potential failure | 20 per 1000 item |
| 9 | Very low probability that the controller will discover a potential failure | 50 per 1000 item |
| 10 | The controller cannot detect the failure | 100 per 1000 item |

Source: (Nastiti & Masduqi, 2023)

4. Risk Priority Number (RPN)

Risk Priority Number (RPN) helps in determining priorities in making improvements to a failure. To get the RPN value, you can use the equation (2.7) formula below.

$$\text{RPN} = \text{Severity} \times \text{Occurence} \times \text{Detection} \quad (2.7)$$

After calculating RPN, the value can then be used as the basis for determining the level of risk and priority of improvement. The higher the RPN value, the higher it is to be prioritized for improvement. The following is the level of risk category that can be seen in Table 2.6.

Table 2. 7 Risk Category Level

| Risk Priority Number (RPN) Value | Category | Treatment |
|---|---|---|
| 192 – 1000 | High | Improvements made at this time |
| 65 – 191 | Medium | Attempts to make improvements |
| 0 – 64 | Low | Risk can be ignored |

Source: Piątkowski & Kamiński, 2017

### *2.2.6 Theory of inventive problem solving (TRIZ).*

TRIZ comes from the Russian language, namely *Teoriya Resheniya Izobretatelskikh Zadatch* and if translated into English, namely Theory of Inventive Problem Solving. TRIZ is a method used in providing suggestions for improvement by eliminating contradictory problems in order to solve problems based on previous experience (Banda et al., 2022). According to Rinawati &

Dei (2015), the main purpose of using TRIZ is to determine the contradiction of each problem and match it with parameters based on 39 engineering parameters defined in the contradiction matrix. Based on (Suryawan, 2014) there are three steps in problem solving using the TRIZ method:

a. Identify problems by looking for factors that can be a problem.
b. Classify the problem by determining the factors in favor (improving parameters) and factors against (worsening parameters) into 39 engineering parameters using a contradiction matrix to find an improvement solution.
c. Finding a solution to a problem by using the inventive principle in resolving contradictions.

The following is an explanation of 39 TRIZ parameters, TRIZ contradiction matrix, and 40 inventive principles of TRIZ.

1. TRIZ 39 Parameter

   In the TRIZ method, there are 39 standardized characters that are technical in nature. This makes it easier to determine factors that can cause contradictions that result in improving parameters and worsening parameters. The 39 TRIZ parameters (Domb et al., 1998) can be seen in table 2.8 below.

Table 2. 8 TRIZ 39 Technical Parameter

| No | Technical Parameter |
|---|---|
| 1 | Weight of moving object |
| 2 | Weight of stationary object |
| 3 | Length or angle of moving object |
| 4 | Length or angle of stationary object |
| 5 | Area of moving object |
| 6 | Area of stationary object |
| 7 | Volume of moving object |
| 8 | Volume of stationary object |
| 9 | Speed |
| 10 | Force |
| 11 | Pressure |
| 12 | Shape |
| 13 | Stability of the object’s composition |
| 14 | Strength |

| No | Technical Parameter |
|---|---|
| 15 | Duration of action of moving object |
| 16 | Duration of action of stationary object |
| 17 | Temperature |
| 18 | Illumination intensity |
| 19 | Use of energy by moving object |
| 20 | Use of energy by stationary object |
| 21 | Power |
| 22 | Loss of energy |
| 23 | Loss of substance |
| 24 | Loss of information |
| 25 | Loss of time |
| 26 | Quantity of substance |
| 27 | Reliability |
| 28 | Measurement accuracy |
| 29 | Manufacturing precision |
| 30 | Object affected harmful factors |
| 31 | Object affected generated factors |
| 32 | Ease of manufacture |
| 33 | Ease of operation |
| 34 | Repairability |
| 35 | Adaptability of versatility |
| 36 | Device complexity |
| 37 | Difficulty of detecting and measuring |
| 38 | Extent of automation |
| 39 | Productivity |

Source: Domb et al., 1998

Table 2. 9 TRIZ 39 System Parameters

| No | System Parameter |
|---|---|
| 1 | Degree of responsibility of employee |
| 2 | Degree of responsibility of supervisor |

| No | System Parameter |
|---|---|
| 3 | Coverage/span of employee responsibility |
| 4 | Coverage/span of supervisor responsibility |
| 5 | Number of contacts/interfaces of employee |
| 6 | Number of contacts/interfaces of supervisor |
| 7 | Bandwidth of employee |
| 8 | Bandwidth of supervisor |
| 9 | Speed of response time |
| 10 | Force or extent of response action |
| 11 | Stress/pressure |
| 12 | Organizational hierarchy/level |
| 13 | Stability of organization |
| 14 | Strength or ability to handle stress/pressure |
| 15 | Time to taken to complete task by employee |
| 16 | Time to taken to complete task by supervisor |
| 17 | Type of interaction |
| 18 | Visibility |
| 19 | Amount of effort put in employee |
| 20 | Amount of effort put in supervisor |
| 21 | Result or amount of output produced |
| 22 | Loss/waste of energy |
| 23 | Loss/waste of members |
| 24 | Loss/waste of information |
| 25 | Loss/waste of time |
| 26 | Number of team members |
| 27 | Reliability/robustness |
| 28 | Actual compared to plan |
| 29 | Precision/consistency |
| 30 | Object affected harmful factors |
| 31 | Object generated harmful factors |
| 32 | Ease of manufacture |
| 33 | Ease of operation |

| No | System Parameter |
|---|---|
| 34 | Ease of repair |
| 35 | Adaptability or versatility |
| 36 | System complexity |
| 37 | Difficulty of detecting and measuring |
| 38 | Extent of automation |
| 39 | Productivity |

Source: Domb et al., 1998

2. Contradiction Matrix of TRIZ

TRIZ contradiction matrix is a table containing 39 horizontal elements (improving parameters), 39 vertical elements (worsening parameters), and 40 inventive principles of TRIZ. In the contradiction matrix, a cross between improving parameters and worsening parameters is made to get the optimal solution to the problem (Oktavian & Aviasti, 2023). The following is the TRIZ contradiction matrix formulated by Atshuller which can be seen in Figure 2.4.

Worsening Feature

Improving Feature

| Features | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1: Weight of moving object | + | - | 15 8 29 34 | - | 29 17 38 34 | - | 29 2 40 28 | - | 2 8 15 38 | 8 10 18 37 | 10 36 37 40 | 10 14 35 40 | 1 35 19 39 | 28 27 18 40 | 5 34 31 35 | - | 6 29 4 38 | 19 1 32 | 35 12 34 31 | - |
| 2: Weight of stationary | - | + | - | 10 1 29 35 | - | 35 30 13 2 | - | 5 35 14 2 | - | 8 10 19 35 | 13 29 10 18 | 13 10 29 14 | 26 39 1 40 | 28 2 10 27 | - | 2 27 19 6 | 28 19 32 22 | 19 32 35 | - | 18 19 28 1 |
| 3: Length of moving object | 8 15 29 34 | - | + | - | 15 17 4 | - | 7 17 4 35 | - | 13 4 8 | 17 10 4 | 1 8 35 | 1 8 10 29 | 1 8 15 34 | 8 35 29 34 | 19 | - | 10 15 19 | 32 | 8 35 24 | - |
| 4: Length of stationary | - | 35 28 40 29 | - | + | - | 17 7 10 40 | - | 35 8 2 14 | - | 28 10 | 1 14 35 | 13 14 15 7 | 39 37 35 | 15 14 28 26 | - | 1 10 35 | 3 35 38 18 | 3 25 | - | - |
| 5: Area of moving object | 2 17 29 4 | - | 14 15 18 4 | - | + | - | 7 14 17 4 | - | 29 30 4 34 | 19 30 35 2 | 10 15 36 28 | 5 34 29 4 | 11 2 13 39 | 3 15 40 14 | 6 3 | - | 2 15 16 | 15 32 19 13 | 19 32 | - |
| 6: Area of stationary | - | 30 2 14 18 | - | 26 7 9 39 | - | + | - | - | - | 1 18 35 36 | 10 15 36 37 | - | 2 38 | 40 | - | 2 10 19 30 | 35 39 38 | - | - | - |
| 7: Volume of moving object | 2 26 29 40 | - | 1 7 4 35 | - | 1 7 4 17 | - | + | - | 29 4 38 34 | 15 35 36 37 | 6 35 36 37 | 1 15 29 4 | 28 10 1 39 | 9 14 15 7 | 6 35 4 | - | 34 39 10 18 | 2 13 10 | 35 | - |
| 8: Volume of stationary | - | 35 10 19 14 | 19 14 | 35 8 2 14 | - | - | - | + | - | 2 18 37 | 24 35 | 7 2 35 | 34 28 35 40 | 9 14 17 15 | - | 35 34 38 | 35 6 4 | - | - | - |
| 9: Speed | 2 28 13 38 | - | 13 14 8 | - | 29 30 34 | - | 7 29 34 | - | + | 13 28 15 19 | 6 18 38 40 | 35 15 18 34 | 28 33 1 18 | 8 3 26 14 | 3 19 35 5 | - | 28 30 36 2 | 10 13 19 | 8 15 35 38 | - |
| 10: Force (Intensity) | 8 1 37 18 | 18 13 1 28 | 17 19 9 36 | 28 10 | 19 10 15 | 1 18 36 37 | 15 9 12 37 | 2 36 18 37 | 13 28 15 12 | + | 18 21 11 | 10 35 40 34 | 35 10 21 | 35 10 14 27 | 19 2 | - | 35 10 21 | - | 19 17 10 | 1 16 36 37 |
| 11: Stress or pressure | 10 36 37 40 | 13 29 10 18 | 35 10 36 | 35 1 14 16 | 10 15 36 28 | 10 15 36 37 | 6 35 10 | 35 24 | 6 35 36 | 36 35 21 | + | 35 4 15 10 | 35 33 2 40 | 9 18 3 40 | 19 3 27 | - | 35 39 19 2 | - | 14 24 10 37 | - |
| 12: Shape | 8 10 29 40 | 15 10 26 3 | 29 34 5 4 | 13 14 10 7 | 5 34 4 10 | - | 14 4 15 22 | 7 2 35 | 35 15 34 18 | 35 10 37 40 | 34 15 10 14 | + | 33 1 18 4 | 30 14 10 40 | 14 26 9 25 | - | 22 14 19 32 | 13 15 32 | 2 6 34 14 | - |
| 13: Stability of the object | 21 35 2 39 | 26 39 1 40 | 13 15 1 28 | 37 | 2 11 13 | 39 | 28 10 19 39 | 34 28 35 40 | 33 15 28 18 | 10 35 21 16 | 2 35 40 | 22 1 18 4 | + | 17 9 15 | 13 27 10 35 | 39 3 35 23 | 35 1 32 | 32 3 27 16 | 13 19 | 27 4 29 18 |
| 14: Strength | 1 8 40 15 | 40 26 27 1 | 1 15 8 35 | 15 14 28 26 | 3 34 40 29 | 9 40 28 | 10 15 14 7 | 9 14 17 15 | 8 13 26 14 | 10 18 3 14 | 10 3 18 40 | 10 30 35 40 | 13 17 35 | + | 27 3 26 | - | 30 10 40 | 35 19 | 19 35 10 | 35 |
| 15: Durability of moving obj. | 19 5 34 31 | - | 2 19 9 | - | 3 17 19 | - | 10 2 19 30 | - | 3 35 5 | 19 2 16 | 19 3 27 | 14 26 28 25 | 13 3 35 | 27 3 10 | + | - | 19 35 39 | 2 19 4 35 | 28 6 35 18 | - |
| 16: Durability of non moving obj. | - | 6 27 19 16 | - | 1 40 35 | - | - | - | 35 34 38 | - | - | - | - | 39 3 35 23 | - | - | + | 19 18 36 40 | - | - | - |
| 17: Temperature | 36 22 6 38 | 22 35 32 | 15 19 9 | 15 19 9 | 3 35 39 18 | 35 38 | 34 39 40 18 | 35 6 4 | 2 28 36 30 | 35 10 3 21 | 35 39 19 2 | 14 22 19 32 | 1 35 32 | 10 30 22 40 | 19 13 39 | 19 18 36 40 | + | 32 30 21 16 | 19 15 3 17 | - |
| 18: Illumination intensity | 19 1 32 | 2 35 32 | 19 32 16 | - | 19 32 26 | - | 2 13 10 | - | 10 13 19 | 26 19 6 | - | 32 30 | 32 3 27 | 35 19 | 2 19 6 | - | 32 35 19 | + | 32 1 19 | 32 35 1 15 |
| 19: Use of energy by moving | 12 18 28 31 | - | 12 28 | - | 15 19 25 | - | 35 13 18 | - | 8 35 | 16 26 21 2 | 23 14 25 | 12 2 29 | 19 13 17 24 | 5 19 9 35 | 28 35 6 18 | - | 19 24 3 14 | 2 15 19 | + | - |
| 20: Use of energy by stationary | - | 19 9 6 27 | - | - | - | - | - | - | - | 36 37 | - | - | 27 4 29 18 | 35 | - | - | - | 19 2 35 32 | - | + |

| Features | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1: Weight of moving object | 12 36 18 31 | 6 2 34 19 | 5 35 3 31 | 10 24 35 | 10 35 20 28 | 3 26 18 31 | 1 3 11 27 | 28 27 35 26 | 28 35 26 18 | 22 21 18 27 | 22 35 31 39 | 27 28 1 36 | 35 3 2 24 | 2 27 28 11 | 29 5 15 8 | 26 30 36 34 | 28 29 26 32 | 26 35 18 19 | 35 3 24 37 |
| 2: Weight of stationary | 15 19 18 22 | 18 19 28 15 | 5 8 13 30 | 10 15 35 | 10 20 35 26 | 19 6 18 26 | 10 28 8 3 | 18 26 28 | 10 1 35 17 | 2 19 22 37 | 35 22 1 39 | 28 1 9 | 6 13 1 32 | 2 27 28 11 | 19 15 29 | 1 10 26 39 | 25 28 17 15 | 2 26 35 | 1 28 15 35 |
| 3: Length of moving object | 1 35 | 7 2 35 39 | 4 29 23 10 | 1 24 | 15 2 29 | 29 35 | 10 14 29 40 | 28 32 4 | 10 28 29 37 | 1 15 17 24 | 17 15 | 1 29 17 | 15 29 35 4 | 1 28 10 | 14 15 1 16 | 1 19 26 24 | 35 1 26 24 | 17 24 26 16 | 14 4 28 29 |
| 4: Length of stationary | 12 8 | 6 28 | 10 28 24 35 | 24 26 | 30 29 14 | - | 15 29 28 | 32 28 3 | 2 32 10 | 1 18 | - | 15 17 27 | 2 25 | 3 | 1 35 | 1 26 | 26 | - | 30 14 7 26 |
| 5: Area of moving object | 19 10 32 18 | 15 17 30 26 | 10 35 2 39 | 30 26 | 26 4 | 29 30 6 13 | 29 9 | 26 28 32 3 | 2 32 | 22 33 28 1 | 17 2 18 39 | 13 1 26 24 | 15 17 13 16 | 15 13 10 1 | 15 30 | 14 1 13 | 2 36 26 18 | 14 30 28 23 | 10 26 34 2 |
| 6: Area of stationary | 17 32 | 17 7 30 | 10 14 18 39 | 30 16 | 10 35 4 18 | 2 18 40 4 | 32 35 40 4 | 26 28 32 3 | 2 29 18 36 | 27 2 39 35 | 22 1 40 | 40 16 | 16 4 | 16 | 15 16 | 1 18 36 | 2 35 30 18 | 23 | 10 15 17 7 |
| 7: Volume of moving object | 35 6 13 18 | 7 15 13 16 | 36 39 34 10 | 2 22 | 2 6 34 10 | 29 30 7 | 14 1 40 11 | 25 26 28 | 25 28 2 16 | 22 21 27 35 | 17 2 40 1 | 29 1 40 | 15 13 30 12 | 10 | 15 29 | 26 1 | 29 26 4 | 35 34 16 24 | 10 6 2 34 |
| 8: Volume of stationary | 30 6 | - | 10 39 35 34 | - | 35 16 32 18 | 35 3 | 2 35 16 | - | 35 10 25 | 34 39 19 27 | 30 18 35 4 | 35 | - | 1 | - | 1 31 | 2 17 26 | - | 35 37 10 2 |
| 9: Speed | 19 35 38 2 | 14 20 19 35 | 10 13 28 38 | 13 26 | - | 10 19 29 38 | 11 35 27 28 | 28 32 1 24 | 10 28 32 25 | 1 28 35 23 | 2 24 35 21 | 35 13 8 1 | 32 28 13 12 | 34 2 28 27 | 15 10 26 | 10 28 4 34 | 3 34 27 16 | 10 18 | - |
| 10: Force (Intensity) | 19 35 18 37 | 14 15 | 8 35 40 5 | - | 10 37 36 | 14 29 18 36 | 3 35 13 21 | 35 10 23 24 | 28 29 37 36 | 1 35 40 18 | 13 3 36 24 | 15 37 18 1 | 1 28 3 25 | 15 1 11 | 15 17 18 20 | 26 35 10 18 | 36 37 10 19 | 2 35 | 3 28 35 37 |
| 11: Stress or pressure | 10 35 14 | 2 36 25 | 10 36 3 37 | - | 37 36 4 | 10 14 36 | 10 13 19 35 | 6 28 25 | 3 35 | 22 2 37 | 2 33 27 18 | 1 35 16 | 11 | 2 | 35 | 19 1 35 | 2 36 37 | 35 24 | 10 14 35 37 |
| 12: Shape | 4 6 2 | 14 | 35 29 3 5 | - | 14 10 34 17 | 36 22 | 10 40 16 | 28 32 1 | 32 30 40 | 22 1 2 35 | 35 1 | 1 32 17 28 | 32 15 26 | 2 13 1 | 1 15 29 | 16 29 1 28 | 15 13 39 | 15 1 32 | 17 26 34 10 |
| 13: Stability of the object | 32 35 27 31 | 14 2 39 6 | 2 14 30 40 | - | 35 27 | 15 32 35 | - | 13 | 18 | 35 24 30 18 | 35 40 27 39 | 35 19 | 32 35 30 | 2 35 10 16 | 35 30 34 2 | 2 35 22 26 | 35 22 39 23 | 1 8 35 | 23 35 40 3 |
| 14: Strength | 10 26 35 28 | 35 | 35 28 31 40 | - | 29 3 28 10 | 29 10 27 | 11 3 | 3 27 16 | 3 27 | 18 35 37 1 | 15 35 22 2 | 11 3 10 32 | 32 40 25 2 | 27 11 3 | 15 3 32 | 2 13 25 28 | 27 3 15 40 | 15 | 29 35 10 14 |
| 15: Durability of moving obj. | 19 10 35 38 | - | 28 27 3 18 | 10 | 20 10 28 18 | 3 35 10 40 | 11 2 13 | 3 | 3 27 16 40 | 22 15 33 28 | 21 39 16 22 | 27 1 4 | 12 27 | 29 10 27 | 1 35 13 | 10 4 29 15 | 19 29 39 35 | 6 10 | 35 17 14 19 |
| 16: Durability of non moving obj. | 16 | - | 27 16 18 38 | 10 | 28 20 10 16 | 3 35 31 | 34 27 6 40 | 10 26 24 | - | 17 1 40 33 | 22 | 35 10 | 1 | 1 | 2 | - | 25 34 6 35 | 1 | 20 10 16 38 |
| 17: Temperature | 2 14 17 25 | 21 17 35 38 | 21 36 29 31 | - | 35 28 21 18 | 3 17 30 39 | 19 35 3 10 | 32 19 24 | 24 | 22 33 35 2 | 22 35 2 24 | 26 27 | 26 27 | 4 10 16 | 2 18 27 | 2 17 16 | 3 27 35 31 | 26 2 19 16 | 15 28 35 |
| 18: Illumination intensity | 32 | 13 16 1 6 | 13 1 | 1 6 | 19 1 26 17 | 1 19 | - | 11 15 32 | 3 32 | 15 19 | 35 19 32 39 | 19 35 28 26 | 28 26 19 | 15 17 13 16 | 15 1 19 | 6 32 13 | 32 15 | 2 26 10 | 2 25 16 |
| 19: Use of energy by moving | 6 19 37 18 | 12 22 15 24 | 35 24 18 5 | - | 35 38 19 18 | 34 23 16 18 | 19 21 11 27 | 3 1 32 | - | 1 35 6 27 | 2 35 6 | 28 26 30 | 19 35 | 1 15 17 28 | 15 17 13 16 | 2 29 27 28 | 35 38 | 32 2 | 12 28 35 |
| 20: Use of energy by stationary | - | - | 28 27 18 31 | - | - | 3 35 31 | 10 36 23 | - | - | 10 2 22 37 | 19 22 18 | 1 4 | - | - | - | - | 19 35 16 25 | - | 1 6 |

Figure 2. 4 TRIZ Contradiction Matrix Part 1

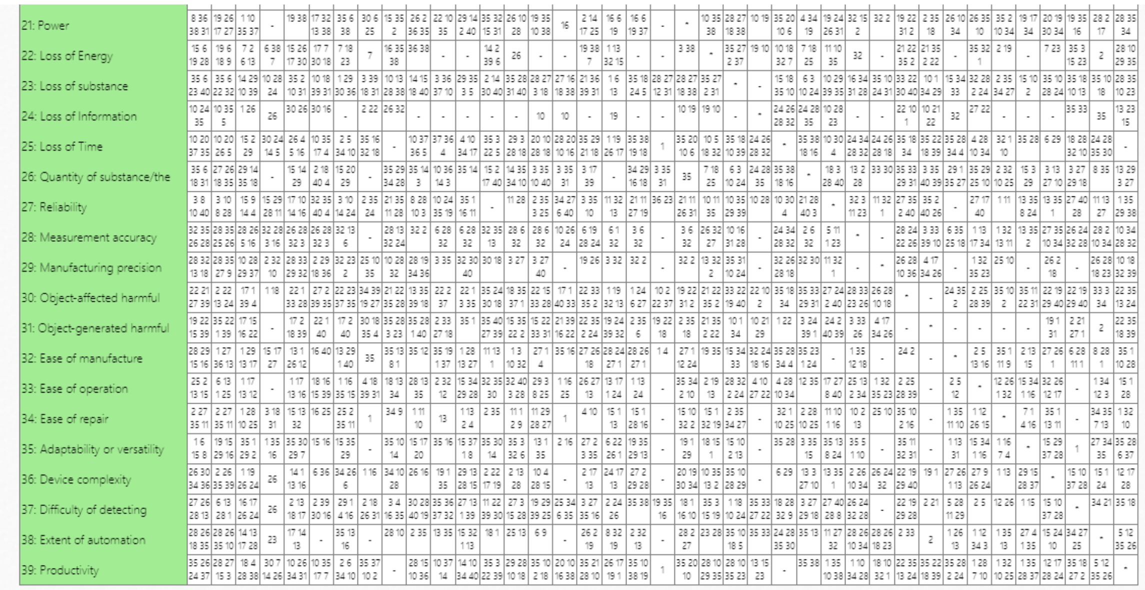

Figure 2. 5 TRIZ Contradiction Matrix Part 2

Source: Solid Creativity, 2023

3. 40 Inventive Principles of TRIZ

   After identifying improving parameters and worsening parameters, 40 Inventive Principle of TRIZ are obtained. This aims to find improvement solutions in the innovation process or the creation of new ideas (Banda et al., 2022). The following are 40 Inventive Principle of TRIZ (Nugraha & Haryono, 2022) which can be seen in table 2.10.

Table 2. 10 40 Inventive Principles of TRIZ

| No | 40 Inventive Principles | No | 40 Inventive Principles |
|---|---|---|---|
| 1 | Segmentation | 21 | Skipping |
| 2 | Taking out/Extraction | 22 | Blessing in disguise |
| 3 | Local Quality | 23 | Feedback |
| 4 | Asymmetry | 24 | Intermediary |
| 5 | Merging | 25 | Self-service |
| 6 | Universality | 26 | Copying |
| 7 | Nested doll | 27 | Cheap short-living objects |
| 8 | Anti-weight | 28 | Mechanics substitution |
| 9 | Preliminary anti-action | 29 | Pneumatics and hydraulics |
| 10 | Preliminary action | 30 | Flexible shells and thin films |

| No | 40 Inventive Principles | No | 40 Inventive Principles |
|---|---|---|---|
| 11 | Beforehand cushioning | 31 | Porous materials |
| 12 | Equipotentiality | 32 | Color changes |
| 13 | The other way around | 33 | Homogeneity |
| 14 | Curvature | 34 | Discarding and recovering |
| 15 | Dynamization | 35 | Parameter changes |
| 16 | Partial or excessive action | 36 | Phase transitions |
| 17 | Another dimension | 37 | Thermal expansion |
| 18 | Mechanical vibration/oscillation | 38 | Strong oxidants |
| 19 | Periodic action | 39 | Inert atmosphere |
| 20 | Continuity of useful action | 40 | Composite materials |

Source: Nugraha & Haryono, 2022

### *2.2.7 Fuzzy multi-criteria decision making (FMCDM)*

Fuzzy multi-criteria decision making (FMCDM) is often used in dealing with something related to a problem. This method helps in considering a target result which will produce an optimal alternative. Fuzzy multi-criteria decision making (FMCDM) is a decision-making method used as a consideration in determining the best alternative from a number of alternatives such as decision alternatives, decision criteria, decision weights, and decision matrices (Astuti et al., 2015). FMCDM is a research operation that aims to get optimal results on complex problems based on several indicators, conflicting objectives, and criteria (Kumar et al., 2017). According to (Bidang et al., 2017), criteria are usually measures, rules, or standards used in decision making.

The purpose of MCDM is to select the best alternative from several exclusive alternatives based on the performance of a criterion decided by the decision maker (Chen, 2005). The decision maker is an expert who has special expertise in solving problems that cannot be solved by others. The expert rating system is expected to be able to handle the vagueness, uncertainty, and dynamic nature of the variables in determining the quality of drinking water products in 600ml bottles. In handling vagueness, uncertainty, stochastic input variables and the dynamic nature of various variables, fuzzy logic can be used because fuzzy logic is able to handle these problems (Aly & Vrana, 2005). Based on (Taufiq & Pratiwi, 2015), there are several common features used in the FMCDM method, including:

1. Alternatives, including objects that are different and have the same opportunity to be selected by the decision maker.
2. Attributes, often referred to as characteristics, components, or decision criteria.
3. Conflict between criteria, usually some criteria have conflicts between criteria.
4. Decision weight, indicating the relative importance of each criterion, W = (W1, W2, ..., n). In MCDM, the importance weight of each criterion will be sought.
5. Decision matrix, a decision matrix X of size m × n, containing elements Xij, which represents the rating of alternatives A1 = (i = 1, 2, ..., m) against criteria C1 (j = 1, 2, ..., n).

### *2.2.8 Fuzzy logic.*

Fuzzy is a method that can be used in a condition that is humane but cannot be solved in an exact way but is adjusted to the context (Rindengan & Langi, 2019).

1. Fuzzy Logic

   Fuzzy in language means vague, so in other words fuzzy logic is a vague logic. Fuzzy logic is a method that has a concept that is easy to understand and is based on natural language so that it can be used in control systems in order to provide decisions that resemble human decisions (Pranata et al., 2015). Based on Wantoro (2017), fuzzy logic is an appropriate way to map an input room into an output room and has a continuous value. According to Muzayyanah et al. (2014) there are several things that need to be known in understanding fuzzy systems, including:

   a. Fuzzy Variables

      Fuzzy variables are input or output variables that will be used in fuzzy system calculations.

   b. Fuzzy Set

      Fuzzy set is a grouping of things based on language variables, which are expressed in membership functions. In this study, a triangular membership function is used with equation 2.10 below.

$$\mu(x) = \begin{cases} \dfrac{(x-a)}{(b-a)}; & a \leq x \leq b \\ \dfrac{(x-c)}{(b-c)}; & b \leq x \leq c \\ 0 \quad ; & x \leq b \text{ or } x \geq c \end{cases} \tag{2.10}$$

c. Universe of Discourse

The universe of discourse is the entire value allowed to be operated on in a fuzzy variable. The universe of discourse is a set of real numbers that always increases monotonically from left to right. The value of the universe of discourse can be positive or negative numbers. Sometimes the value of the universe of discourse not limited to its upper limit.

d. Domain

The domain of a fuzzy set is the entire value allowed in the universe of discussion and can be operated on in a fuzzy set. The domain is also a set of real numbers with positive or negative values that always increase monotonically from left to right.

2. Fuzzy Set

The basic idea of fuzzy set theory is that an element belongs to a fuzzy set with a certain degree of membership, which is not only true or false (0 or 1) but can be partly true or partly false to a certain degree. Fuzzy sets are used to anticipate where a variable value can be included in two different sets. According to Kusumadewi (2004), the membership function value $\mu_A(x)$ has two possibilities, which are:

a. One (1), meaning that an item becomes a member of a set, or
b. Zero (0), meaning that an item is not a member of a set.

Fuzzy sets have two attributes, namely linguistic and numerical. Linguistic attributes are attributes used to name a group that represents a certain state or condition using natural language, such as young, middle-aged, old, while numerical attributes are a value that indicates the size of a variable (Wardani et al., 2017).

### *2.2.9 Fuzzy mamdani.*

The mamdani method was first introduced by Ebrahim Mamdani in 1975 when designing steam engine and boiler control systems. Mamdani fuzzy logic is a method that is very flexible and has tolerance for the data it has and has the advantage of being more intuitive and acceptable to many parties (Andani, 2013). In addition, according to Rahman & Yanti (2023) the advantage of the Mamdani method is that it can convert uncertain data into clear data. The mamdani method is commonly known as the Max-Min method (Buana, 2017). Based on Owel et al. (2018), there are several stages in the mamdani method, which are as follows:

a. Fuzzy Set Formation

In the Mamdani method, both input variables and output variables are divided into one or more fuzzy sets.

b. Application of Implication Function (Rule)

In the Mamdani method, the MIN implication function is used.

c. Rule Based

At this stage, the system consists of several rules, so that the inference results are obtained from the collection and correlation of the rules.

d. Defuzzification

Defuzzification is the process of processing the fuzzy set resulting from the composition of fuzzy rules to produce an output in the form of a number in the domain of the fuzzy set.

# CHAPTER III
# RESEARCH METHODOLOGY

## 3.1 Object of Research

This research was conducted at one of the companies producing bottled drinking water products, namely PT Narmada Awet Muda located in Mataram, Lombok, West Nusa Tenggara. The type of product studied is bottled drinking water in 600 ml bottles with a research focus on knowing the causes of product defects in an effort to minimize the number of defective products so that appropriate improvement proposals can be obtained in helping companies in carrying out quality control.

## 3.1 Data Collection Methods

Data collection methods in this study include types and sources of data and data collection techniques. The following are the data collection methods in this study.

### *3.1.1 Types and sources of data.*

The following are the types and sources of data used by researchers in conducting this research:

1. Primary Data

   Primary data is obtained by researchers directly from the first source or object of research, both individuals and agencies. The primary data that has been collected will be the calculation input in this study. Primary data in this study include the company's business processes, data on the amount of production, the number of defective products, data on the types of defective products, the causes of defective products, the value of severity, occurrence, detection, and the value of matching criteria against an alternative in the production of bottled drinking water in 600 ml bottles.

2. Secondary Data

   Secondary data is obtained indirectly in order to obtain supporting data that is relevant to the research needs, can be through books, internet sites, journals, and archives that are generally published or not generally published. Secondary data in this study include literature related to the Six Sigma Method, DMAIC, FMEA, TRIZ, FMCDM, and production data of PT. Narmada Awet Muda which includes data on production results, data on the number of defects for the, and data on the type of defect for the period November - December 2022.

### *3.1.2 Data collection techniques.*

Data collection is useful for collecting the required data and information related to the problems that occur. The data and information will be processed to achieve the objectives of the study. The following are the techniques used by researchers in collecting data:

1. Observation

   Observation is carried out through direct observation of the production process at PT. Narmada Awet Muda, especially in the production process of drinking water in 600 ml bottles. This observation aims to find out the condition of the company, the production process, and the problems experienced during the production process with the assistance of the internal parties of PT. Narmada Awet Muda.

2. Interview

   Interviews are conducted by asking questions directly to sources or related parties with the aim of obtaining data related to the problem being studied. In this study, interviews were conducted with employees of the production department, quality control department, and their staff at PT. Narmada Awet Muda.

3. Questionnaire

   The questionnaire is conducted by providing a set of written questions to be answered by respondents. The questionnaire is addressed to experts who work at PT Narmada Awet Muda to obtain weighted values on severity, occurrence, detection, and the suitability of a criterion for alternatives.

4. Literature Study

   Literature study is carried out to obtain supporting data by exploring books, internet sites, journals, and archives that are generally published or not generally published which are related to the problem at hand.

## 3.2 Research Flow

The research flow explains the stages carried out by researchers in conducting research. The research flow is made to form a more focused and directed research so that it can facilitate the work and process of analyzing problems that may occur. The following is a diagram of the research flow carried out which is shown in figure 3.1:

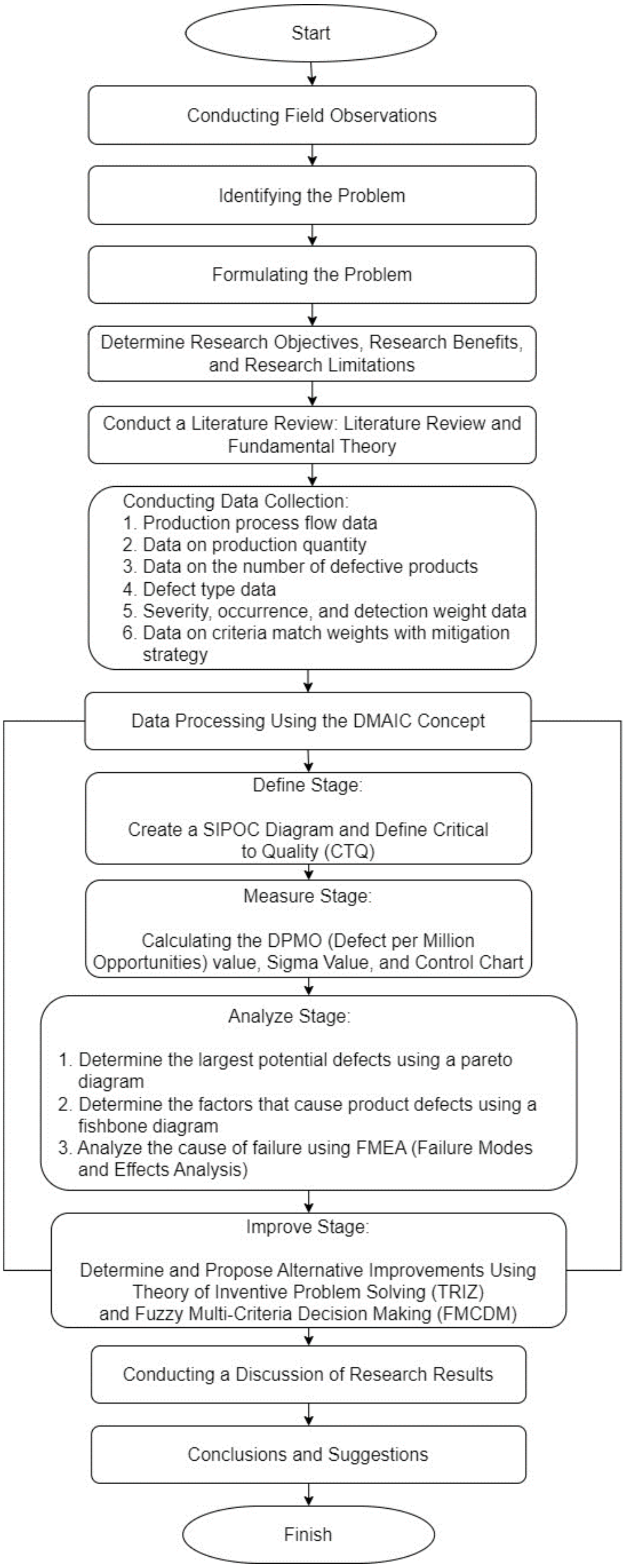


Figure 3. 1 Research Flow Chart

Based on Figure 2.8, the following is an explanation of the flowchart of the research conducted.

1. Field Observation

   Field observations are carried out through direct observation of the entire bottled drinking water production process at PT. Narmada Awet Muda.

2. Problem Identification

   Problem identification in this study was carried out to find out the problems and causes of defects in bottled drinking water products at PT. Narmada Awet Muda.

3. Problem Formulation

   Problem formulation is carried out in order to achieve the research objectives carried out by researchers.

4. Determining Research Objectives, Benefits, and Limitations

   Research objectives are carried out to answer the formulation of problems that have been determined. Meanwhile, the benefits of this research are made to provide benefits to related parties such as companies, researchers, and further research. Problem limitation is carried out to make it easier for researchers to limit the scope of the problem so that research can be more focused.

5. Literature Review

   Literature review is carried out by conducting a literature review and theoretical basis from various similar studies that can be obtained through journals, books, the internet, and other sources to support research. The literature review in this research includes Six Sigma, DMAIC stages, FMEA, TRIZ, and FMCDM.

6. Data Collection

   Data collection is carried out to obtain data on the company needed in the study. The data needed in this study include:

   a. Production process flow data
   b. Data on production quantity
   c. Data on the number of defective products
   d. Defect type data
   e. Severity, occurrence, and detection weight data
   f. Data on criteria match weights with mitigation strategy

7. Data Processing

Data processing is carried out with reference to the Six Sigma method with the DMAIC (Define, Measure, Analyze, Improve, and Control) stages. This research uses the DMAIC stages but does not use the control stage.

a. Define

The initial stage in an effort to improve quality is the define stage. At this stage, defining the problems that occur related to quality standards that cause product defects is carried out. At this stage, a SIPOC diagram is made to identify the main aspects of a process and define CTQ (Critical to Quality).

b. Measure

At the measure stage, sampling is carried out at PT. Narmada Awet Muda for the period November - December 2022 as data that will be used in data processing. The purpose of the measure stage is to understand the condition of the company by calculating DPMO which aims to determine the ratio of the number of defects in one million opportunities, as well as calculating the sigma value to determine the level of product quality or production process in the company. In addition, at this stage the control chart calculation will also be carried out to determine the upper limit and lower limit in a process.

c. Analyze

The analyze stage focuses on analyzing the main causes of CTQ and must be controlled to achieve success. At this stage there are several tools used, namely as follows:

1) Bar Chart

Bar charts are tools used to visualize data to compare several data from different variables and to determine the increase or decrease in a period.

2) Fishbone Diagram

A cause-and-effect diagram or fishbone diagram is a method for analyzing the cause of a problem with the aim of knowing the overall relationship between the defect and its cause.

3) Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is used to find the cause of a problem by describing potential failures that may occur in a process. FMEA can also be used in prioritizing improvements to failures that often occur. The prioritization of improvements in FMEA is carried out with a weighting scale using a questionnaire based on severity, occurrence, and detection. The determination of categories for Severity, Occurrence, and Detection values can be seen in table 2.4, table 2.5, and table 2.6. After weighting, the next step is to calculate the Risk Priority Number (RPN) value. The level of risk category based on the RPN value can be seen in table 2.7. To do the weighting, the researcher made a questionnaire and conducted interviews with internal company parties.

d. Improve

The last stage is the improve stage. At this stage contains suggestions for improvements to the problems faced by the company. To get an optimal improvement proposal, it is carried out using the Theory of Inventive Problem Solving (TRIZ) and Fuzzy Multi-Criteria Decision Making (FMCDM) methods.

1) Theory of Inventive Problem Solving (TRIZ)

This method is used to obtain an improvement solution based on the determination of improving parameters and worsening parameters. The determination of the two parameters is based on 39 TRIZ parameters which can be seen in tables 2.8 and 2.9. After determining the two parameters, the improving parameters and worsening parameters will be crossed. The crossing results in the TRIZ principle based on 40 inventive of TRIZ which can be seen in table 2.10. From these principles, several improvement solutions can be produced in overcoming the problems faced by the company.

2) Fuzzy Multi-Criteria Decision Making (FMCDM)

Fuzzy logic is much wider than traditional logical systems, fuzzy logic is needed to handle complex problems in terms of search, decision or problem in answering questions and control problems where fuzzy logic is an extension of traditional reasoning. The following is a comparison between fuzzy logic and traditional logic shown in table 3.1.

Table 3. 1 Fuzzy logic and Traditional Logic Comparison

| **Fuzzy Logic** | **Traditional Logic** |
|---|---|
| • Value representation in traditional logic only handles | • Value representation in fuzzy logic allows the use of |

| Fuzzy Logic | Traditional Logic |
| --- | --- |
| binary correctness values, which are true (1) or false (0). | membership degrees that permit the representation of values in a more flexible form. |
| • Designed to handle uncertainty by incorporating the concept of membership that allows a statement to have a partial degree of truth. | • It cannot directly handle uncertainty or ambiguity because statements in this logic must be evaluated as true or false without a middle value. |
| • The conclusions produced by fuzzy logic are more comprehensive or accurate and detailed because they consider all possible truth values based on predefined fuzzy rules. | • The conclusions produced by traditional logic are firmer and more definitive as they only recognize binary truth values. |

Based on the comparison in table 3.1 above, this research uses fuzzy logic in selecting the best alternative in minimizing the number of defects of water products in 600ml bottles that can be carried out by the company. This method is carried out with the help of MATLAB software. There are several stages carried out in this method, which are:

a. Mitigation Action Identification

At this stage, the criteria that will be used in weighting the suitability of alternatives are determined. At this stage, risk mitigation mapping is also made to help identify potential risks that occur.

b. Fuzzy-rule based.

After mapping and determining the parameter range, the next step is to create a rule-based in MATLAB. In this research, rule-based will be focused on using IF-THEN which is the basis of Mamdani fuzzification.

c. Defining Fuzzy Inputs

In this study, the input criteria used in determining the matching degree in this fuzzy calculation are human resource capabilities, technical capabilities, and cost capabilities. In this study, there are 5 parameters, namely very low, low, medium, high, and very high with a range of 0-5. The range of each input parameter can be seen in table 3.2 below.

Table 3. 2 Input Parameter Range

| Parameter | Range | Information |
|---|---|---|
| Very Low | $x \leq 1$ | Capabilities in human resources, technical, and cost owned by the company are very low in carrying out mitigation actions. |
| Low | $2 \leq x < 3$ | Capabilities in human resources, technical, and cost owned by the company are low in carrying out mitigation actions. |
| Moderate | $3 \leq x < 4$ | Capabilities in human resources, technical, and cost owned by the company are moderate or sufficient in carrying out mitigation actions. |
| High | $3 < x < 5$ | Capabilities in human resources, technical, and cost owned by the company are high in carrying out mitigation actions. |
| Very High | $x \geq 5$ | Capabilities in human resources, technical, and cost owned by the company are very high in carrying out mitigation actions. |

d. Defining Fuzzy Outputs

The output of this fuzzy calculation is the matching degree between input criteria and alternatives in the form of preventive actions. In this study, there are 5 input parameters, namely very low, low, medium, high, and very high with a range of 0-5. The range of each output parameter can be seen in table 3.3 below.

Table 3. 3 Output Parameter Range

| Parameter | Range | Information |
|---|---|---|
| Very Low | $x \leq 1$ | The level of match between input criteria and mitigation actions is very low, so the |

| Parameter | Range | Information |
|---|---|---|
| | | potential for problems to be prevented immediately is very low. |
| Low | $2 \leq x < 3$ | The level of match between input criteria and mitigation actions is low, so the potential for problems to be prevented immediately is low. |
| Moderate | $3 \leq x < 4$ | The level of match between input criteria and mitigation actions is medium, so the potential for problems to be prevented immediately is medium. |
| High | $3 < x < 5$ | The level of match between input criteria and mitigation actions is high, so the potential for problems to be prevented immediately is high. |
| Very High | $x \geq 5$ | The level of match between input criteria and mitigation actions is very high, so the potential for problems to be prevented immediately is very high. |

e. Defuzzification

Defuzzification is the output of fuzzy logic. After defining fuzzy rules, input range parameters, and output range parameters, the last step is to find the matching degree value of an alternative based on the criteria.

f. Optimal Alternative Selection

After obtaining the results of the suitability test, the next stage is to rank the alternatives in the form of preventive actions to minimize defects in drinking water products in 600ml bottles that can be carried out by the company with the highest to lowest priority order based on the capabilities of the input criteria owned by the company.

8. Discussion

   At this stage, a discussion is carried out based on the results of data processing that has been obtained previously. The results of the data processing will then be processed into information and summarized to help determine the proposed improvements.

9. Conclusion and Suggestion

   This stage is the last stage carried out in the research. The conclusion is done by summarizing the results of the research that has been carried out from start to finish, which is done to answer all the problem formulations in the research. Meanwhile, suggestions are proposals that will be given to companies and related parties based on the results of the research.

# CHAPTER IV
# COLLECTION AND PROCESSING DATA

## 4.1 Data Collection

The following are the data that will be used in data processing. The data used includes company profiles, company production processes, and company historical data in the form of production quantities, number of defects, and types of product defects at PT. Narmada Awet Muda.

### *4.1.1 Company description.*

Figure 4. 1 PT Narmada Awet Muda Logo

PT. Narmada Awet Muda is a company in the form of PT (Limited Liability Company) which was established in 1994 and actively operates in September 1995 until now. PT Narmada Awet Muda is located at Jl. Sandu Baya No. 88 Bertais-Mataram, Lombok, West Nusa Tenggara. The company has two factories. The first factory is located in Selat, Narmada District, West Lombok Regency, West Nusa Tenggara. While the second factory is located in East Lingsar Hamlet, Lingsar Village, Lingsar District, West Lombok, West Nusa Tenggara. PT Narmada Awet Muda is engaged in the business of mineral water processing industry with spring water obtained from mountain springs and according to legend comes from the flow of Mount Rinjani springs. The name Narmada Awet Muda itself is taken from one of the historical relics in Narmada District which is famous for the legend of “Awet Muda Water".

PT Narmada Awet Muda is the first mineral water company in Lombok, West Nusa Tenggara as a bottled drinking water company. In carrying out its operations, the company is very concerned about quality, safety, health and environmentally friendly products. The marketing area of bottled mineral water products from PT. Narmada Awet Muda is distributed to the West Nusa Tenggara region.

*4.1.2 Company vision, mission, and values.*

In achieving the company's goals, PT Narmada Awet Muda has the following vision, mission, and values:

1. Company Vision

   The vision of PT Narmada Awet Muda is "To become the market leader of the Bottled Drinking Water (AMDK) company in West Nusa Tenggara by 80% with the implementation of World Class Manufacturing (WCM)".

2. Company Mission

   The mission of PT Narmada Awet Muda is as follows:

   a. Develop operational excellence.

   b. Develop people and process.

3. Value Perusahaan

   The values that are the basis for the work system of PT. Narmada Awet Muda are:

   a. R1 – Concise

      The activity of sorting and removing useless items (less needed)

   b. R2 – Neat

      The activity of grouping items, providing a place to store them, storing them in place, and providing clear identity so that they can be easily recognized.

   c. R3 – Clean

      The activity of cleaning the work environment, work tools and others while checking for defects or damage then repairing them and finding the source of the problem.

   d. R4 – Maintain

      Stabilizing and building order and discipline in the implementation of concise, neat, and clean.

   e. R5 – Diligent

      Habituation in carrying out workplace arrangement activities that are safe, secure, and productive.

*4.1.3 Company organizational structure.*

The following is the organizational structure at PT. Narmada Awet Muda which is shown in figure 4.2:

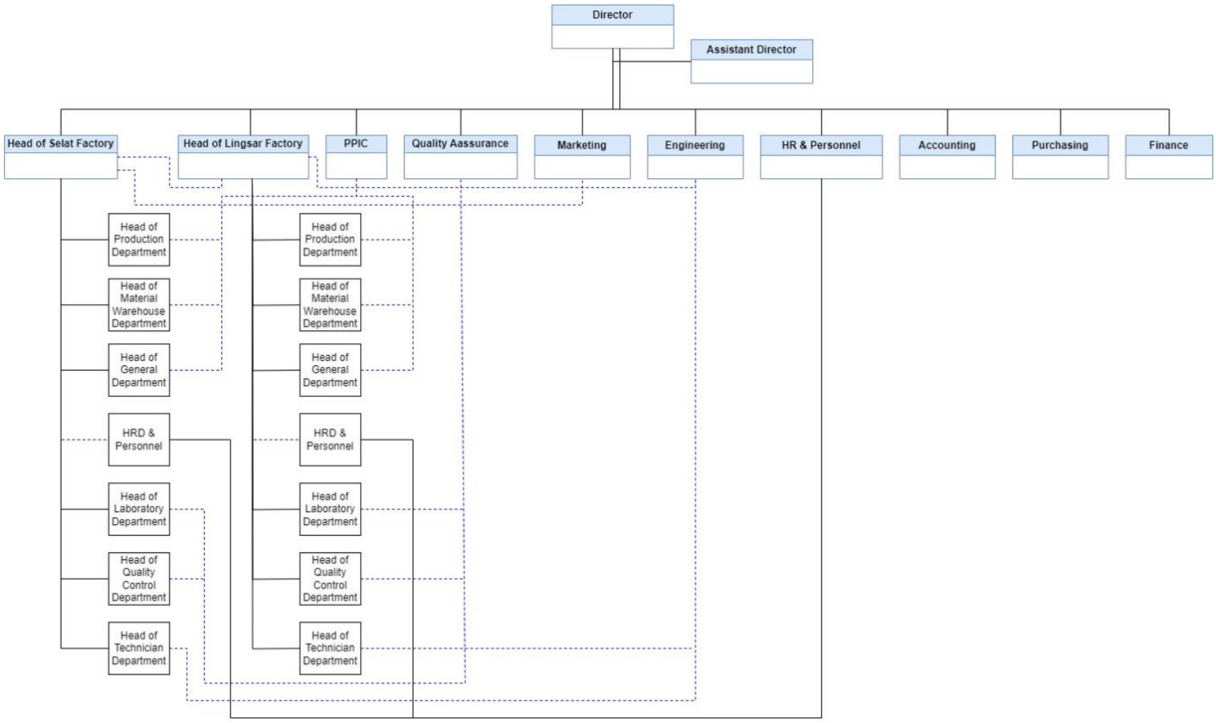


Figure 4. 2 Organizational structure of PT Narmada Awet Muda

### *4.1.4 Production results.*

As a company engaged in the bottled drinking water (AMDK) processing industry, PT Narmada Awet Muda has two different brands with different types and sizes of packaging. The following are some of the results of PT. Narmada Awet Muda's production shown in Figure 4.3.

Figure 4. 3 Packaged Drinking Water Products

1. Packaged Drinking Water Brand Narmada

   Narmada Mineral Water is distributed to West Nusa Tenggara, especially the West Lombok and Central Lombok regions. Narmada mineral water is also distributed to several hotels such as Qunci Villas, Aston Inn, and Golden Palace. Narmada mineral water products are divided into several sizes, namely:

a. Cup 200 ml
b. Cup 220 ml
c. Bottle 330 ml
d. Bottle 600 ml
e. Bottle 1500 ml
f. Gallon 19 L

2. Packaged Drinking Water Brand Rafa

   Rafa Mineral Water is distributed to West Nusa Tenggara, especially the East Lombok and Sumbawa regions. Rafa mineral water products are divided into several sizes, namely:

   a. Cup 220 ml
   b. Bottle 330 ml
   c. Bottle 600 ml

### *4.1.5 Production process.*

In the process of producing bottled drinking water, several stages must be carried out. Figure 4.4 shows the flow of the production process of drinking water in 600ml bottles at PT Narmada Awet Muda:

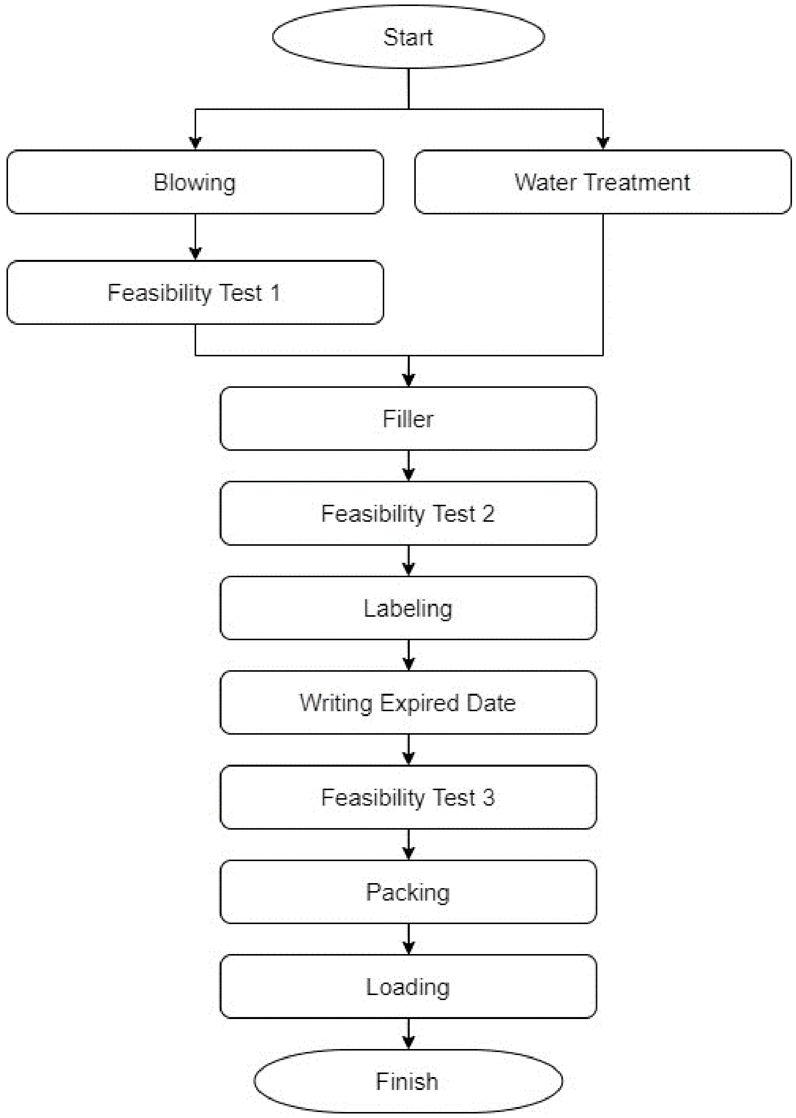


Figure 4. 4 Flowchart of Bottle Water Production Process

a. Water Treatment

In this process, water is filtered and sterilized to kill bacteria, viruses, and germs in the water and reduce or eliminate taste and odor problems in the water so that the water is safe for consumption.

b. Blowing

In this process, the development of preforms into final products is carried out using the blow mold production method on different machines. The preform will be mounted on a mold accompanied by the insertion of a pin which will blow air into the preform. The mold will be closed then high-pressure air will be blown into the preform so that it follows the mold and becomes a bottle package. After the temperature drops, the mold will automatically open.

c. Feasibility Test 1

In this process, a check is made to find out whether there are any rejects on the packaging such as the bottle is bent, the bottom of the bottle is tilted, and the mouth of the bottle is not circular.

d. Filler

In this process, water that has been previously tested for quality is filled into the packaging and at the same time, the packaging is carried out in the form of installing bottle caps and sealing the bottle caps.

e. Feasibility Test 2

In this process, a check is made to find out whether there is a reject such as a bottle cap not being installed, or the volume of water not being according to a predetermined standard.

f. Labeling

In this process, a label is placed on the bottle packaging which functions as a source of product and company information. On the bottle packaging, the installation or attachment of the label is located in the middle of the package.

g. Writing Expired Date

In this process, the product will be printed in the form of an expired date to determine the time limit for product use before the product is damaged or can no longer be consumed.

h. Feasibility Test 3

Finished products that have gone through the previous process will be checked before entering the packing process, such as checking the label to find out whether the label has been properly attached to the package. Then there is a check for writing the expired date to find out whether the expired date has been printed on the packaging.

i. Packing

Finished products that have passed the checking stage will be packed into cartons and sealed on cardboard to protect the product's quality and prevent damage.

j. Loading

In this process, finished goods will; be arranged into pallets and then transported by forklifts to be stored in the finished goods storage warehouse.

*4.1.6 Production number data.*

PT Narmada Awet Muda implements a "Make to Stock" production system in producing bottled drinking water. The following is the production data for bottled drinking water in 600 ml bottles in the period November - December 2022 which is shown in Table 4.1:

Table 4. 1 Total Production Data for November - December 2022

| No | Period | Number of Production (Pcs) |
|---|---|---|
| 1 | 01-Nov-22 | 74467 |
| 2 | 02-Nov-22 | 121232 |
| 3 | 03-Nov-22 | 113543 |
| 4 | 04-Nov-22 | 80973 |
| 5 | 05-Nov-22 | 27905 |
| 6 | 06-Nov-22 | 40039 |
| 7 | 08-Nov-22 | 58496 |
| 8 | 09-Nov-22 | 75840 |
| 9 | 10-Nov-22 | 61497 |
| 10 | 11-Nov-22 | 26964 |
| 11 | 12-Nov-22 | 65916 |
| 12 | 13-Nov-22 | 54891 |
| 13 | 16-Nov-22 | 77714 |
| 14 | 17-Nov-22 | 76222 |
| 15 | 18-Nov-22 | 70402 |
| 16 | 19-Nov-22 | 63216 |
| 17 | 20-Nov-22 | 60036 |
| 18 | 22-Nov-22 | 30944 |
| 19 | 23-Nov-22 | 72377 |
| 20 | 24-Nov-22 | 62364 |
| 21 | 25-Nov-22 | 82566 |
| 22 | 26-Nov-22 | 60047 |
| 23 | 27-Nov-22 | 68058 |
| 24 | 30-Nov-22 | 78457 |
| 25 | 01-Dec-22 | 68761 |
| 26 | 02-Dec-22 | 69916 |
| 27 | 03-Dec-22 | 60748 |
| 28 | 04-Dec-22 | 63781 |
| 29 | 06-Dec-22 | 48839 |
| 30 | 07-Dec-22 | 65292 |
| 31 | 08-Dec-22 | 62201 |
| 32 | 09-Dec-22 | 70469 |
| 33 | 10-Dec-22 | 63948 |

| No | Period | Number of Production (Pcs) |
|---|---|---|
| 34 | 11-Dec-22 | 60459 |
| 35 | 12-Dec-22 | 20907 |
| 36 | 13-Dec-22 | 41696 |
| 37 | 14-Dec-22 | 68221 |
| 38 | 15-Dec-22 | 95125 |
| 39 | 16-Dec-22 | 107615 |
| 40 | 17-Dec-22 | 68927 |
| 41 | 18-Dec-22 | 54121 |
| 42 | 25-Dec-22 | 20023 |
| 43 | 26-Dec-22 | 33789 |
| 44 | 27-Dec-22 | 90484 |
| 45 | 28-Dec-22 | 90793 |
| 46 | 29-Dec-22 | 99546 |
| 47 | 30-Dec-22 | 80577 |
| 48 | 31-Dec-22 | 5905 |
| | **Total** | **3116309** |

### *4.1.7 Defective product number data.*

The following is data on the number of defective products in 600 ml bottled drinking water in the November - December 2022 period shown in Table 4.2.

Table 4. 2 Defective Product Data for the Period November - December 2022

| No | Period | Number of Defective Products (Pcs) |
|---|---|---|
| 1 | 01-Nov-22 | 2755 |
| 2 | 02-Nov-22 | 1400 |
| 3 | 03-Nov-22 | 1847 |
| 4 | 04-Nov-22 | 933 |
| 5 | 05-Nov-22 | 545 |
| 6 | 06-Nov-22 | 487 |
| 7 | 08-Nov-22 | 800 |
| 8 | 09-Nov-22 | 1200 |
| 9 | 10-Nov-22 | 1425 |
| 10 | 11-Nov-22 | 1524 |
| 11 | 12-Nov-22 | 1236 |
| 12 | 13-Nov-22 | 1107 |
| 13 | 16-Nov-22 | 1346 |
| 14 | 17-Nov-22 | 2806 |
| 15 | 18-Nov-22 | 2290 |

| No | Period | Number of Defective Products (Pcs) |
|---|---|---|
| 16 | 19-Nov-22 | 912 |
| 17 | 20-Nov-22 | 996 |
| 18 | 22-Nov-22 | 680 |
| 19 | 23-Nov-22 | 1169 |
| 20 | 24-Nov-22 | 828 |
| 21 | 25-Nov-22 | 1254 |
| 22 | 26-Nov-22 | 983 |
| 23 | 27-Nov-22 | 930 |
| 24 | 30-Nov-22 | 985 |
| 25 | 01-Dec-22 | 1897 |
| 26 | 02-Dec-22 | 1468 |
| 27 | 03-Dec-22 | 1108 |
| 28 | 04-Dec-22 | 973 |
| 29 | 06-Dec-22 | 1007 |
| 30 | 07-Dec-22 | 1260 |
| 31 | 08-Dec-22 | 1457 |
| 32 | 09-Dec-22 | 1373 |
| 33 | 10-Dec-22 | 1092 |
| 34 | 11-Dec-22 | 1563 |
| 35 | 12-Dec-22 | 531 |
| 36 | 13-Dec-22 | 728 |
| 37 | 14-Dec-22 | 1861 |
| 38 | 15-Dec-22 | 2077 |
| 39 | 16-Dec-22 | 2255 |
| 40 | 17-Dec-22 | 1391 |
| 41 | 18-Dec-22 | 1057 |
| 42 | 25-Dec-22 | 1207 |
| 43 | 26-Dec-22 | 2253 |
| 44 | 27-Dec-22 | 2380 |
| 45 | 28-Dec-22 | 2449 |
| 46 | 29-Dec-22 | 3282 |
| 47 | 30-Dec-22 | 1449 |
| 48 | 31-Dec-22 | 985 |
| **Total** | | **67541** |

*4.1.8 Defect type data.*

In carrying out the production process of drinking water in 600 ml packages, PT Narmada Awet Muda still finds defective products. The types of defects experienced during the production process are shown in Table 4.3 below:

Table 4. 3 Defect Type Data

| **Defect Type** | **Description** |
|---|---|
| Cap Defects | Imperfect cap shape, improper or skewed cap installation which causes product leakage. |
| Bottle Defects | Imperfect bottle shapes such as dents, damage, and dirt. |
| Volume Defects | The volume of water is not in accordance with company standards such as less volume and more volume. |

## 4.2 Data Processing

The define stage is the first stage carried out in the Six Sigma analysis. At this stage, SIPOC diagrams and CTQ (Critical to Quality) definitions are made.

*4.2.1 Define.*

The define stage is the first stage carried out in the Six Sigma analysis which aims to define the problems that occur related to quality standards that cause product defects. At this stage, SIPOC diagrams and CTQ (Critical to Quality) definitions are made.

1. SIPOC Diagram

   SIPOC (Suppliers, Inputs, Process, Outputs, and Costumers) diagram is a diagram that aims to identify and provide an overview of the general production flow starting from the procurement of raw materials to become a finished product which will then be sold to customers. The following is a SIPOC diagram of the production of drinking water in 600ml bottles at PT. Narmada Awet Muda which is shown in Figure 4.5 below.

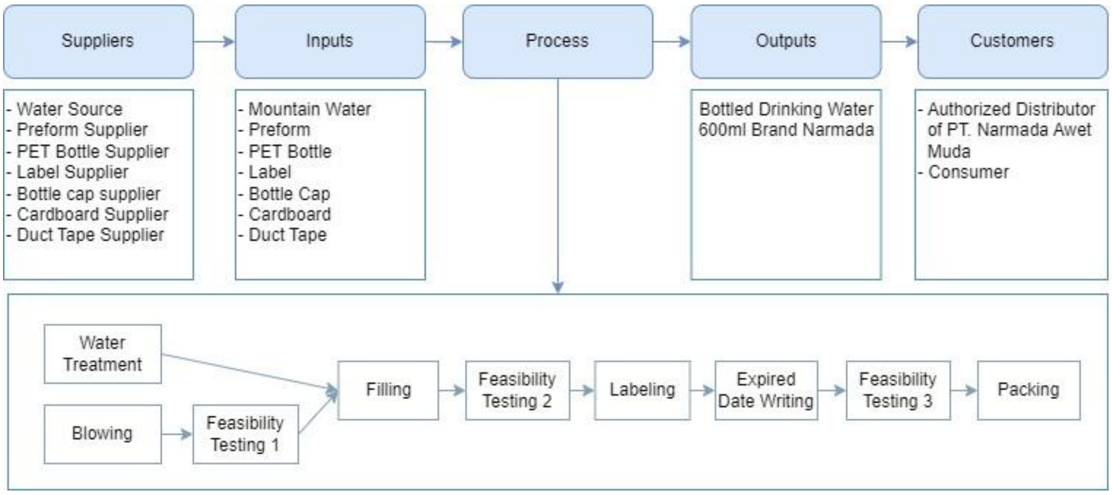


Figure 4. 5 SIPOC Diagram

The explanation of Figure 4.5 related to the SIPOC diagram on the production of 600ml drinking water at PT Narmada Awet Muda is as follows:

a. Supplier

Suppliers are parties that supply raw materials or supporting materials to a company to meet production needs to be used as finished products. Based on Figure 4.5, it can be seen that PT Narmada Awet Muda has several suppliers in meeting its production needs, including water sources originating from mountain springs, preform suppliers, PET bottle suppliers, label suppliers, bottle cap suppliers, cardboard suppliers, and duct tape suppliers.

b. Inputs

Inputs are raw materials that will be used in the production process.

c. Process

The production process of drinking water in 600ml bottles at PT Narmada Awet Muda consists of several stages, including water treatment, blowing, feasibility test 1, filling, feasibility test 2, labeling, expired date writing, feasibility test 3, and packaging.

d. Outputs

Output is the final result of the production process. The output produced is drinking water in 600ml bottles of the Narmada brand which is packed into a cardboard box. In one cardboard box there are 24 bottle units.

e. Customers

After the drinking water product in 600ml bottles is finished and packaging has been done, the product will then be sent to authorized distributors and to all consumers who order products to PT Narmada Awet Muda.

2. CTQ (Critical to Quality) Identification

CTQ (Critical to Quality) is an important characteristic or measurable quality standard of a product that must be maintained in order to achieve a product specification standard because it is related to customer needs and satisfaction. In this study, three CTQs were identified, namely cap defects, bottle defects, and volume defects.

### *4.2.2 Measure.*

The measure stage is the stage of collecting samples at the company which will be used as data to be processed before making improvements. At this stage, the calculation of DPMO, sigma value, and control chart is carried out with the aim of knowing the condition of the production process on bottled drinking water in 600ml bottles at PT. Narmada Awet Muda.

1. Calculation of DPMO Value

DPMO (Defect Per Million Opportunity) is a measure of failure in Six Sigma that shows the ratio of the number of defects per one million opportunities if there are more than one defect. The formula used in calculating DPMO can be seen in equation 4.1 below:

$$\text{DPMO} = \frac{\text{Total number of defects found in sample}}{\text{Sample size} \times \text{Number of defect opportunities}} \times 1.000.000 \qquad (4.1)$$

Based on the calculation using equation 4.1 above, the following is a recapitulation of the calculation of DPMO value in the production of 600ml bottled drinking water for the period November - December 2022 which can be seen in table 4.4:

Table 4. 4 Recapitulation of DPMO Value Calculation

| No | Period | Number of Production | Number of Defect | Percentage of Defective Products | CTQ | DPMO |
|---|---|---|---|---|---|---|
| 1 | 01-Nov-22 | 74467 | 2755 | 4% | 3 | 12332,1 |
| 2 | 02-Nov-22 | 121232 | 1400 | 1% | 3 | 3849,4 |
| 3 | 03-Nov-22 | 113543 | 1847 | 2% | 3 | 5422,3 |
| 4 | 04-Nov-22 | 80973 | 933 | 1% | 3 | 3840,8 |
| 5 | 05-Nov-22 | 27905 | 545 | 2% | 3 | 6510,2 |
| 6 | 06-Nov-22 | 40039 | 487 | 1% | 3 | 4054,4 |
| 7 | 08-Nov-22 | 58496 | 800 | 1% | 3 | 4558,7 |
| 8 | 09-Nov-22 | 75840 | 1200 | 2% | 3 | 5274,3 |

| No | Period | Number of Production | Number of Defect | Percentage of Defective Products | CTQ | DPMO |
|---|---|---|---|---|---|---|
| 9 | 10-Nov-22 | 61497 | 1425 | 2% | 3 | 7724,0 |
| 10 | 11-Nov-22 | 26964 | 1524 | 6% | 3 | 18839,9 |
| 11 | 12-Nov-22 | 65916 | 1236 | 2% | 3 | 6250,4 |
| 12 | 13-Nov-22 | 54891 | 1107 | 2% | 3 | 6722,4 |
| 13 | 16-Nov-22 | 77714 | 1346 | 2% | 3 | 5773,3 |
| 14 | 17-Nov-22 | 76222 | 2806 | 4% | 3 | 12271,2 |
| 15 | 18-Nov-22 | 70402 | 2290 | 3% | 3 | 10842,5 |
| 16 | 19-Nov-22 | 63216 | 912 | 1% | 3 | 4808,9 |
| 17 | 20-Nov-22 | 60036 | 996 | 2% | 3 | 5530,0 |
| 18 | 22-Nov-22 | 30944 | 680 | 2% | 3 | 7325,1 |
| 19 | 23-Nov-22 | 72377 | 1169 | 2% | 3 | 5383,8 |
| 20 | 24-Nov-22 | 62364 | 828 | 1% | 3 | 4425,6 |
| 21 | 25-Nov-22 | 82566 | 1254 | 2% | 3 | 5062,6 |
| 22 | 26-Nov-22 | 60047 | 983 | 2% | 3 | 5456,8 |
| 23 | 27-Nov-22 | 68058 | 930 | 1% | 3 | 4554,9 |
| 24 | 30-Nov-22 | 78457 | 985 | 1% | 3 | 4184,9 |
| 25 | 01-Dec-22 | 68761 | 1897 | 3% | 3 | 9196,1 |
| 26 | 02-Dec-22 | 69916 | 1468 | 2% | 3 | 6998,9 |
| 27 | 03-Dec-22 | 60748 | 1108 | 2% | 3 | 6079,8 |
| 28 | 04-Dec-22 | 63781 | 973 | 2% | 3 | 5085,1 |
| 29 | 06-Dec-22 | 48839 | 1007 | 2% | 3 | 6872,9 |
| 30 | 07-Dec-22 | 65292 | 1260 | 2% | 3 | 6432,6 |
| 31 | 08-Dec-22 | 62201 | 1457 | 2% | 3 | 7808,0 |
| 32 | 09-Dec-22 | 70469 | 1373 | 2% | 3 | 6494,6 |
| 33 | 10-Dec-22 | 63948 | 1092 | 2% | 3 | 5692,1 |
| 34 | 11-Dec-22 | 60459 | 1563 | 3% | 3 | 8617,4 |
| 35 | 12-Dec-22 | 20907 | 531 | 3% | 3 | 8466,1 |
| 36 | 13-Dec-22 | 41696 | 728 | 2% | 3 | 5819,9 |
| 37 | 14-Dec-22 | 68221 | 1861 | 3% | 3 | 9093,0 |
| 38 | 15-Dec-22 | 95125 | 2077 | 2% | 3 | 7278,1 |
| 39 | 16-Dec-22 | 107615 | 2255 | 2% | 3 | 6984,8 |
| 40 | 17-Dec-22 | 68927 | 1391 | 2% | 3 | 6726,9 |
| 41 | 18-Dec-22 | 54121 | 1057 | 2% | 3 | 6510,1 |
| 42 | 25-Dec-22 | 20023 | 1207 | 6% | 3 | 20093,6 |
| 43 | 26-Dec-22 | 33789 | 2253 | 7% | 3 | 22226,2 |
| 44 | 27-Dec-22 | 90484 | 2380 | 3% | 3 | 8767,7 |
| 45 | 28-Dec-22 | 90793 | 2449 | 3% | 3 | 8991,1 |
| 46 | 29-Dec-22 | 99546 | 3282 | 3% | 3 | 10989,9 |
| 47 | 30-Dec-22 | 80577 | 1449 | 2% | 3 | 5994,3 |
| 48 | 31-Dec-22 | 5905 | 985 | 17% | 3 | 55602,6 |
| | | | **Average** | | | **8621,3** |

Based on the recapitulation of DPMO values in table 4.4, the following is a graph of DPMO values which can be seen in Figure 4.6:

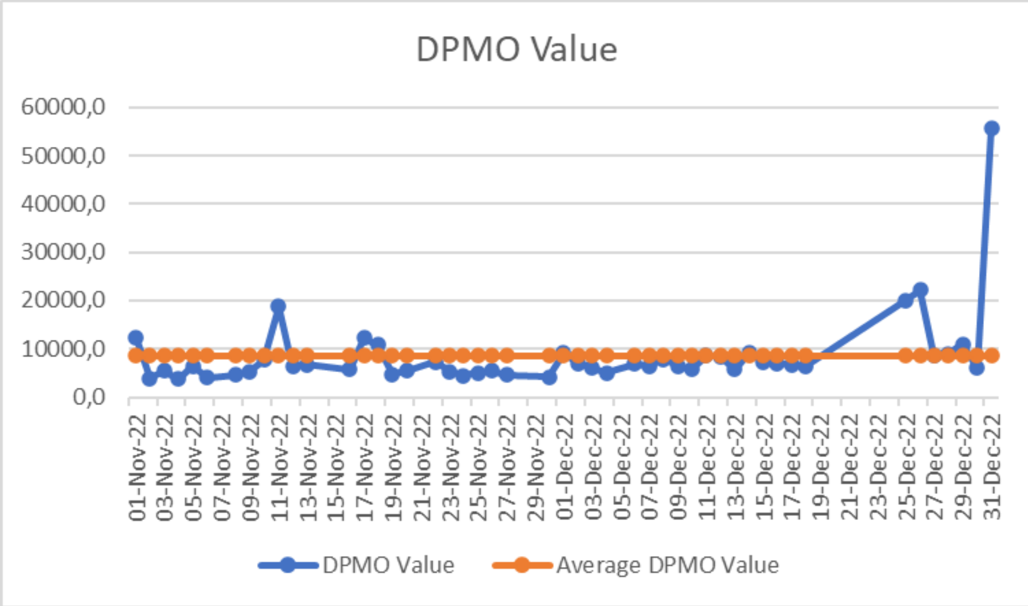


Figure 4. 6 DPMO Value Graph

Based on Figure 4.6, it is known that the lowest DPMO value occurred in the 4 November 2022 period with a value of 3840,8 and the highest DPMO value occurred in the 31 December 2022 period with a value of 55602,6. Meanwhile, the average DPMO value is 8621,3.

2. Calculation of Sigma Value

After calculating DPMO, the next step is to calculate the sigma value. In calculating the sigma value, you can use the Ms. Excel formula, the following is the formula used which can be seen in equation 4.2:

$$\text{Sigma Value} = \text{NORMSINV}\left(1 - \frac{\text{DPMO}}{1.000.000}\right) + 1{,}5 \qquad (4.2)$$

Based on the calculation using equation 4.2 above, the following is a recapitulation of the calculation of the sigma value in the production of 600ml bottled drinking water for the period November - December 2022 which can be seen in Table 4.5:

Table 4. 5 Calculation of Sigma Value

| No | Period | DPMO | Sigma Value |
|---|---|---|---|
| 1 | 01-Nov-22 | 12332,1 | 3,75 |
| 2 | 02-Nov-22 | 3849,4 | 4,17 |
| 3 | 03-Nov-22 | 5422,3 | 4,05 |

| No | Period | DPMO | Sigma Value |
|---|---|---|---|
| 4 | 04-Nov-22 | 3840,8 | 4,17 |
| 5 | 05-Nov-22 | 6510,2 | 3,98 |
| 6 | 06-Nov-22 | 4054,4 | 4,15 |
| 7 | 08-Nov-22 | 4558,7 | 4,11 |
| 8 | 09-Nov-22 | 5274,3 | 4,06 |
| 9 | 10-Nov-22 | 7724,0 | 3,92 |
| 10 | 11-Nov-22 | 18839,9 | 3,58 |
| 11 | 12-Nov-22 | 6250,4 | 4,00 |
| 12 | 13-Nov-22 | 6722,4 | 3,97 |
| 13 | 16-Nov-22 | 5773,3 | 4,03 |
| 14 | 17-Nov-22 | 12271,2 | 3,75 |
| 15 | 18-Nov-22 | 10842,5 | 3,80 |
| 16 | 19-Nov-22 | 4808,9 | 4,09 |
| 17 | 20-Nov-22 | 5530,0 | 4,04 |
| 18 | 22-Nov-22 | 7325,1 | 3,94 |
| 19 | 23-Nov-22 | 5383,8 | 4,05 |
| 20 | 24-Nov-22 | 4425,6 | 4,12 |
| 21 | 25-Nov-22 | 5062,6 | 4,07 |
| 22 | 26-Nov-22 | 5456,8 | 4,05 |
| 23 | 27-Nov-22 | 4554,9 | 4,11 |
| 24 | 30-Nov-22 | 4184,9 | 4,14 |
| 25 | 01-Dec-22 | 9196,1 | 3,86 |
| 26 | 02-Dec-22 | 6998,9 | 3,96 |
| 27 | 03-Dec-22 | 6079,8 | 4,01 |
| 28 | 04-Dec-22 | 5085,1 | 4,07 |
| 29 | 06-Dec-22 | 6872,9 | 3,96 |
| 30 | 07-Dec-22 | 6432,6 | 3,99 |
| 31 | 08-Dec-22 | 7808,0 | 3,92 |
| 32 | 09-Dec-22 | 6494,6 | 3,98 |
| 33 | 10-Dec-22 | 5692,1 | 4,03 |
| 34 | 11-Dec-22 | 8617,4 | 3,88 |
| 35 | 12-Dec-22 | 8466,1 | 3,89 |
| 36 | 13-Dec-22 | 5819,9 | 4,02 |
| 37 | 14-Dec-22 | 9093,0 | 3,86 |
| 38 | 15-Dec-22 | 7278,1 | 3,94 |
| 39 | 16-Dec-22 | 6984,8 | 3,96 |
| 40 | 17-Dec-22 | 6726,9 | 3,97 |
| 41 | 18-Dec-22 | 6510,1 | 3,98 |
| 42 | 25-Dec-22 | 20093,6 | 3,55 |
| 43 | 26-Dec-22 | 22226,2 | 3,51 |
| 44 | 27-Dec-22 | 8767,7 | 3,88 |

| No | Period | DPMO | Sigma Value |
|---|---|---|---|
| 45 | 28-Dec-22 | 8991,1 | 3,87 |
| 46 | 29-Dec-22 | 10989,9 | 3,79 |
| 47 | 30-Dec-22 | 5994,3 | 4,01 |
| 48 | 31-Dec-22 | 55602,6 | 3,09 |
| **Average** | | | **3,94** |

Based on the results of the calculation of the sigma value in Table 4.5, the following is a graph of the sigma value which can be seen in Figure 4.7:

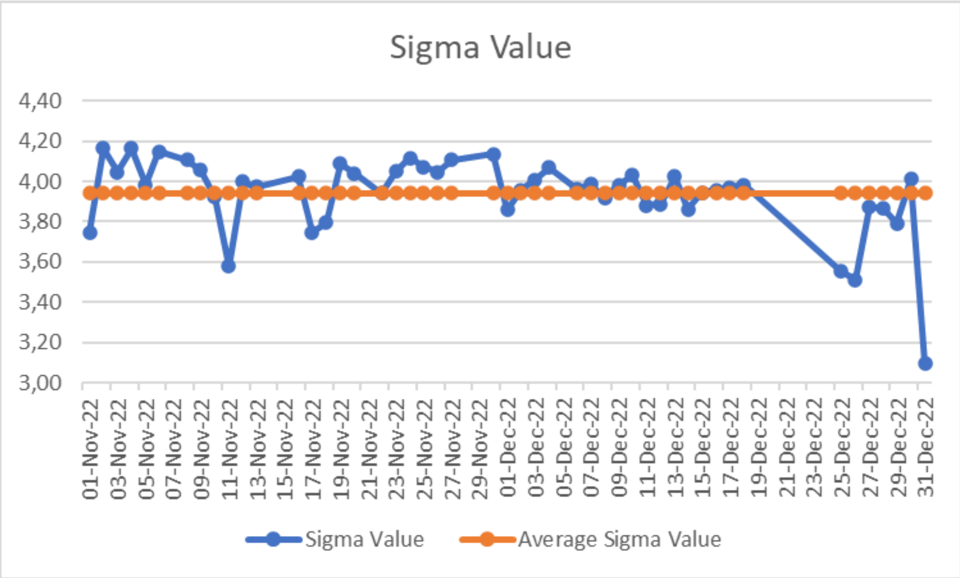


Figure 4. 7 Sigma Value Graph

Based on Figure 4.7, it is known that the lowest sigma value occurred in the period 31 December 2022 with a sigma value of 3,09 and the highest sigma value occurred in the period 4 November 2022 with a value of 4,17. As for the overall average sigma value of 3,94.

3. Calculation of Control Chart

Control chart is a graphic method used to evaluate whether a process is still within the control limits or not so that problems can be solved, and improvement proposals can be made. The control chart that will be used in this study is the p control chart. The p control chart is used to measure the proportion of failure or non-conformity of several products during production. The steps for making p control chart include the following:

a. Calculating the Proportion of Damage (P)

In calculating the proportion of damage can use the following formula equation 4.3:

$$P = \frac{\text{Number of defective products}}{\text{Number of samples examined}} \quad (4.3)$$

b. Calculating the Center Line (CL)

In calculating the center line, you can use the following formula equation 4.4:

$$\overline{P} = \frac{\text{Total number of defective products}}{\text{Total number of samples examined}} \quad (4.4)$$

c. Calculating UCL (Upper Control Limit)

In calculating the UCL, you can use the following formula equation 4.5:

$$UCL = \overline{P} + 3\sqrt{\frac{\overline{P}(1-\overline{P})}{n_i}} \quad (4.5)$$

d. Calculating LCL (Lower Control Limit)

In calculating LCL, you can use the following equation 4.6:

$$LCL = \overline{P} - 3\sqrt{\frac{\overline{P}(1-\overline{P})}{n_i}} \quad (4.6)$$

Based on the equations above, the following is a recapitulation of the results of the calculation of the control chart on the production of 600ml bottled drinking water for the November - December 2022 period which can be seen in table 4.6:

Table 4. 6 Recapitulation of Control Chart Calculation

| No | Period | Number of Production | Number of Defect | Defect Proportion | CL | UCL | LCL |
|---|---|---|---|---|---|---|---|
| 1 | 01-Nov-22 | 74467 | 2755 | 0,03700 | 0,02167 | 0,02327 | 0,02007 |
| 2 | 02-Nov-22 | 121232 | 1400 | 0,01155 | 0,02167 | 0,02293 | 0,02042 |
| 3 | 03-Nov-22 | 113543 | 1847 | 0,01627 | 0,02167 | 0,02297 | 0,02038 |
| 4 | 04-Nov-22 | 80973 | 933 | 0,01152 | 0,02167 | 0,02321 | 0,02014 |
| 5 | 05-Nov-22 | 27905 | 545 | 0,01953 | 0,02167 | 0,02429 | 0,01906 |
| 6 | 06-Nov-22 | 40039 | 487 | 0,01216 | 0,02167 | 0,02386 | 0,01949 |
| 7 | 08-Nov-22 | 58496 | 800 | 0,01368 | 0,02167 | 0,02348 | 0,01987 |
| 8 | 09-Nov-22 | 75840 | 1200 | 0,01582 | 0,02167 | 0,02326 | 0,02009 |
| 9 | 10-Nov-22 | 61497 | 1425 | 0,02317 | 0,02167 | 0,02343 | 0,01991 |
| 10 | 11-Nov-22 | 26964 | 1524 | 0,05652 | 0,02167 | 0,02433 | 0,01901 |
| 11 | 12-Nov-22 | 65916 | 1236 | 0,01875 | 0,02167 | 0,02337 | 0,01997 |
| 12 | 13-Nov-22 | 54891 | 1107 | 0,02017 | 0,02167 | 0,02354 | 0,01981 |
| 13 | 16-Nov-22 | 77714 | 1346 | 0,01732 | 0,02167 | 0,02324 | 0,02011 |
| 14 | 17-Nov-22 | 76222 | 2806 | 0,03681 | 0,02167 | 0,02326 | 0,02009 |
| 15 | 18-Nov-22 | 70402 | 2290 | 0,03253 | 0,02167 | 0,02332 | 0,02003 |
| 16 | 19-Nov-22 | 63216 | 912 | 0,01443 | 0,02167 | 0,02341 | 0,01994 |
| 17 | 20-Nov-22 | 60036 | 996 | 0,01659 | 0,02167 | 0,02346 | 0,01989 |
| 18 | 22-Nov-22 | 30944 | 680 | 0,02198 | 0,02167 | 0,02416 | 0,01919 |

| No | Period | Number of Production | Number of Defect | Defect Proportion | CL | UCL | LCL |
|---|---|---|---|---|---|---|---|
| 19 | 23-Nov-22 | 72377 | 1169 | 0,01615 | 0,02167 | 0,02330 | 0,02005 |
| 20 | 24-Nov-22 | 62364 | 828 | 0,01328 | 0,02167 | 0,02342 | 0,01992 |
| 21 | 25-Nov-22 | 82566 | 1254 | 0,01519 | 0,02167 | 0,02319 | 0,02015 |
| 22 | 26-Nov-22 | 60047 | 983 | 0,01637 | 0,02167 | 0,02346 | 0,01989 |
| 23 | 27-Nov-22 | 68058 | 930 | 0,01366 | 0,02167 | 0,02335 | 0,02000 |
| 24 | 30-Nov-22 | 78457 | 985 | 0,01255 | 0,02167 | 0,02323 | 0,02011 |
| 25 | 01-Dec-22 | 68761 | 1897 | 0,02759 | 0,02167 | 0,02334 | 0,02001 |
| 26 | 02-Dec-22 | 69916 | 1468 | 0,02100 | 0,02167 | 0,02333 | 0,02002 |
| 27 | 03-Dec-22 | 60748 | 1108 | 0,01824 | 0,02167 | 0,02345 | 0,01990 |
| 28 | 04-Dec-22 | 63781 | 973 | 0,01526 | 0,02167 | 0,02340 | 0,01994 |
| 29 | 06-Dec-22 | 48839 | 1007 | 0,02062 | 0,02167 | 0,02365 | 0,01970 |
| 30 | 07-Dec-22 | 65292 | 1260 | 0,01930 | 0,02167 | 0,02338 | 0,01996 |
| 31 | 08-Dec-22 | 62201 | 1457 | 0,02342 | 0,02167 | 0,02342 | 0,01992 |
| 32 | 09-Dec-22 | 70469 | 1373 | 0,01948 | 0,02167 | 0,02332 | 0,02003 |
| 33 | 10-Dec-22 | 63948 | 1092 | 0,01708 | 0,02167 | 0,02340 | 0,01995 |
| 34 | 11-Dec-22 | 60459 | 1563 | 0,02585 | 0,02167 | 0,02345 | 0,01990 |
| 35 | 12-Dec-22 | 20907 | 531 | 0,02540 | 0,02167 | 0,02469 | 0,01865 |
| 36 | 13-Dec-22 | 41696 | 728 | 0,01746 | 0,02167 | 0,02381 | 0,01953 |
| 37 | 14-Dec-22 | 68221 | 1861 | 0,02728 | 0,02167 | 0,02335 | 0,02000 |
| 38 | 15-Dec-22 | 95125 | 2077 | 0,02183 | 0,02167 | 0,02309 | 0,02026 |
| 39 | 16-Dec-22 | 107615 | 2255 | 0,02095 | 0,02167 | 0,02301 | 0,02034 |
| 40 | 17-Dec-22 | 68927 | 1391 | 0,02018 | 0,02167 | 0,02334 | 0,02001 |
| 41 | 18-Dec-22 | 54121 | 1057 | 0,01953 | 0,02167 | 0,02355 | 0,01980 |
| 42 | 25-Dec-22 | 20023 | 1207 | 0,06028 | 0,02167 | 0,02476 | 0,01859 |
| 43 | 26-Dec-22 | 33789 | 2253 | 0,06668 | 0,02167 | 0,02405 | 0,01930 |
| 44 | 27-Dec-22 | 90484 | 2380 | 0,02630 | 0,02167 | 0,02313 | 0,02022 |
| 45 | 28-Dec-22 | 90793 | 2449 | 0,02697 | 0,02167 | 0,02312 | 0,02022 |
| 46 | 29-Dec-22 | 99546 | 3282 | 0,03297 | 0,02167 | 0,02306 | 0,02029 |
| 47 | 30-Dec-22 | 80577 | 1449 | 0,01798 | 0,02167 | 0,02321 | 0,02013 |
| 48 | 31-Dec-22 | 5905 | 985 | 0,16681 | 0,02167 | 0,02736 | 0,01599 |
| | **Total** | **3116309** | **67541** | | | | |
| | **Average** | **64923,1** | **1407,1** | | | | |

Based on the recapitulation of the control chart calculation in table 4.6, the following is a control chart graph which can be seen in Figure 4.8:

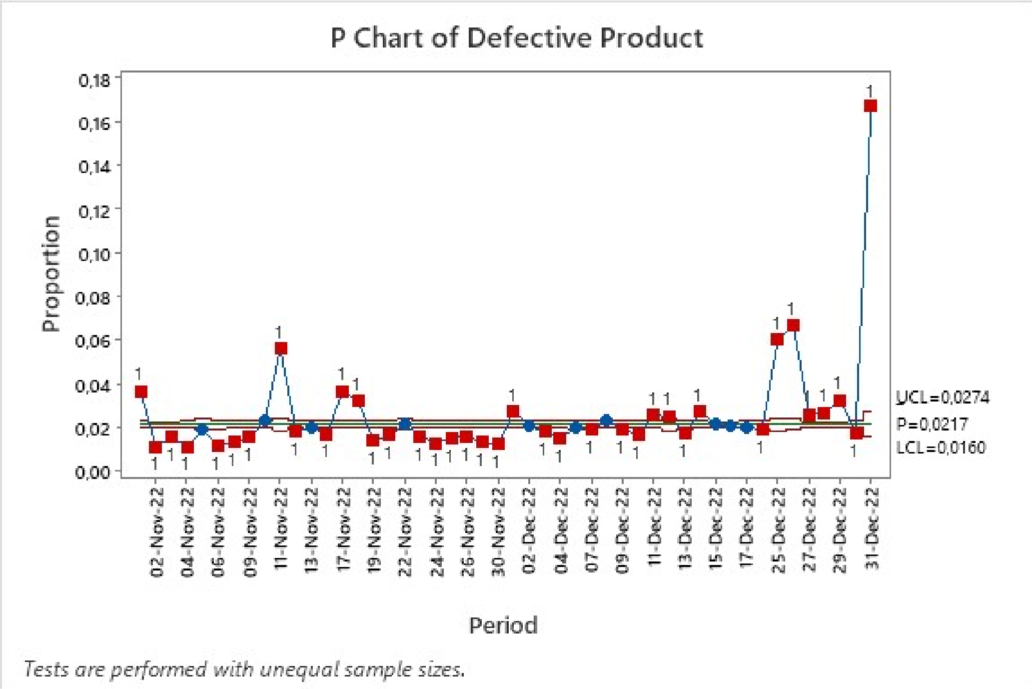


Figure 4. 8 P Control Chart

Based on the p control chart graph in Figure 4.8, It can be seen that there is a proportion of defect that crosses the limit line of the p control chart and there are fluctuations in the data, which means that there are several times the production process in the company is in an unstable or out of control condition. Therefore, it is necessary to conduct further analysis to determine the cause of the instability in the production process.

### *4.2.3 Analyze.*

The analyze stage is a stage carried out with the aim of analyzing the root causes of a problem with CTQ in the form of defective products. At this stage, bar chart, fishbone diagrams, and FMEA are made.

1. Bar Chart

   Bar chart making uses data on the number of product defects for the November - December 2022 period in 600ml bottled drinking water, of which there are 3 types of defects. The following is data on defect frequency for each defect type shown in Table 4.7.

Table 4. 7 Defect Frequency

| No. | Defect Type | Defect Frequency |
|---|---|---|
| 1 | Cap Defect | 25761 |
| 2 | Bottle Defect | 22476 |
| 3 | Volume Defect | 19304 |
| | **Total** | **67541** |

Based on Table 4.7 above, a bar chart can be made. The following is a bar chart that can be seen in Figure 4.9.

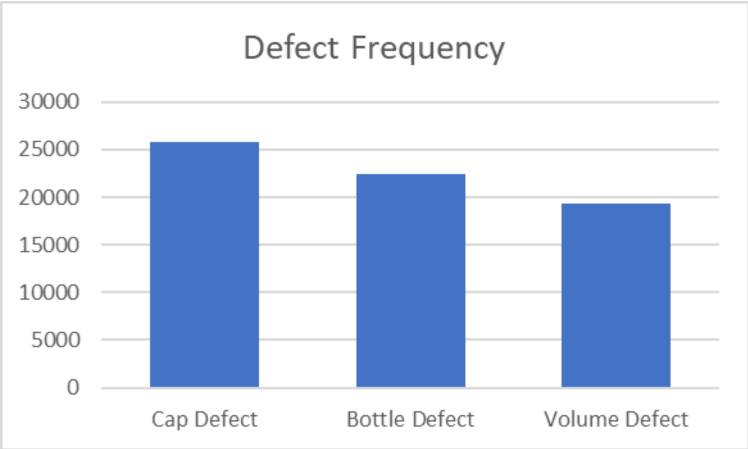


Figure 4. 9 Bar Chart

Based on the bar chart in Figure 4.9 above, of the three types of defects, it can be seen that the type of defect that occurs most often or produces the most defective products during production is cap defects with the total defect is 25,761.

2. Fishbone Diagram

Based on the bar chart above, it is known that the most common type of defect that produces a high number of product defects is the type of bottle cap defect. To analyze the causes of these defects, a fishbone diagram based on man, method, machine, material, and environmental factors is used. The following is a fishbone diagram showing the causes of product defects which can be seen in Figure 4.10:

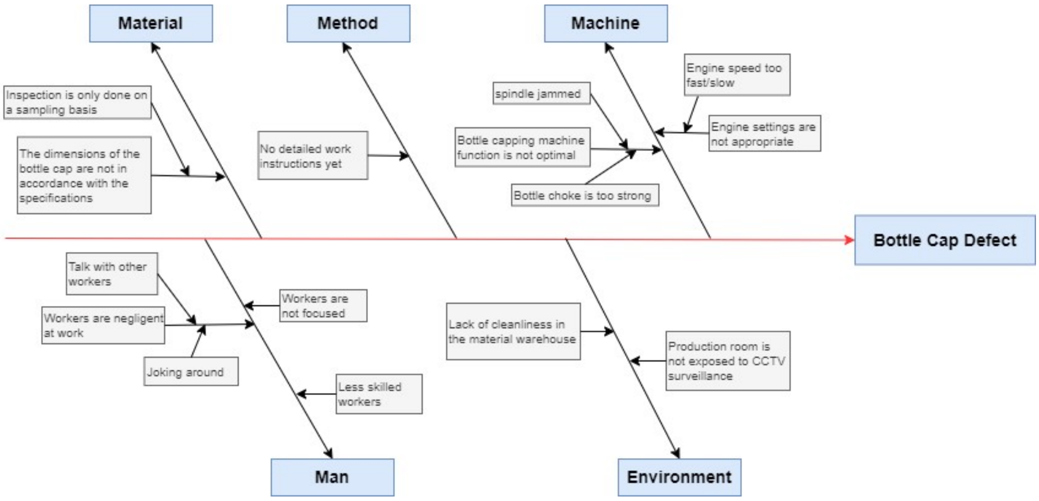


Figure 4. 10 Fishbone Diagram of Bottle Cap Defect

3. Failure Mode and Effect Analysis (FMEA)

After identifying the causes of defects in a product using a fishbone diagram, the next step is to identify potential failures using the Failure Mode and Effect Analysis (FMEA) method by providing an assessment based on three components, namely Severity, Occurrence, and Detection.

The assessment below is obtained based on the results of interviews and filling out questionnaires conducted with PT Narmada Awet Muda production department staff. The following is a recapitulation of the results of the FMEA questionnaire which can be seen in Table 4.8.

Table 4. 8 Recapitulation of FMEA Questionnaire

| Potential Failure Mode | Potential Effect of Failure | Code | Potential Cause of Failure | S | O | D | RPN | Risk Category |
|---|---|---|---|---|---|---|---|---|
| Damage to Bottle Cap | The cap is not completely attached to the bottle making the product unfit for consumption | | **Man:** | | | | | |
| | | P1 | Workers are negligent in performing work. | 8 | 7 | 4 | 224 | High |
| | | P2 | Workers are less skilled. | 7 | 6 | 3 | 126 | Medium |
| | | P3 | Workers are not focused in doing the work. | 4 | 4 | 3 | 48 | Low |
| | | | **Material:** | | | | | |

| Potential Failure Mode | Potential Effect of Failure | Code | Potential Cause of Failure | S | O | D | RPN | Risk Category |
|---|---|---|---|---|---|---|---|---|
| | | P4 | The dimensions of the bottle cap are not in accordance with the specifications. | 6 | 4 | 4 | 96 | Medium |
| | | | **Method:** | | | | | |
| | | P5 | There is no detailed work instruction. | 9 | 7 | 4 | 252 | High |
| | | | **Machine:** | | | | | |
| | | P6 | Inappropriate machine settings. | 7 | 5 | 3 | 105 | Medium |
| | | P7 | The function of the bottle capping machine is not optimal. | 9 | 5 | 6 | 270 | High |
| | | | **Environment:** | | | | | |
| | | P8 | Lack of cleanliness of material warehouse. | 6 | 5 | 4 | 120 | Medium |
| | | P9 | The production room is not exposed to CCTV surveillance. | 6 | 4 | 3 | 72 | Medium |

Based on table 4.8 above, there are 9 potential causes of failure in the type of bottle cap defect. After obtaining the RPN value for each potential cause of failure, the risk category can be known where the range for the low category is 0 - 64, the medium category is 65 - 191, and the high category is 192 - 1000.

### *4.2.4 Improve.*

The improve stage is the stage used in developing and selecting the optimal solution based on the analysis that has been done previously such as making fishbone diagrams and RPN assessments with the FMEA method to get quality improvement proposals for products. The methods used to obtain optimal improvement proposals are TRIZ and Fuzzy MCDM.

1. Theory of Inventive Problem Solving (TRIZ)

   TRIZ is a method used in providing improvement proposals by eliminating contradictory problems in order to solve problems based on previous experience (Banda et al., 2022). The following is a technical contradiction based on the determination of improving parameters and worsening parameters that occur in the most potential types of defects in the production of bottled drinking water in 600ml bottles which can be seen in Table 4.9.

Table 4. 9 Technical Contradiction

| Code | Causes | Improving Parameter | >< | Worsening Parameter |
|---|---|---|---|---|
| P1 | Workers are negligent in performing work. | (2) Degree of responsibility of supervisor | >< | (11) Stress/pressure |
| P2 | Workers are less skilled. | (27) Reliability | >< | (25) Lost of time |
| P3 | Workers are not focused in doing the work. | (14) Strength | >< | (22) Lost of energy |
| P4 | The dimensions of the bottle cap are not in accordance with the specifications. | (29) Accuracy of manufacturing | >< | (11) Stress/pressure |
| P5 | There is no detailed work instruction. | (33) Ease of operation | >< | (35) Adaptability/ versatility |
| P6 | Inappropriate machine settings. | (29) Measurement precision | >< | (25) Loss of time |
| P7 | The function of the bottle capping machine is not optimal. | (34) Ease of repair | >< | (22) Loss of energy |
| P8 | Lack of cleanliness of material warehouse. | (32) Ease or manufacture | >< | (22) Loss of energy |
| P9 | The production room is not exposed to CCTV surveillance. | (27) Reliability | >< | (22) Loss of energy |

Based on table 4.9 above which is a technical contradiction, improving parameters are parameters used to overcome the cause of a problem. However, the improvement has an impact called contradiction. After categorizing improving parameters and worsening parameters based on their causes, then the two parameters will be crossed into a contradiction matrix where the meeting of the two parameters will produce the best alternative based on the 40 Inventive Principle of TRIZ to reduce the number of defective products in the production of bottled drinking water in 600ml bottles. The following are the results based on the contradiction matrix which can be seen in table 4.10.

Table 4. 10 Contradiction Matrix Results

| **Code** | **Improving Parameter** | **><** | **Worsening Parameter** | **Inventive Principles** |
|---|---|---|---|---|
| P1 | (2) Degree of responsibility of supervisor | >< | (11) Stress/pressure | 13, 29, 10, 18 |
| P2 | (27) Reliability | >< | (25) Lost of time | 10, 30, 4 |
| P3 | (14) Strength | >< | (22) Lost of energy | 35 |
| P4 | (29) Accuracy of manufacturing | >< | (11) Stress/pressure | 3, 35 |
| P5 | (33) Ease of operation | >< | (35) Adaptability/ versatility | 15, 34, 1, 16 |
| P6 | (29) Measurement precision | >< | (25) Loss of time | 32, 26, 28, 18 |
| P7 | (34) Ease of repair | >< | (22) Loss of energy | 5, 1, 32, 19 |
| P8 | (32) Ease of manufacture | >< | (22) Loss of energy | 19, 35 |
| P9 | (27) Reliability | >< | (22) Loss of energy | All |

After obtaining the inventive principles in table 4.10, then the optimal solution selection is carried out in accordance with the company's conditions so that the company can minimize the occurrence of defects in drinking water products in 600ml bottles. The following is an improvement solution that can be applied by PT. Narmada Awet Muda which can be seen in Table 4.11.

Table 4. 11 Solution of Contradiction Analysis Results

| **Code** | **Causes** | **Conflict Parameter** | **Result of TRIZ Contradiction Matrix** | **Pre-TRIZ solution** | **TRIZ-Based Solutions** |
|---|---|---|---|---|---|
| P1 | Workers are negligent in performing work. | (2) Degree of responsibility of supervisor >< (11) Stress/pressure | (13) The other way around<br>(29) Pneumatics and hydraulics<br>(10) Preliminary action<br>(18) Mechanical vibration/oscillation | Conduct briefings in the form of weekly evaluations to workers before carrying out work. | (10) Preliminary action:<br>• Create a draft employee performance appraisal report.<br>• Conduct strict supervision of workers. |
| P2 | Workers are less skilled. | (27) Reliability >< (25) Loss of time | (10) Preliminary action<br>(30) Flexible shells and thin films<br>(4) Asymmetry | Positioning less-skilled employees alongside employees who have been working for a long time. | (10) Preliminary Action:<br>• Provide technical training to workers to improve operational skills and manufacturing skills.<br>• Create a draft employee performance appraisal report. |
| P3 | Workers are not focused in doing the work. | (14) Strength >< (22) Loss of energy | (35) Parameter changes | Direct monitoring of employee work by supervisors. | (35) Parameter changes:<br>• Making visual controls containing warnings to stay focused at work. |

| Code | Causes | Conflict Parameter | Result of TRIZ Contradiction Matrix | Pre-TRIZ solution | TRIZ-Based Solutions |
|---|---|---|---|---|---|
| P4 | The dimensions of the bottle cap are not in accordance with the specifications. | (29) Accuracy of manufacturing >< (11) Stress/pressure | (3) Local Quality<br>(35) Parameter changes | • Provide samples of good bottle cap products and those that are not suitable for use.<br>• Contact the supplier | (35) Parameter changes:<br>• Conduct supervision to increase worker accuracy during the process of checking and maintaining material quality. |
| P5 | There is no detailed work instruction. | (33) Ease of operation >< (35) Adaptability/versatility | (15) Dynamization<br>(34) Discarding and recovering<br>(1) Segmentation<br>(16) Partial or excessive action | Inform workers about work instructions verbally. | (15) Dynamization:<br>• Creating detailed work instructions as work guidelines so that workers are easier to do their jobs. |
| P6 | Inappropriate machine settings. | (29) Measurement precision >< (25) Loss of time | (32) Color changes<br>(26) Copying<br>(28) Mechanics substitution<br>(18) Mechanical vibration/oscillation | Control of each machine before the production process is carried out. | (26) Copying:<br>• Making copies of the guidelines based on the optimized machine settings and save it into a document. |
| P7 | The function of the bottle capping | (34) Ease of repair >< (22) Loss of energy | (15) Dynamization<br>(1) Segmentation<br>(32) Color changes<br>(19) Periodic action | Creating a machine maintenance schedule check sheet. | (19) Periodic action:<br>• Make a report in the form of a recap of downtime data to find out how often and how |

| Code | Causes | Conflict Parameter | Result of TRIZ Contradiction Matrix | Pre-TRIZ solution | TRIZ-Based Solutions |
|---|---|---|---|---|---|
| | machine is not optimal. | | | | long machines experience problems to identify problem patterns.<br>• Checking and maintaining the machine regularly |
| P8 | Lack of cleanliness of material warehouse. | (32) Ease of manufacture >< (22) Loss of energy | (19) Periodic action<br>(35) Parameter changes | • Make a warehouse cleaning schedule.<br>• Conduct periodic warehouse cleaning. | (19) Periodic action:<br>• Conduct regular inventory monitoring to ensure the stock of raw materials is under control to avoid the accumulation of unnecessary items and cause a lot of dirt.<br>• Create a checklist form to inspect the cleanliness of the warehouse. |
| P9 | The production room is not exposed to CCTV surveillance. | (27) Reliability >< (22) Loss of energy | All | Supervision of the production process is carried out directly by supervisors on the production floor. | (24) Intermediary:<br>• Install CCTV in the production room to make it easier to monitor the production process. |

Table 4.14 shows the solution performed by the company before the proposed ideal solution based on TRIZ and the improvement solutions for each contradiction obtained from the inventive principles of TRIZ that can be applied by companies in minimizing product defects. The selection of solutions for each contradiction is done by selecting principles that are suitable and feasible to be used as improvement proposals.

2. Fuzzy Multi Criteria Decision Making (FMCDM)

Fuzzy Multi Criteria Decision Making (FMCDM) is a method used in making decisions on several alternatives based on criteria as a consideration in providing improvement proposals (Lubis, 2017).

a. Mitigation Action Identification

The purpose of this decision is to select the best improvement solution to minimize product defects in bottled drinking water in 600ml bottles using FMCDM, there are several criteria and alternatives used in decision making. The criteria used in selecting the best improvement solution can be seen in Table 4.15.

Table 4. 12 Criteria for Selection of the Best Improvement Solution

| **Criteria** | **Information** |
|---|---|
| $C_1$ | Human Resource Capability |
| $C_2$ | Technical Capability |
| $C_3$ | Cost Capability |

Based on table 4.12, there are three criteria which are obtained based on the results of the literature review. Then discussions and verification with experts are carried out based on these results.

In identifying a cause of failure in drinking water products in 600ml bottles, risk mitigation action mapping is used. The following is a risk mitigation action mapping that shows the order of the causes of failure with RPN values from the highest to the lowest category and their preventive actions which can be seen in table 4.13.

Table 4. 13 Risk Mitigation Action Mapping

| Code | Potential Cause of Failure | Prevention Action | Code |
|---|---|---|---|
| P7 | The function of the bottle capping machine is not optimal. | Make report of downtime data recap. | A1 |
| | | Checking and maintaining the machine regularly. | A2 |
| P5 | There is no detailed work instruction. | Create detailed work instructions. | A3 |
| P1 | Workers are negligent in performing work. | Create a draft employee performance appraisal report. | A4 |
| | | Conduct strict supervision to workers. | A5 |
| P2 | Workers are less skilled. | Provide technical training to workers. | A6 |
| | | Create a draft employee performance appraisal report. | A4 |
| P8 | Lack of cleanliness of material warehouse. | Conduct regular inventory monitoring. | A7 |
| | | Make a checklist form in warehouse cleanliness inspection. | A8 |
| P6 | Inappropriate machine settings. | Make copies of guidelines based on optimized machine settings and save into document. | A9 |
| P4 | The dimensions of the bottle cap are not in accordance with the specifications. | Supervise the process of checking and maintaining material quality. | A10 |
| P9 | The production room is not exposed to CCTV surveillance. | Installing CCTV in the production room. | A11 |

| Code | Potential Cause of Failure | Prevention Action | Code |
|---|---|---|---|
| P3 | Workers are not focused in doing the work. | Create a visual control containing a warning to stay focused at work. | A12 |

After defining the strategy in the form of preventive actions, the next step is to determine the degree of compatibility (Dk) to assist in choosing an improvement solution decision to minimize defects in bottled drinking water products in 600ml bottles. To obtain the degree of suitability (Dk), fuzzy logic is used with the help of FIS (Fuzzy Inference System) in MATLAB based on three criteria, namely human resource capability, technical capability, and cost capability.

b. Fuzzy Mitigation Action

In performing calculations, researchers use fuzzy logic to determine the degree of suitability (Dk). In this study, there are three input variables, namely human resource capabilities, technical capabilities, and cost capabilities, where the scores of these variables come from the opinions of experts. The three inputs will be processed with fuzzy methods to get an output in the form of a matching degree for mitigation actions to choose the best alternative in minimizing product defects.

1) Defining Fuzzy Rules

1) Defining Fuzzy Rules

The following is a rule in determining the matching degree (Dk) based on input variables.

1. If (Human Resource Capability is Very Low) and (Technical Capability is Very Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
2. If (Human Resource Capability is Very Low) and (Technical Capability is Very Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).

3. If (Human Resource Capability is Very Low) and (Technical Capability is Very Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Very Low).
4. If (Human Resource Capability is Very Low) and (Technical Capability is Very Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is Low).
5. If (Human Resource Capability is Very Low) and (Technical Capability is Very Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Moderate).
6. If (Human Resource Capability is Very Low) and (Technical Capability is Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
7. If (Human Resource Capability is Very Low) and (Technical Capability is Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).
8. If (Human Resource Capability is Very Low) and (Technical Capability is Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Low).
9. If (Human Resource Capability is Very Low) and (Technical Capability is Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is Low).
10. If (Human Resource Capability is Very Low) and (Technical Capability is Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Moderate).
11. If (Human Resource Capability is Very Low) and (Technical Capability is Moderate) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
12. If (Human Resource Capability is Very Low) and (Technical Capability is Moderate) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).

13. If (Human Resource Capability is Very Low) and (Technical Capability is Moderate and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Low).
14. If (Human Resource Capability is Very Low) and (Technical Capability is Moderate) and (Cost Capability is High) then (Matching Degree Mitigation Action is Moderate).
15. If (Human Resource Capability is Very Low) and (Technical Capability is Moderate) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Moderate).
16. If (Human Resource Capability is Very Low) and (Technical Capability is High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
17. If (Human Resource Capability is Very Low) and (Technical Capability is High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Low).
18. If (Human Resource Capability is Very Low) and (Technical Capability is High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
19. If (Human Resource Capability is Very Low) and (Technical Capability is High) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
20. If (Human Resource Capability is Very Low) and (Technical Capability is High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
21. If (Human Resource Capability is Very Low) and (Technical Capability is Very High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Moderate).
22. If (Human Resource Capability is Very Low) and (Technical Capability is Very High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Moderate).

23. If (Human Resource Capability is Very Low) and (Technical Capability is Very High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
24. If (Human Resource Capability is Very Low) and (Technical Capability is Very High) and (Cost Capability is High) then (Matching Degree Mitigation Action is Very High).
25. If (Human Resource Capability is Very Low) and (Technical Capability is Very High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
26. If (Human Resource Capability is Low) and (Technical Capability is Very Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
27. If (Human Resource Capability is Low) and (Technical Capability is Very Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).
28. If (Human Resource Capability is Low) and (Technical Capability is Very Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Low).
29. If (Human Resource Capability is Low) and (Technical Capability is Very Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is Moderate).
30. If (Human Resource Capability is Low) and (Technical Capability is Very Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Moderate).
31. If (Human Resource Capability is Low) and (Technical Capability is Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
32. If (Human Resource Capability is Low) and (Technical Capability is Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).

33. If (Human Resource Capability is Low) and (Technical Capability is Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Low).
34. If (Human Resource Capability is Low) and (Technical Capability is Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is Moderate).
35. If (Human Resource Capability is Low) and (Technical Capability is Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is High).
36. If (Human Resource Capability is Low) and (Technical Capability is Moderate) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
37. If (Human Resource Capability is Low) and (Technical Capability is Moderate) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).
38. If (Human Resource Capability is Low) and (Technical Capability is Moderate) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Low).
39. If (Human Resource Capability is Low) and (Technical Capability is Moderate) and (Cost Capability is High) then (Matching Degree Mitigation Action is Moderate).
40. If (Human Resource Capability is Low) and (Technical Capability is Moderate) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is High).
41. If (Human Resource Capability is Low) and (Technical Capability is High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
42. If (Human Resource Capability is Low) and (Technical Capability is High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).

43. If (Human Resource Capability is Low) and (Technical Capability is High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
44. If (Human Resource Capability is Low) and (Technical Capability is High) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
45. If (Human Resource Capability is Low) and (Technical Capability is High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
46. If (Human Resource Capability is Low) and (Technical Capability is Very High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Moderate).
47. If (Human Resource Capability is Low) and (Technical Capability is Very High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Moderate).
48. If (Human Resource Capability is Low) and (Technical Capability is Very High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
49. If (Human Resource Capability is Low) and (Technical Capability is Very High) and (Cost Capability is High) then (Matching Degree Mitigation Action is Very High).
50. If (Human Resource Capability is Low) and (Technical Capability is Very High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
51. If (Human Resource Capability is Moderate) and (Technical Capability is Very Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
52. If (Human Resource Capability is Moderate) and (Technical Capability is Very Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).

53. If (Human Resource Capability is Moderate) and (Technical Capability is Very Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Low).
54. If (Human Resource Capability is Moderate) and (Technical Capability is Very Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is Moderate).
55. If (Human Resource Capability is Moderate) and (Technical Capability is Very Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Moderate).
56. If (Human Resource Capability is Moderate) and (Technical Capability is Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
57. If (Human Resource Capability is Moderate) and (Technical Capability is Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very Low).
58. If (Human Resource Capability is Moderate) and (Technical Capability is Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Low).
59. If (Human Resource Capability is Moderate) and (Technical Capability is Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is Moderate).
60. If (Human Resource Capability is Moderate) and (Technical Capability is Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is High).
61. If (Human Resource Capability is Moderate) and (Technical Capability is Moderate) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
62. If (Human Resource Capability is Moderate) and (Technical Capability is Moderate and (Cost Capability is Low) then (Matching Degree Mitigation Action is Low).

63. If (Human Resource Capability is Moderate) and (Technical Capability is Moderate) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
64. If (Human Resource Capability is Moderate) and (Technical Capability is Moderate) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
65. If (Human Resource Capability is Moderate) and (Technical Capability is Moderate) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
66. If (Human Resource Capability is Moderate) and (Technical Capability is High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Low).
67. If (Human Resource Capability is Moderate) and (Technical Capability is High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Moderate).
68. If (Human Resource Capability is Moderate) and (Technical Capability is High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
69. If (Human Resource Capability is Moderate) and (Technical Capability is High) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
70. If (Human Resource Capability is Moderate) and (Technical Capability is High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
71. If (Human Resource Capability is Moderate) and (Technical Capability is Very High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Moderate).
72. If (Human Resource Capability is Moderate) and (Technical Capability is Very High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Moderate).

73. If (Human Resource Capability is Moderate) and (Technical Capability is Very High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
74. If (Human Resource Capability is Moderate) and (Technical Capability is Very High) and (Cost Capability is High) then (Matching Degree Mitigation Action is Very High).
75. If (Human Resource Capability is Moderate) and (Technical Capability is Very High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
76. If (Human Resource Capability is High) and (Technical Capability is Very Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Low).
77. If (Human Resource Capability is High) and (Technical Capability is Very Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Low).
78. If (Human Resource Capability is High) and (Technical Capability is Very Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
79. If (Human Resource Capability is High) and (Technical Capability is Very Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
80. If (Human Resource Capability is High) and (Technical Capability is Very Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
81. If (Human Resource Capability is High) and (Technical Capability is Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Very Low).
82. If (Human Resource Capability is High) and (Technical Capability is Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Low).

83. If (Huma Resources is High) and (Technical Capability is Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
84. If (Human Resource Capability is High) and (Technical Capability is Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
85. If (Human Resource Capability is High) and (Technical Capability is Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
86. If (Human Resource Capability is High) and (Technical Capability is Moderate) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Low).
87. If (Human Resource Capability is High) and (Technical Capability is Moderate) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Low).
88. If (Human Resource Capability is High) and (Technical Capability is Moderate) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
89. If (Human Resource Capability is High) and (Technical Capability is Moderate) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
90. If (Human Resource Capability is High) and (Technical Capability is Moderate) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
91. If (Human Resource Capability is High) and (Technical Capability is High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Low).
92. If (Human Resource Capability is High) and (Technical Capability is High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Moderate).

93. If (Human Resource Capability is High) and (Technical Capability is High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
94. If (Human Resource Capability is High) and (Technical Capability is High) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
95. If (Human Resource Capability is High) and (Technical Capability is High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
96. If (Human Resource Capability is High) and (Technical Capability is Very High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is High).
97. If (Human Resource Capability is High) and (Technical Capability is Very High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is High).
98. If (Human Resource Capability is High) and (Technical Capability is Very High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
99. If (Human Resource Capability is High) and (Technical Capability is Very High) and (Cost Capability is High) then (Matching Degree Mitigation Action is Very High).
100. If (Human Resource Capability is High) and (Technical Capability is Very High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
101. If (Human Resource Capability is Very High) and (Technical Capability is Very Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Low).
102. If (Human Resource Capability is Very High) and (Technical Capability is Very Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Low).

103. If (Human Resource Capability is Very High) and (Technical Capability is Very Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
104. If (Human Resource Capability is Very High) and (Technical Capability is Very Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
105. If (Human Resource Capability is Very High) and (Technical Capability is Very Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
106. If (Human Resource Capability is Very High) and (Technical Capability is Low) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Low).
107. If (Human Resource Capability is Very High) and (Technical Capability is Low) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Low).
108. If (Human Resource Capability is Very High) and (Technical Capability is Low) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Moderate).
109. If (Human Resource Capability is Very High) and (Technical Capability is Low) and (Cost Capability is High) then (Matching Degree Mitigation Action is High).
110. If (Human Resource Capability is Very High) and (Technical Capability is Low) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
111. If (Human Resource Capability is Very High) and (Technical Capability is Moderate) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is Moderate).
112. If (Human Resource Capability is Very High) and (Technical Capability is Moderate) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Moderate).

113. If (Human Resource Capability is Very High) and (Technical Capability is Moderate) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
114. If (Human Resource Capability is Very High) and (Technical Capability is Moderate) and (Cost Capability is High) then (Matching Degree Mitigation Action is Very High).
115. If (Human Resource Capability is Very High) and (Technical Capability is Moderate) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
116. If (Human Resource Capability is Very High) and (Technical Capability is High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is High).
117. If (Human Resource Capability is Very High) and (Technical Capability is High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is High).
118. If (Human Resource Capability is Very High) and (Technical Capability is High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is High).
119. If (Human Resource Capability is Very High) and (Technical Capability is High) and (Cost Capability is High) then (Matching Degree Mitigation Action is Very High).
120. If (Human Resource Capability is Very High) and (Technical Capability is High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).
121. If (Human Resource Capability is Very High) and (Technical Capability is Very High) and (Cost Capability is Very Low) then (Matching Degree Mitigation Action is High).
122. If (Human Resource Capability is Very High) and (Technical Capability is Very High) and (Cost Capability is Low) then (Matching Degree Mitigation Action is Very High).

123. If (Human Resource Capability is Very High) and (Technical Capability is Very High) and (Cost Capability is Moderate) then (Matching Degree Mitigation Action is Very High).
124. If (Human Resource Capability is Very High) and (Technical Capability is Very High) and (Cost Capability is High) then (Matching Degree Mitigation Action is Very High).
125. If (Human Resource Capability is Very High) and (Technical Capability is Very High) and (Cost Capability is Very High) then (Matching Degree Mitigation Action is Very High).

2) Defining Fuzzy Inputs

The inputs used are human resource capabilities, technical capabilities, and cost capabilities based on the results of discussions with experts. Calculations are carried out using the help of MATLAB software in measuring the membership function of each parameter in each input variable. The following is the membership function of each parameter on the input variable based on parameter range that can be seen in Table 3.1.

$$\mu\text{Very Low} = \begin{cases} 0, & x \geq 2 \\ \frac{2-x}{2}, & 0 \leq x \leq 2 \\ 1, & x \leq 1 \end{cases} \tag{4.8}$$

$$\mu\text{Low} = \begin{cases} 0, & x \leq 1 \; or \; x \geq 3 \\ \frac{x-1}{1}, & 1 \leq x \leq 3 \\ \frac{3-x}{1}, & 2 \leq x \leq 3 \end{cases} \tag{4.9}$$

$$\mu\text{Moderate} = \begin{cases} 0, & x \leq 2 \; or \; x \geq 4 \\ \frac{x-2}{1}, & 2 \leq x \leq 2.8 \\ \frac{4-x}{1}, & 3 \leq x \leq 4 \end{cases} \tag{4.10}$$

$$\mu\text{High} = \begin{cases} 0, & x \leq 3 \ or \ x \geq 4 \\ \dfrac{x-3}{1}, & 3 \leq x \leq 4 \\ \dfrac{4-x}{1}, & 3 \leq x \leq 5 \end{cases} \tag{4.11}$$

$$\mu\text{Very High} = \begin{cases} 0, & x \leq 4 \\ \dfrac{2-x}{2}, & 4 \leq x \leq 5 \\ 1, & x \geq 5 \end{cases} \tag{4.12}$$

Furthermore, the membership function of each parameter will be used in making curves for fuzzy calculations. The following is the membership function of each input parameter which can be seen in table 4.14.

Table 4. 14 Input Parameter Membership Function

| **Function** | **Variable** | **Fuzzy Indicators (Impact)** | **Range** | **Unit of Range** |
|---|---|---|---|---|
| Input | Human Resource Capability | Very Low | 0 – 5 | [0 0 1 1,5] |
| | | Low | | [1 1,5 2 2,5] |
| | | Moderate | | [1,75 2,25 2,75 3,25] |
| | | High | | [2,5 3 3,5 4] |
| | | Very High | | [3,5 4,5 5 5] |
| | Technical Capability | Very Low | 0 – 5 | [0 0 1 1,5] |
| | | Low | | [1 1,5 2 2,5] |
| | | Moderate | | [1,75 2,25 2,75 3,25] |
| | | High | | [2,5 3 3,5 4] |
| | | Very High | | [3,5 4,5 5 5] |
| | Cost Capability | Very Low | 0 – 5 | [0 0 1 1,5] |
| | | Low | | [1 1,5 2 2,5] |
| | | Moderate | | [1,75 2,25 2,75 3,25] |
| | | High | | [2,5 3 3,5 4] |
| | | Very High | | [3,5 4,5 5 5] |

Based on table 4.14, membership function plots can be made for each variable. The following are membership function plots for human resource variables shown in Figure 4.11, technical variables in Figure 4.12, and cost variables in Figure 4.13.

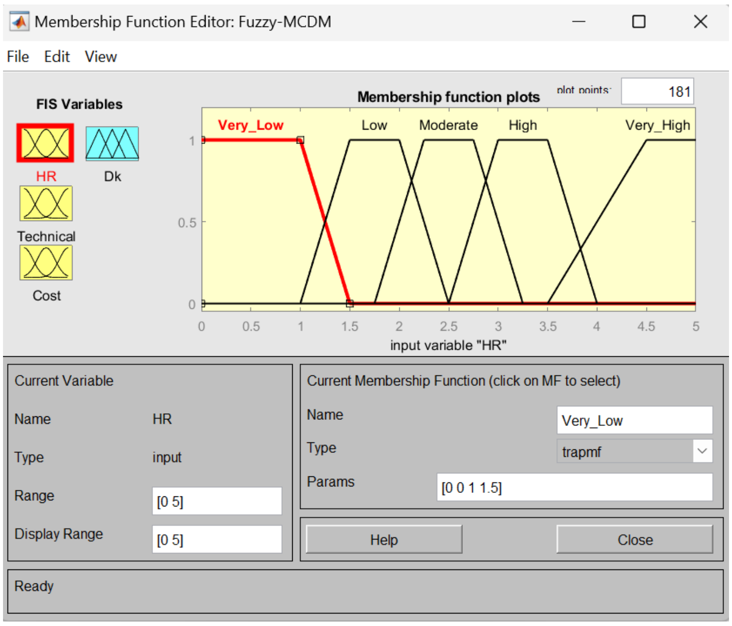


Figure 4. 11 Membership Function Input of Human Resource

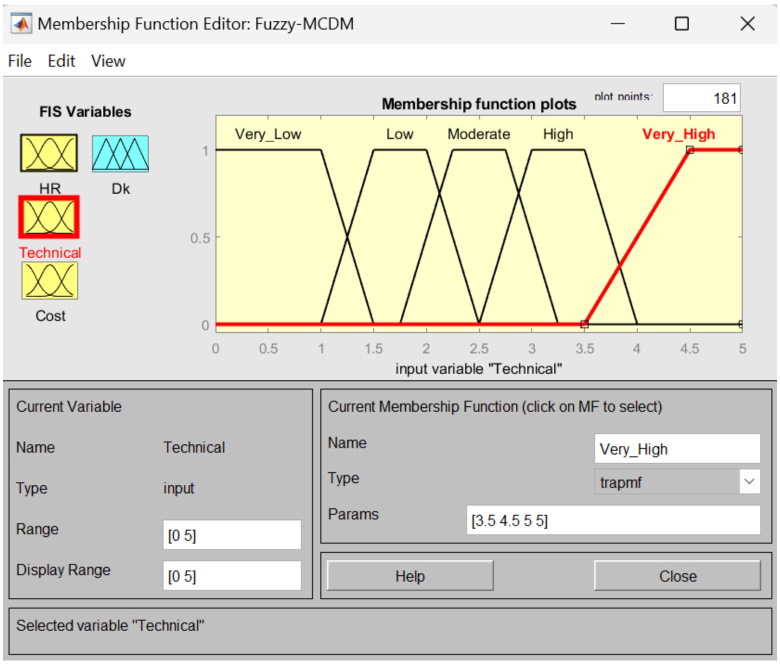


Figure 4. 12 Membership Function Input of Technical


Figure 4. 13 Membership Function Input of Cost

3) Defining Fuzzy Output

The output in this fuzzy calculation is the matching degree (Dk). The results obtained from the output are based on the calculation of input variables where the assessment is based on the opinions of experts. Similar to the input variables, the parameters of the membership function variables on the output variables also use the help of MATLAB software. The following is the membership function parameter on the output variable in the form of matching degree (Dk):

$$\mu\text{Very Low} = \begin{cases} 0, & x \geq 2 \\ \dfrac{2-x}{2}, & 0 \leq x \leq 2 \\ 1, & x \leq 1 \end{cases} \tag{4.13}$$

$$\mu\text{Low} = \begin{cases} 0, & x \leq 1 \; or \; x \geq 3 \\ \dfrac{x-1}{1}, & 1 < x \leq 3 \\ \dfrac{3-x}{1}, & 2 \leq x < 3 \end{cases} \tag{4.14}$$

$$\mu\text{Moderate} = \begin{cases} 0, & x \leq 2 \; or \; x \geq 4 \\ \frac{x-2}{1}, & 2 < x \leq 2.8 \\ \frac{4-x}{1}, & 3 \leq x < 4 \end{cases} \quad (4.15)$$

$$\mu\text{High} = \begin{cases} 0, & x \leq 3 \; or \; x \geq 4 \\ \frac{x-3}{1}, & 3 < x \leq 4 \\ \frac{4-x}{1}, & 3 < x < 5 \end{cases} \quad (4.16)$$

$$\mu\text{Very High} = \begin{cases} 0, & x \leq 4 \\ \frac{2-x}{2}, & 4 < x \leq 5 \\ 1, & x \geq 5 \end{cases} \quad (4.17)$$

The result of the parameter range at the output is the same as the result at the input. From the results of these membership parameters, a curve will be made for fuzzy calculations. The following is the membership function of each output parameter which can be seen in table 4.15.

Table 4. 15 Output Parameter Membership Function

| **Function** | **Variable** | **Fuzzy Indicators (Impact)** | **Range** | **Unit of Range** |
|---|---|---|---|---|
| Output | Matching Degree of Mitigation Action | Very Low | 0 – 5 | [0 0 1 2] |
| | | Low | | [1 2 3] |
| | | Moderate | | [2 3 4] |
| | | High | | [3 4 5] |
| | | Very High | | [3,5 4,5 5 5] |

The following are membership function plots for output variables based on table 4.15 which can be seen in Figure 4.14.

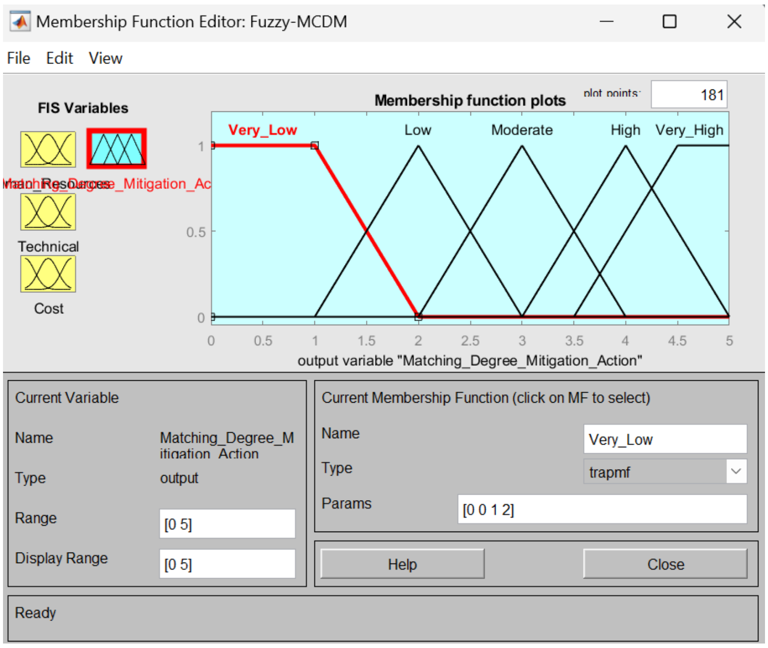


Figure 4. 14 Membership Function Output of Matching Degree

4) Calculation Result (Defuzzification)

After making curves on the input and output variables, then the calculation is carried out by entering the weight of each criterion or input variable so that the degree of suitability of each alternative or mitigation action is obtained. The following are the results of defuzzification calculations based on rule composition which can be seen in Figure 4.15.


Figure 4. 15 Defuzzification Calculation Process

Based on Figure 4.15, the following is the weighting of each criterion or input variable carried out by the expert and the defuzzification results in the form of the matching degree of mitigation actions based on each criterion shown in table 4.16.

Table 4. 16 Calculation Fuzzy Result (Defuzzification)

| Prevention Action | Code | HR Capability | Technical Capability | Cost Capability | Matching Degree |
|---|---|---|---|---|---|
| Make report of downtime data. | A1 | 3 | 4,5 | 5 | 4,47 |
| Checking and maintaining the machine regularly. | A2 | 3 | 3 | 3 | 3,58 |
| Create detailed work instructions. | A3 | 2 | 2 | 3,5 | 3,42 |
| Create a draft employee performance appraisal report. | A4 | 4 | 4 | 4 | 4,38 |
| Conduct strict supervision to workers. | A5 | 2,5 | 3 | 3,5 | 4 |
| Provide technical training to workers. | A6 | 3,5 | 4 | 4 | 4,38 |
| Conduct regular inventory monitoring. | A7 | 5 | 5 | 5 | 4,47 |
| Make a checklist form in warehouse cleanliness inspection. | A8 | 3,5 | 4,5 | 4,5 | 4,47 |
| Make copies of guidelines based on optimized machine settings and save into document. | A9 | 2 | 3 | 4 | 4,28 |
| Supervise the process of checking and maintaining material quality. | A10 | 2 | 3,5 | 3 | 3,58 |
| Installing CCTV in the production room. | A11 | 1 | 2 | 4 | 3 |
| Create a visual control containing a warning to stay focused at work. | A12 | 3 | 4 | 3 | 4,13 |

5) Optimal Alternative Selection

After calculating the fuzzy matching degree in Table 4.16, the best improvement solution in minimizing the defect of drinking water products in 600ml bottles can be obtained, which is shown in Table 4.17.

Table 4. 17 Ranking of Improvement Solutions

| **Alternative** | **Prevention Action** |
|---|---|
| A1 | Create report downtime data. |
| A7 | Conduct regular inventory monitoring. |
| A8 | Make a checklist form in warehouse cleanliness inspection. |
| A4 | Create a draft employee performance appraisal report. |
| A6 | Provide technical training to workers. |
| A9 | Make copies of guidelines based on optimized machine settings. |
| A12 | Create a visual control containing a warning to stay focused at work. |
| A5 | Conduct strict supervision to workers. |
| A2 | Checking and maintaining the machine regularly. |
| A10 | Supervise the process of checking and maintaining material quality. |
| A3 | Create detailed work instructions. |
| A11 | Installing CCTV in the production room. |

Based on table 4.18 above, the ranking of improvement solutions in the form of prevention actions that can be carried out from those with the highest to the lowest degree of suitability value is obtained. The higher the degree of suitability value, the better the alternative is to be carried out according to the match with the existing criteria in an effort to minimize product defects in bottled drinking water in 600ml bottles.

# CHAPTER V
# DISCUSSION

## 5.1 Define

The define stage is the first stage where at this stage the SIPOC diagram is made and the CTQ (Critical to Quality) is defined. There are several elements in the SIPOC diagram that have been built, starting from the source of water and raw material suppliers such as preform suppliers which are used as the basic material for making bottles, PET bottle suppliers which are used as auxiliary materials to anticipate if there is a problem with the blow machine, label suppliers which are used as labels containing information related to product and company brands, bottle cap suppliers which are used as covers in keeping the contents of the bottle from being contaminated, cardboard suppliers which are used as drinking water packing materials, and duct tape suppliers which are used as sealing cardboard packaging so that the product remains safe until it reaches consumers. Input in the form of raw materials will be processed through several processes to become a finished product in the form of drinking water in 600ml bottles that are ready to be sold to all customers of PT. Narmada Awet Muda.

There are several stages carried out by PT Narmada Awet Muda in producing drinking water in 600 ml bottles, starting from water treatment which aims to purify water so that it is suitable for consumption, then the blowing process aims to make bottles that will be used as packaging, then a feasibility test will be carried out to find out whether the bottle is suitable for use. The next process is the filling process, water that has gone through the water treatment process will be flowed into the bottle, then a second feasibility test will be carried out to find out if there are rejects in the product. Products that pass the feasibility test will then enter the labeling process or the installation of labels on the bottle. The bottle will be given an expiration date to indicate the durability or shelf life of the product. Then the third feasibility test will be carried out to find out if there are product rejects and ensure that the product is suitable for consumption by customers. In the last stage, products that pass the third feasibility test will be packed into cardboard boxes in accordance with the production requirements. The final product will then be distributed to all consumers of PT Narmada Awet Muda products.

In addition to identifying aspects using SIPOC diagrams, at this stage CTQ determination is also carried out to determine important characteristics to prioritize improvements to non-conforming drinking water products in 600ml bottles. The results of CTQ determination are based on the results of interviews with production department staff with reference to company data. There are three types of defects that cause defects in drinking water products in 600ml bottles, including defects in bottle caps, defects in bottles, and defects in water volume.

## 5.2 Measure

The measure stage is the second stage in which at this stage the calculation of DPMO, sigma value, and control chart is carried out. The data used at this stage is data on the number of productions and the number of defects in the period November - December 2022 for drinking water products in 600ml bottles.

### *5.2.1 Calculation of DPMO value.*

Based on data for the period November - December 2022, production data was obtained for 48 days which had been reduced by holidays. The total product of drinking water in 600ml bottles produced for 48 days is 3.116.309 bottles, with the amount of production per day fluctuating, the average amount of production is 64.923 bottles per day. In each production, three product feasibility tests were carried out, which obtained a total of 67.541 bottles of defective products, with an average product defect value of 1.407 bottles per day.

With a total production of 3.116.309 bottles and a total product defect of 64.923 bottles, the average DPMO value is 8.621. This means that during the production period of 600ml bottled drinking water for the period November - December 2022, the company has the possibility of producing 8.621 defects out of one million opportunities for the products produced. The highest DPMO value occurred on 31 December 2022 with a DPMO value of 55.603. Meanwhile, the lowest DPMO value occurred on 4 November 2022 with a DPMO value of 3.841. Based on this, the DPMO value is influenced by the total amount of production and the total number of defective products produced during production in the November - December 2022 period. The greater the ratio of the number of defective products that occur, the greater the DPMO value generated, and vice versa.

### *5.2.2 Calculation of sigma value.*

Based on the calculation results, the highest sigma value occurred on 4 November 2022 with a sigma value of 4,17. While the lowest sigma value is on 31 December 2022, with a sigma value of 3,09. The average sigma value for the November – December 2022 period in the production of 600ml bottled drinking water is 3,94.

Based on Gaperz (2007), the sigma value of 3.94 is already above the industry average in Indonesia. But from the total production for 2 months there is a percentage of defects of 3% which exceeds the target set by the company which is 1%. Bottle cap defects are the dominant factor that causes product defects with a percentage of 38.14%. The bottle defect type has a percentage of defects of 33.28%, and the lowest is the volume defect type with a percentage of 28.58%.

With a sigma value of 3.94, it shows that the company has a relatively good quality level. However, the company still has defects in some of its processes. This can lead to additional costs, lost customers, or other quality-related issues. Nevertheless, the company still has opportunities to improve the process so that the company can achieve a higher sigma level so that it can reduce the problems experienced. Therefore, a long-term improvement planning proposal is needed which aims to minimize the occurrence of defects and reduce the number of financial losses, as well as to get the appropriate results and achieve the targets set by the company. The following is a comparison graph between the DPMO value and the sigma value shown in Figure 5.1

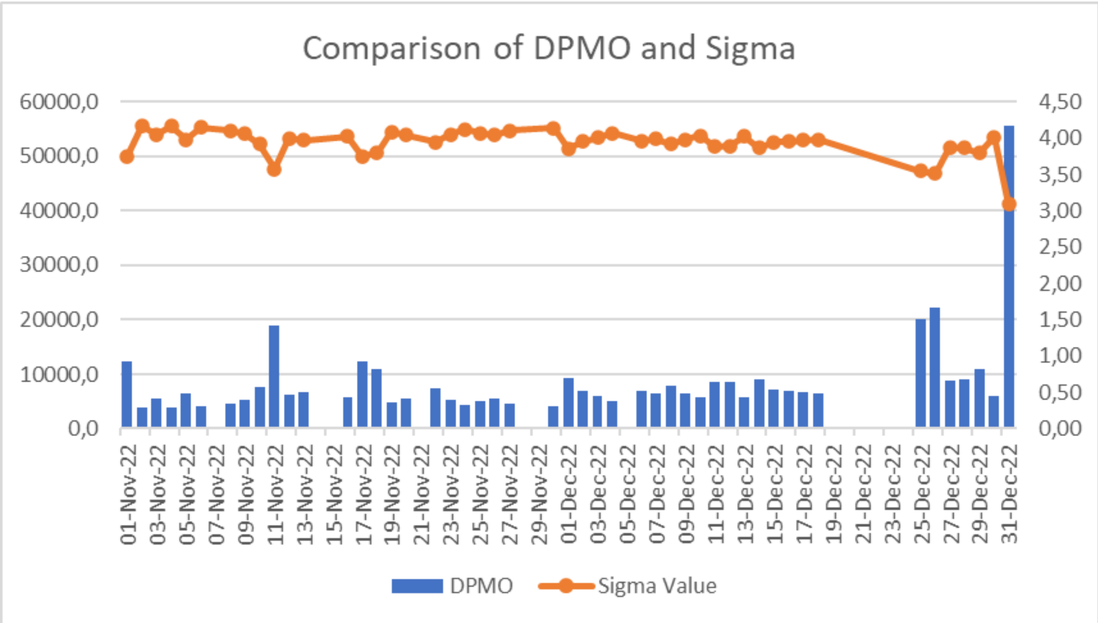


Figure 5. 1 Comparison of DPMO and Sigma Value

Based on Figure 5.1 which is a comparison graph between the DPMO value and the sigma value, it can be seen that there is a relationship between the two, namely the DPMO value and the sigma value are inversely proportional. The higher the DPMO value, the lower the sigma value. On the other hand, the lower the DPMO value, the higher the resulting sigma value.

### *5.2.3 Control chart calculation.*

The p control chart is used to measure the proportion of failure or non-conformity of some products during production. There are three limits that must be determined in calculating the control chart, including the Upper Control Limit (UCL), Center Line (CL), and Lower Control Limit (LCL). Based on the calculation of the control chart in November – December 2022 with 48 periods in the production of 600ml bottled drinking water, the center line (CL) value is 0,02167. While the UCL and LCL values produce different values for each period.

Based on the results of the control chart for November – December 2022 with 48 periods, there are 10 points that are within the control limits. Meanwhile, there are 38 points outside the control limits, such as 14 points above the upper control limit (UCL) line and 24 points below the lower control limit (LCL) line. The existence of deviations outside the control limits indicates that the quality control carried out by PT. Narmada Awet Muda is still not optimal and the production process carried out is still in an unstable or out of control condition so that defective products are still found that are not in accordance with company standards.

## 5.3 Analyze

The analyze stage is the third stage in which at this stage several tools are used in the form of bar chart to determine the most frequent product defects, fishbone diagrams to determine the causes of problems in the form of product defects, and FMEA which is used in determining priority improvements based on the causes of defective products.

### *5.3.1 Bar Chart.*

The bar chart analysis in this study uses defective product data from November - December 2022 with 48 periods containing 3 types of defects in the product. Based on the results of the bar chart, the most dominant type of defect and should be analyzed further is the type of defect in the bottle cap with a defect frequency of 25,761 bottles. The next highest frequency occurs in the type of defect in the bottle with a defect frequency of 22,467 bottles. The lowest frequency occurs in the type of water volume defect with a defect frequency of 19,304 bottles.

### *5.3.2 Fishbone diagram.*

In identifying, the causal factors were obtained from interviews with internal company parties, namely production department staff who work at PT Narmada Awet Muda. Fishbone diagram analysis is carried out based on man, method, machine, material, and environmental factors.

a. Man

The man factors that influence the occurrence of this type of defect in bottle caps are negligent workers in doing their work, less skilled workers, and workers not focusing on work. For the factor of negligent workers in doing their work is caused by workers who sometimes chat and joke with other workers which makes workers less concerned about their work. For the factor of unskilled workers, namely that there are differences in the expertise of each worker and the company is lacking in providing training to workers. The factor that workers are not focused on their work is caused by a noisy work environment and sometimes being talked to by other workers.

b. Method

The method factor that causes this type of defect in bottle caps is that there is no detailed work instruction. For the factor that there is no detailed work instruction, it causes workers to not have guidelines so that workers have difficulty understanding work procedures.

c. Machine

Machine factors that cause defects in bottle caps are inappropriate machine settings and non-optimal bottle capping machine functions. For the inappropriate setting factor due to operator error in setting the speed on the machine either too fast or too slow. This can cause the resulting product not to match the predetermined specifications. Meanwhile, non-optimal bottle capping machine functions such as bottle chokes that are too strong and stuck spindles can hinder the production process due to poor machine performance and can cause bottle cap defects in products. The occurrence of this can cause losses both in terms of maintenance costs, production costs, and machine damage.

d. Material

The material factor that causes this type of defect in bottle caps is that the dimensions of the bottle caps do not match the specifications. PT Narmada Awet Muda gets materials from suppliers. However, sometimes it is found that some materials are not suitable and during the inspection stage, materials that do not meet these specifications pass, resulting in products that are not in accordance with company standards. This is because inspections are only carried out on a sampling basis. If the quality of the material is lower than the standard provisions, the quality of the products produced is also reduced, causing product defects.

e. Environment

Environmental factors that cause this type of defect in bottle caps are the lack of cleanliness of the material warehouse and the production room is not exposed to CCTV surveillance. For the factor of lack of cleanliness of the material warehouse, it causes a lot of dirty material that cannot be used. For the factor that some production rooms are not exposed to CCTV surveillance, it can have an impact on the safety of workers and the company. In addition, the absence of CCTV in the production room makes it difficult for supervisors to control the performance of employees in completing their tasks whether they are in accordance with the SOP or not.

### *5.3.3 Failure mode and effect analysis (FMEA)*

Failure Mode and Effect Analysis (FMEA) is used to identify the priority of potential failures in products. In prioritizing the causes of product failure, it is done by giving the severity level (Severity - S), the frequency level of the cause of failure (Occurrence - O), and the level of detection of the cause of failure (Detection - D). The assessment is carried out by experts. The ranking of weighting values from the highest to the lowest value can be seen below.

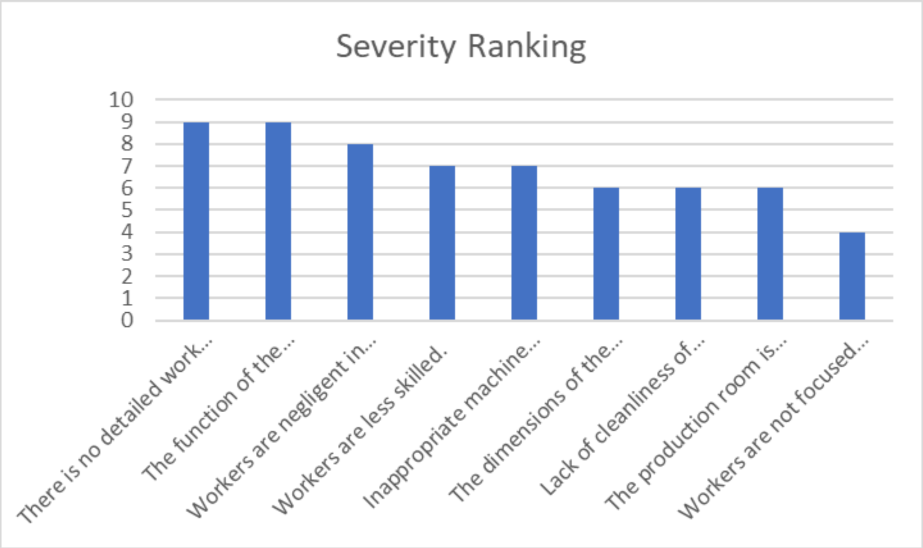


Figure 5. 2 Severity Ranking

Based on Figure 5.2 above which is the severity, it is known that there are nine causes of defects in bottle caps. The absence of detailed work instructions and the non-optimal function of the bottle capping machine have the highest value of 9. In the rating criteria, a value of 9 means that the failure that occurs has a very high adverse effect where the consequences are very dangerous and affect consumer safety. The next sequence is that workers are negligent in doing their work, getting a value of 8. Workers are less skilled, and the machine settings are not appropriate, getting a value of 7. The dimensions of the bottle cap do not match the specifications, the lack of cleanliness of the material warehouse, and the production room is not exposed to CCTV surveillance, getting a value of 6. Workers are not focused, getting a value of 4.

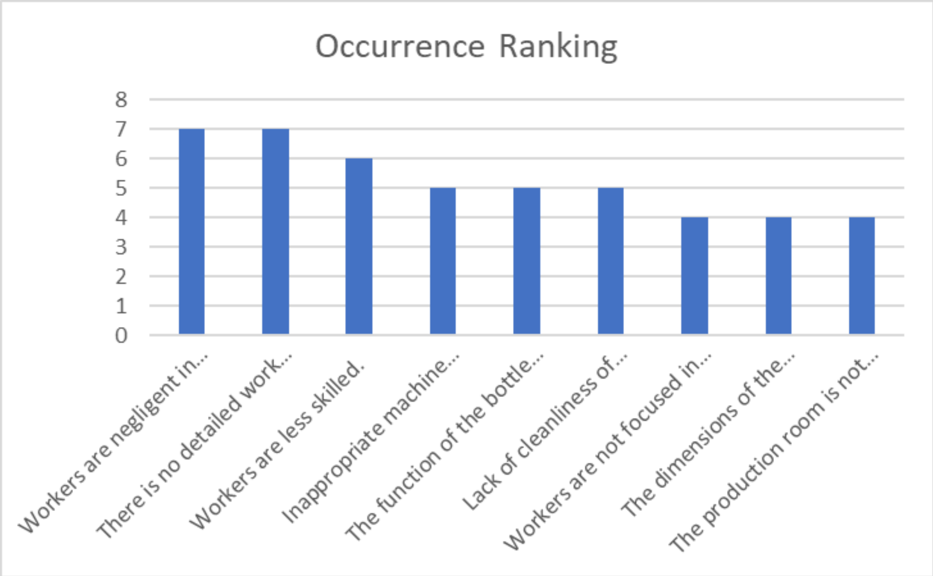


Figure 5. 3 Occurrence Ranking

Based on Figure 5.3 above which is the frequency level (occurrence), it is known that workers are negligent in doing their work and there is no detailed work instruction to obtain the highest value of 7. In the rating criteria, a value of 7 means that the frequency level of failure is high or occurs repeatedly. Machine settings are not appropriate, the function of the bottle capping machine is not optimal, and the lack of cleanliness of the material warehouse receives a value of 5. Workers are not focused on working, the dimensions of the bottle cap do not meet specifications, and the production room is not exposed to CCTV surveillance obtains a value of 4.

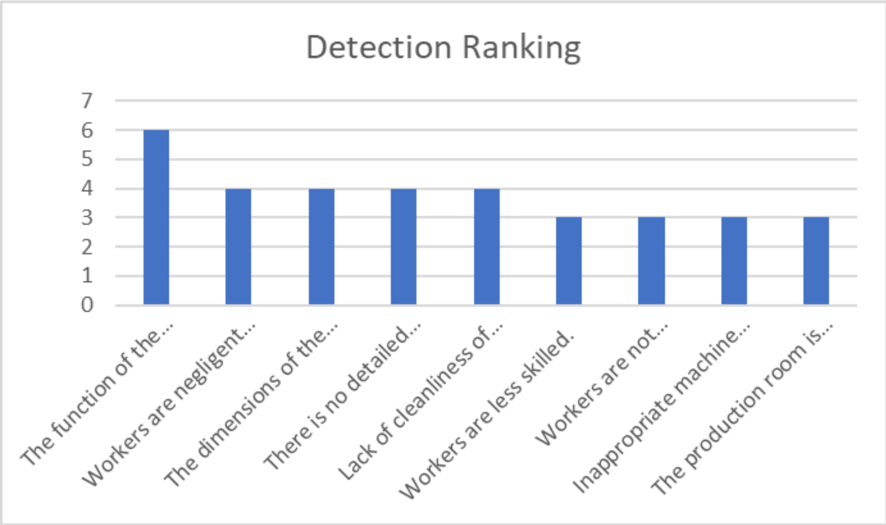


Figure 5. 4 Detection Ranking

Based on Figure 5.4 above, which is the detection level, it is known that the function of the bottle capping machine is not optimal and has the highest value of 6. In the rating criteria, a value of 6 means that the possibility of the controller to detect failure is low. The next sequence is that workers are negligent in doing their work, the dimensions of the bottle cap are not according to specifications, there is no detailed work instruction, and the lack of cleanliness of the material warehouse gets a value of 4. Less skilled workers, workers are not focused, machine settings are not appropriate, and the production room is not exposed to CCTV surveillance received a score of 3.

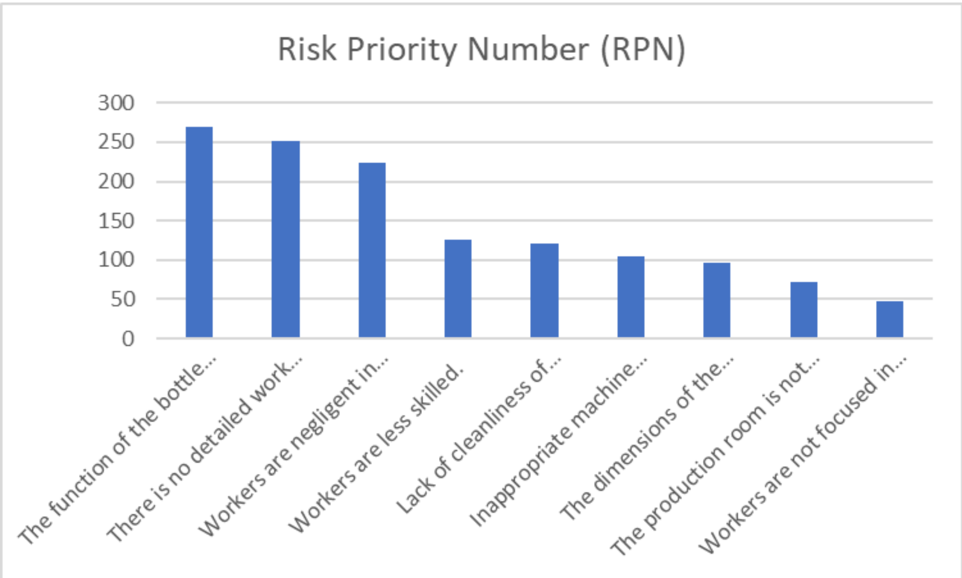


Figure 5. 5 Risk Priority Number

Figure 5.5 above is the ranking of the risk priority number obtained from the results of multiplying the severity, occurrence, and detection values. Based on (Piątkowski & Kamiński, 2017), the RPN values that are include in the high category are the function of the bottle capping machine is not optimal with a value of 270, there is no detailed work bond of 252, and workers are negligent in doing their work with a value of 224. This means that improvements need to be made to the value category. The next sequence is unskilled workers with a score of 126, lack of cleanliness of the material warehouse with a score of 120, inappropriate machine settings with a score of 105, bottle cap dimensions not according to specifications with a score of 96, the workspace is not exposed to CCTV surveillance with a score of 72, and workers are not focused with a score of 48.

## 5.4 Improve

The improve stage is the last stage which aims to develop and select the optimal solution based on the analysis that has been done in the previous stage. At this stage the TRIZ and Fuzzy MCDM methods are used.

### *5.4.1 TRIZ*

In the previous stage, the factors causing the occurrence of bottle cap defects in the production process of drinking water in 600ml bottles were identified using the FMEA method. Furthermore, the TRIZ method is used which aims to select the best solution to the problem at hand. This is supported by research conducted by Boangmanalu et al. (2020) which states that the TRIZ method can be used in determining improvement proposals at the improve stage which helps solve a problem based on previous events that cause contradictions. At this stage, a cross between two parameters based on 39 TRIZ parameters, namely improving parameters and worsening parameters, is carried out into a contradiction matrix. After obtaining the results, the selection of improvement proposals will then be made based on the 40 inventive principles of TRIZ. The proposed improvements for the most dominant cause of defects in the production of bottled drinking water in 600ml bottles, including:

1. Workers are negligent in performing work.

   For the cause of negligent workers in doing their work, the improving parameter is chosen, namely degree of responsibility of supervisor (2) and for the worsening parameter, namely stress/pressure (11). Based on this selection, a technical contradiction model was produced, namely "If a draft employee performance appraisal report is made and strict supervision is carried out by the supervisor, it can prevent deviations made by workers during work, but these actions can cause stress or pressure on workers". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 13, 29, 10, 18. Selected improvement solutions with the principle of preliminary action (10) because it is considered appropriate and feasible to be used as a proposal for improvement of the problems that occur. Based on table 2.8 regarding 40 inventive principles of TRIZ, the purpose of the preliminary action (10) principle is to take action or preparation before a serious problem occurs in order to minimize the impact that will be caused.

Based on these problems, the researcher provides an improvement solution, namely making a draft employee performance report and conducting strict supervision by supervisors to workers so that no workers are found who make deviations when doing their jobs.

2. Workers are less skilled.

   The result of the selected improving parameter is reliability (27) with a worsening parameter, namely loss of time (25). Based on this selection, a technical contradiction model is generated, namely "If a technical training for workers provided and a draft employee performance assessment report is made, it can improve employee skills in doing their work, but with these actions it can cause wasted time in the production process because of the need for worker training during working hours". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 10, 30, 4. An improvement solution was chosen with the preliminary action (10) principle because it was deemed appropriate and feasible to be used as a proposed improvement of the problems that occurred. The purpose of the preliminary action (10) principle is to take action or preparation before a serious problem occurs in order to minimize the impact that will be caused.

   Based on these problems, the researcher provides an improvement solution, namely provide technical training to workers and making a draft employee performance appraisal report so that it can improve the ability or skills of employees in doing their work.

3. Workers are not focused in doing the work.

   In this contradiction, the improving parameter chosen is strength (14) with the worsening parameter is loss of energy (22). Based on this selection, the resulting technical contradiction model is "If a visual control is made related to a warning to stay focused, it can increase worker concentration, but with this action it means that the operator will spend more energy in completing his work and the company needs to spend more on making the visual control". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 35. The purpose of the principle of parameter changes (35) is to make changes to the parameters in improving the performance of a problem faced.

Based on these problems, researchers provide an improvement solution, namely making visual controls that contain warnings for workers to stay focused on doing their work so as to improve work performance.

4. The dimensions of the bottle cap are not in accordance with the specifications.

   In this contradiction, the improving parameter is selected, namely accuracy of manufacturing (29) and for the worsening parameter, namely stress/pressure (11). Based on this selection, the resulting technical contradiction model is "If supervision is carried out on the process of checking and maintaining material quality, manufacturing accuracy can be maintained properly so as to minimize the occurrence of deviations in the product, but this action will cause stress or pressure on workers". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 3, 35. Selected improvement solutions with the principle of parameter changes (35) because it is considered appropriate and feasible to be used as a proposed improvement of the problems that occur. The purpose of the principle of parameter changes (35) is to make changes to the parameters in improving the performance of a problem encountered.

   Based on these problems, researchers provide an improvement solution, namely supervising the process of checking and maintaining the quality of materials so as to increase the accuracy of workers which can also increase manufacturing accuracy.

5. There is no detailed work instruction.

   The result of the selected improving parameter is ease of operation (33) with a worsening parameter, namely adaptability/versatility (35). Based on this selection, a technical contradiction model is produced, namely "If work instructions are made, it will make it easier for workers to do their jobs, but making work instructions requires workers to adapt to the work instructions". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 15, 34, 1, 16. An alternative with the dynamization (15) principle was chosen because it was deemed appropriate and feasible to be used as a proposal for improvement of the problems that occurred. The purpose of the dynamization (15) principle is to make changes to the dynamics and workflow in a particular system or process.

Based on these problems, researchers provide suggestions for improvement, namely making detailed work instructions as a guide for workers so that workers are more directed in doing their work.

6. Inappropriate machine settings.

   The result of the selected improving parameter is measurement precision (29) with the worsening parameter is loss of time (25). Based on this selection, a technical contradiction model is generated, namely "If a guide is copied based on the optimal machine settings is carried out, it can minimize the occurrence of measurement errors in the machine settings, but taking these actions can cause wasted production time due to temporary production stops and machine checks". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 32, 26, 28, 18. The alternative with the copying (26) principle was chosen because it was considered appropriate and feasible to be used as a proposal for improvement of the problems that occurred. The purpose of the copying (26) principle is to adopt or copy a concept or element in dealing with a problem.

   Based on these problems, researchers provide suggestions for improvement, namely making copies of the guidelines based on the optimized machine setting.

7. The function of the bottle capping machine is not optimal.

   For the cause of the non-optimal bottle capping machine, the improving parameter of ease of repair (34) and the worsening parameter of loss of energy (22) were selected. Based on this selection, a technical contradiction model was generated, namely "If create a report of downtime recap is carried out and do checking and maintaining the machine regularly, it will find out how often and how long machines experience problems and cause the machine function to work optimally so as to reduce the number of product defects, but by taking these actions, workers must do additional work which requires more energy". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 15, 1, 32, 19. An alternative with the principle of periodic action (19) was chosen because it was deemed appropriate and feasible to be used as a proposal for improvement of the problems that occurred. The purpose of the periodic action (19) principle is to take action periodically or repeatedly.

Based on these problems, researchers provide suggestions for improvement, namely taking periodic action, namely by making a report of downtime recap and do checking and maintaining machines regularly.

8. Lack of cleanliness of material warehouse.

   The result of the selected improving parameter is ease of manufacture (32) with the worsening parameter is loss of energy (22). Based on this selection, a technical contradiction model is generated, namely "if conduct regular inventory monitoring and making a checklist form for warehouse cleanliness inspections is carried out, it can ensure the stock of materials is under control to avoid the accumulation of unnecessary item that cause the dirt, which can increase efficiency and effectiveness in the production process and minimize errors in the manufacturing process, but with these actions workers must do additional work which means they need more energy in the process". The resulting inventive principle based on the meeting between improving parameters and worsening parameters is 19, 35. An alternative with the principle of periodic action (19) was chosen because it was deemed appropriate and feasible to be used as a proposal for improvement of the problems that occurred. The purpose of the periodic action (19) principle is to take action periodically or repeatedly.

   Based on these problems, researchers provide suggestions for improvement, namely conduct regular inventory monitoring and making a checklist form in inspecting warehouse cleanliness.

9. The production room is not exposed to CCTV surveillance.

   The result of the selected improving parameter is reliability (27) with a worsening parameter, namely loss of energy (22). Based on this selection, the resulting technical contradiction model is "if CCTV is installed in the production room, it will make it easier for the company to monitor the production process, but this action can cause an increase in electrical power consumption due to the operation of the CCTV system". The cross between improving parameters and worsening parameters results in all inventive principles. Based on table 2.8 regarding 40 inventive principles of TRIZ, the researcher chose the intermediary principle (24) as a proposed improvement. The purpose of the intermediary principle (24) is to use additional elements or objects in a system.

Based on these problems, researchers provide suggestions for improvement, namely installing CCTV in the production room to make it easier for companies to monitor the production process.

### *5.4.2 Fuzzy multi-criteria decision making (FMCDM)*

After getting an improvement proposal based on the inventive principle of TRIZ, the next step is to determine the best alternative. In determining this decision, the fuzzy mamdani method is used with the help of MATLAB software.

In general, mitigation can be interpreted as prevention which includes strategies to overcome the problems being faced and prevent risks that may occur. In this study, there are 9 risks that cause product defects in 600ml bottled drinking water which are the top priority for immediate action. To overcome a risk, risk mitigation is required. Based on Table 4.13, there are 12 preventive actions that can be taken by the company in an effort to minimize product defects in 600ml bottled drinking water.

In implementing the mitigation strategy, there are several variables that influence the company in implementing the strategy. Based on Mustikarini (2014), human resources, technical, and cost factors can be used in making prioritized decisions related to product defect repair proposals in accordance with company conditions. The following are the factors that the company considers in taking mitigation actions:

1. Human Resource Capability

   Human resources play a very important role in risk management. Human resource factors include the ability to master science and technology, the skills possessed by workers, the experience of workers, and employee loyalty to the company. In general, there are two roles of human resources in risk management. First, humans as a source of risk such as human error or negligence in doing their work. Second, the skills possessed in overcoming a problem encountered. Human resource skills are very influential in taking mitigation actions. Skilled human resources make it possible to take preventive action to reduce potential company losses.

2. Technical Capability

   Technical factors include the facilities and infrastructure that support the company and refer to knowledge and skills that involve technological aspects or specialized expertise. Technical skills enable human resources to perform more accurate and specific risk analysis. Risk management often involves the use of technology so that individuals with technical skills can implement mitigation actions appropriately.

3. Cost Capability

   Cost factors include capital and costs incurred by the company in carrying out quality control. There are three crucial costs at PT Narmada Awet Muda, namely production costs, manufacturing costs, and allocation costs. Production costs are costs incurred in the production of a product. Production costs include risk management costs that will be used when a problem occurs and requires these costs.

The three criteria are used as considerations in taking mitigation actions. Based on table 4.18, the following are the prioritized mitigation strategies that can be used as the best repair solution based on the ranking of the fuzzy matching degree from highest to lowest.

1. Create a report of downtime data.

   The mitigation action with the highest rank is to create a report of downtime data with a degree match value of 4,47. The report of downtime data is used to find out how often and how long machines experience problems so the company can identify the problem patterns. The function of this mitigation action is to enable the company to carry out routine maintenance planning more effectively, so as to reduce the risk of unexpected downtime. In addition, this action also aims to prevent the occurrence of greater repair costs caused by more serious machine damage so that the company will not experience large losses.

2. Conducted regular inventory monitoring.

   The second-ranked mitigation action is conducted regular inventory monitoring with a match degree value of 4,47. This mitigation action aims to ensure the stock of raw materials is under control to avoid the accumulation of unnecessary items and cause a lot of dirt. The main purpose of this mitigation action is the maintenance of raw materials so that there are no losses for the company due to dirty raw materials that cannot be used for production.

3. Make a checklist form in warehouse cleanliness inspection.

   The third ranked mitigation action is to create a checklist form in the warehouse cleanliness inspection with a match degree value of 4,47. This mitigation action aims to systematically identify warehouse conditions and ensure compliance with hygiene standards. In addition, this action also aims to assist in reporting findings during warehouse inspections more easily so as to assist management in taking the necessary actions in dealing with these findings.

4. Create a draft employee performance appraisal report.

   The mitigation action with the fourth rank is to draft an employee performance appraisal report with a match degree value of 4,38. This mitigation action aims to assist in evaluating employee performance and measuring employee performance progress over time so that there is no loss to the company caused by the emergence of defective products due to the negligence of workers. In addition, this action also helps the human resource department in identifying employee strengths and weaknesses so that it can consider employee development. It can also help in making decisions such as salary increases and rewards.

5. Provide technical skills training to workers.

   The mitigation action with the fifth rank is to provide technical training to workers with a match degree value of 4,38. This mitigation action aims to improve the operational skills, manufacturing skills, and knowledge of employees at work. Therefore, the training carried out is technical skills training. The training is organized by the Human Resources Department in collaboration with external training providers. The training is aimed at employees who work at PT Narmada Awet Muda so that employee skills and competencies can increase and can help reduce errors that may occur due to lack of understanding or employee skills in carrying out their duties. Employee training can be used as a long-term investment that can provide a number of benefits such as increased skills, productivity, employee loyalty, and the quality of products produced.

6. Make a copy of the manual based on the optimized machine settings.

   The seventh-ranked mitigation action is to make a copy of the manual based on the optimized machine settings with a degree match value of 4,28. The purpose of this action is to ensure that the machine operates consistently according to predetermined parameters and to assist operators in reducing the risk of errors in operating the machine. In addition, using optimal settings can reduce wear and tear on the machine, which can help the company reduce repair costs.

7. Create a visual control containing a warning to stay focused at work.

   The mitigation action with the eighth rank is to create a visual control containing a warning to stay focused at work with a degree of suitability value of 4,13. The purpose of this action is to increase productivity so that workers can work more effectively and efficiently and prevent accidents in the workplace. In addition, worker focus affects product quality so this action can help maintain product quality.

8. Conduct strict supervision to workers.

   The mitigation action with the ninth rank is to conduct strict supervision of workers with a match degree value of 4. The purpose of this action is to increase worker productivity and ensure the quality of products produced in accordance with company standards.

9. Checking and maintaining the machine regularly.

   The mitigation action with the eleventh rank is to check and maintain the machine regularly with a match degree value of 3,58. The purpose of this mitigation action is to prevent the risk of sudden damage to the machine and cause product defects. In addition, this action is also very influential so that the machine can have a longer service life. So, with this action it can help the company in controlling long-term costs such as reducing the cost of repairing and replacing machines that must be issued.

10. Supervise the process of checking and maintaining material quality.

    The twelfth-ranked mitigation action is to conduct regular machine checks and maintenance with a degree match value of 3,58. The main purpose of this action is to ensure that the materials used are of good quality so that the products produced have a high level of quality. This supervision is carried out to assist in identifying materials that are defective or not in accordance with standard provisions that cause financial and reputational losses to the company.

11. Create detailed work instructions.

    The thirteenth ranked mitigation action is to create detailed work instructions with a degree match value of 3,42. The purpose of this action is to assist in standardizing operations during production activities. The existence of detailed work instructions can reduce the risk of errors caused by workers. In addition, work instructions also help in controlling product quality in accordance with the predetermined quality standards.

12. Installing CCTV in the production room.

    The mitigation action with the last rank is to install CCTV in the production room with a match degree value of 3. The purpose of this action is to supervise during production activities in real time. CCTV monitoring can assist the company in monitoring the quality of products produced so that if a product defect is detected, management can take action quickly.

# CHAPTER VI
# CONCLUSION

## 6.1 Conclusion

Based on data collection, data processing, and data analysis that has been carried out, the conclusions that can be drawn from this research are as follows:

1. Based on the results of the calculation of the DPMO value and the sigma value during the period November – December 2022 at the measure step, the average DPMO value is 8.621,3 and the average sigma value is 3,94. Based on the sigma value, it can be seen that PT Narmada Awet Muda is above the industry average in Indonesia and shows that the company has a relatively good quality level. If PT Narmada Awet Muda continues to make improvements to minimize product defects, then the average sigma value can increase. However, the company still has defects in some of its processes. Nevertheless, the company still has the opportunity to improve the process so that the company can achieve a higher sigma level so as to reduce the problems experienced.
2. Based on the results of identification and analysis at the analyze stage using bar chart, fishbone diagrams, and FMEA, it can be seen that the most dominant type of defect that causes product defects is bottle cap defects. Meanwhile, the most potential factor that affects the occurrence of product defects is the function of the bottle capping machine is not optimal during the production process.
3. Mitigation actions were generated based on the inventive principle of TRIZ. There are 12 mitigation actions obtained. In determining the priority of mitigation actions, it is processed with fuzzy logic by calculating the degree of compatibility of each criterion in the form of human resource capabilities, technical capabilities, and cost capabilities. Based on the calculation of matching degree fuzzy, the proposed improvement solutions in minimizing product defects in 600ml bottled drinking water with the highest priority actions are create a report of downtime data (A1), conduct regular inventory monitoring (A7), make a checklist form in warehouse cleanliness inspection (A8), create a draft employee performance appraisal report (A4), provide technical training to workers (A6), and the rest are also still included in the priority category to be mitigated as soon as possible.

### 6.2 Recommendation

Based on the results of the study, the suggestions that can be recommended by researchers are as follows:

1. For Company

   Suggestions that can be given to PT. Narmada Awet Muda are to carry out regular quality control and make improvements by caring more about the risks that may occur in the company starting from periodically identifying risks, making risk lists, and determining the proper handling methods to minimize defective products that occur.

2. For Further Research

   Suggestions that can be given to further research are to involve more workers to get more causes of product defects from various different perspectives and can also conduct research related to quality control as a whole to the control step.

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# APPENDIX

## A- FMEA Questionnaire

### KUESIONER FMEA

Kuesioner ini digunakan dalam mengidentifikasi terkait kerusakan produk yang terjadi pada jenis **cacat tutup botol** yang paling potensial berdasarkan penyebab dan efek guna mendapatkan nilai *Risk Priority Number* (RPN) berdasarkan beberapa kriteria pada setiap komponen, antara lain:

a. *Severity* : Tingkat keparahan terhadap kegagalan yang terjadi.
b. *Occurrence* : Tingkat frekuensi yang menyebabkan terjadinya kegagalan.
c. *Detection* : Tingkat pendeteksian/pengontrolan penyebab terjadinya kegagalan.

**Petunjuk Pengisian**

Jawaban merupakan persepsi Bapak/Ibu terhadap faktor risiko yang terjadi dengan memberikan skala penilaian angka dengan rentang 1-10 pada masing-masing kolom *Severity* (S), *Occurrence* (O), dan *Detection* (D) berdasarkan keterangan terkait kriteria penilaian yang dijelaskan dibawah. Atas kerjasama Bapak/Ibu dalam mengisi kuesioner ini, saya ucapkan terima kasih.

**Keterangan**

1. Nilai *Severity*

   *Severity* merupakan langkah pertama untuk menganalisa risiko, yaitu menghitung seberapa besar dampak atau intensitas kejadian memengaruhi hasil akhir proses. Dampak tersebut di rating mulai skala 1-10, dimana 10 merupakan dampak terburuk. Adapun penentuan nilai *severity* dapat dilihat pada table dibawah ini:

Tabel 1. Rating dan Kriteria *Severity*

| Rating | Kriteria |
|---|---|
| 1 | Neglible severity (pengaruh buruk yang dapat diabaikan). Kegagalan tidak berdampak pada kinerja produk. Konsumen mungkin tidak akan memperhatikan kecacatan ini. |
| 2<br>3 | Mild severity (pengaruh buruk yang ringan). Akibat yang ditimbulkan hanya bersifat ringan. Konsumen tidak akan merasakan perubahan kinerja produk. Perbaikan dapat dikerjakan pada saat pemeliharaan regular. |
| 4<br>5<br>6 | Moderate severity (pengaruh buruk yang sedang). Konsumen akan merasakan penurunan kinerja namun masih dalam batas toleransi. Perbaikan yang dilakukan tidak memakan biaya yang mahal dan dapat selesai dalam waktu singkat. |
| 7<br>8 | High severity (pengaruh buruk yang tinggi). Konsumen akan merasakan penurunan kinjerja produk yang tidak bisa diterima dan berada diluar batas toleransi. Perbaikan yang dilakukan memerlukan biaya yang sangat mahal. |
| 9<br>10 | Potential safety problems (masalah keamanan potensial). Akibat yang ditimbulkan sangat berbahaya dan berpengaruh terhadap keselamatan konsumen. Kondisi ini bertentangan dengan hukum. |

# A- FMEA Questionnaire (Continued)

2. Nilai *Occurrence*

*Occurrence* merupakan kemungkinan bahwa penyebab kegagalan akan terjadi dan menghasilkan bentuk kegagalan selama masa produksi produk. *Occurance* merupakan nilai *rating* yang disesuaikan dengan frekuensi yang diperkirakan dan atau angka kumulatif dari kegagalan yang dapat terjadi. Penentuan nilai *occurrence* dapat dilihat pada table dibawah ini:

Tabel 2. Rating dan Kriteria *Occurence*

| Rating | Probabilitas Kegagalan | Kriteria |
|---|---|---|
| 1 | Remote | 0,01 per 1000 item |
| 2 | Low | 0,1 per 1000 item |
| 3 | | 0,5 per 1000 item |
| 4 | Moderate | 1 per 1000 item |
| 5 | | 2 per 1000 item |
| 6 | | 5 per 1000 item |
| 7 | High | 10 per 1000 item |
| 8 | | 20 per 1000 item |
| 9 | Very High | 50 per 1000 item |
| 10 | | 100 per 1000 item |

3. Nilai *Detection*

*Detection* berfungsi untuk upaya pencegahan terhadap proses produksi dan mengurangi tingkat kegagalan pada proses produksi. Adapun penentuan nilai *detection* dapat dilihat pada table dibawah ini:

Tabel 3. Rating dan Kriteria *Detection*

| Rating | Kemungkinan Deteksi | Frekuensi Kejadian |
|---|---|---|
| 1 | Kegagalan dalam proses tidak dapat terjadi karena telah dicegah melalui desain solusi | 0,01 per 1000 item |
| 2 | Kemungkinan pengontrol untuk mendeteksi kegagalan sangat tinggi | 0,1 per 1000 item |
| 3 | Kemungkinan pengontrol untuk mendeteksi kegagalan tinggi | 0,5 per 1000 item |
| 4 | Kemungkinan pengontrol untuk mendeteksi kegagalan agak tinggi | 1 per 1000 item |
| 5 | Kemungkinan pengontrol untuk mendeteksi kegagalan sedang | 2 per 1000 item |
| 6 | Kemungkinan pengontrol untuk mendeteksai kegagalan rendah | 5 per 1000 item |
| 7 | Kemungkinan pengontrol untuk mendeteksai kegagalan sangat rendah | 10 per 1000 item |
| 8 | Jarang kemungkinan pengontrol akan menemukan potensi kegagalan | 20 per 1000 item |

# A- FMEA Questionnaire (Continued)

| Rating | Kemungkinan Deteksi | Frekuensi Kejadian |
|---|---|---|
| 9 | Sangat jauh kemungkinan pengontrol akan menemukan potensi kegagalan | 50 per 1000 item |
| 10 | Pengontrol tidak dapat mendeteksi kegagalan | 100 per 1000 item |

**TABEL PENILAIAN**

| Potential Failure Mode | Potential Failure Effect | S | Potential Causes | O | Current Process Controls | D | RPN |
|---|---|---|---|---|---|---|---|
| Cacat Tutup Botol | Proses produksi tidak berjalan dengan efektif maupun efisien sehingga terjadi banyaknya defect pada tutup botol. | | **Manusia:** | | | | |
| | | | Pekerja lalai dalam melakukan pekerjaan. | | Melakukan briefing berupa evaluasi mingguan kepada para pekerja sebelum melakukan pekerjaan. | | |
| | | | Pekerja kurang terampil. | | Menempatkan karyawan yang kurang terampil bersama karyawan yang sudah lama bekerja. | | |
| | | | Pekerja tidak fokus dalam melakukan pekerjaan. | | Pemantauan langsung terhadap pekerjaan karyawan oleh supervisor. | | |
| | Material yang tidak sesuai tidak dapat diproses sehingga banyak waktu serta biaya yang terbuang. | | **Material:** | | | | |
| | | | Dimensi tutup botol tidak sesuai dengan spesifikasi. | | Memberikan contoh produk tutup botol yang baik dan | | |

# A- FMEA Questionnaire (Continued)

| Potential Failure Mode | Potential Failure Effect | S | Potential Causes | O | Current Process Controls | D | RPN |
|---|---|---|---|---|---|---|---|
| | | | | | yang tidak layak pakai dan menghubungi pemasok | | |
| | Tidak adanya mekanisme kerja menyebabkan pekerja kesulitan untuk memahami prosedur kerja. | | **Metode:** | | | | |
| | | | Tidak ada instruksi kerja yang terperinci | | Menginformasikan instruksi kerja kepada pekerja secara verbal. | | |
| | Mesin harus diberhentikan sehingga terdapat *opportunity loss*. Jika mesin dipaksa untuk produksi maka akan menimbulkan banyak produk defect. | | **Mesin:** | | | | |
| | | | Pengaturan mesin yang tidak tepat. | | Kontrol setiap mesin sebelum proses produksi dilakukan. | | |
| | | | Fungsi mesin *bottle capping* tidak optimal | | Membuat checksheet jadwal perawatan mesin. | | |
| | Terdapat beberapa bahan baku yang kotor. Selain itu, pengawas tidak dapat memonitor kegiatan | | **Lingkungan:** | | | | |
| | | | Kurangnya kebersihan gudang material | | Membuat jadwal pembersihan dan melakukan pembersihan gudang secara berkala | | |
| | produksi secara berkala dari jarak jauh. | | Ruang produksi tidak terpapar pengawasan CCTV | | Melakukan pengawasan proses produksi secara langsung oleh supervisor di lantai produksi. | | |

## B- Fuzzy Match Degree Questionnaire

### KUESIONER DERAJAT KECOCOKAN FUZZY

Kuesioner ini digunakan dalam mengidentifikasi terkait **tingkat kecocokan suatu kriteria terhadap masing-masing tindakan mitigasi** yang akan digunakan dalam pemilihan solusi perbaikan yang dapat diterapkan dalam meminimalisir jumlah produk cacat. Berikut merupakan kriteria yang digunakan pada penilaian ini:

Tabel 1. Kriteria Penilaian

| Kriteria | Keterangan |
|---|---|
| $C_1$ | Kemampuan Sumber Daya Manusia |
| $C_2$ | Kemampuan Teknis |
| $C_3$ | Kemampuan Biaya |

- **Penilaian Kecocokan Suatu Kriteria Terhadap Alternatif**

Dalam upaya meminimalisir produk cacat, terdapat beberapa tindakan mitigasi yang diusulkan oleh peneliti. Adapun tindakan mitigasi tersebut yaitu sebagai berikut:

Tabel 2. Alternatif Perbaikan

| Alternatif | Tindakan Mitigasi |
|---|---|
| $A_1$ | Membuat laporan rekap data downtime. |
| $A_2$ | Memeriksa dan merawat mesin secara teratur. |
| $A_3$ | Membuat instruksi kerja yang terperinci. |
| $A_4$ | Membuat draft laporan penilaian kinerja karyawan. |
| $A_5$ | Melakukan pengawasan yang ketat terhadap pekerja. |
| $A_6$ | Memberikan pelatihan teknis kepada pekerja. |
| $A_7$ | Melakukan pemantauan inventaris secara berkala. |
| $A_8$ | Membuat *checksheet* dalam pemeriksaan kebersihan gudang. |
| $A_9$ | Membuat salinan panduan berdasarkan pengaturan mesin yang optimal dan menyimpannya ke dalam dokumen. |
| $A_{10}$ | Mengawasi proses pengecekan material dan menjaga kualitas material. |
| $A_{11}$ | Memasang CCTV di ruang produksi. |

# B- Fuzzy Match Degree Questionnaire (Continued)

| Alternatif | Tindakan Mitigasi |
|---|---|
| $A_{12}$ | Membuat kontrol visual yang berisi peringatan untuk tetap fokus dalam bekerja. |

Penilaian kecocokan suatu kriteria terhadap tindakan mitigasi dilakukan dengan mengisikan table penilaian berdasarkan beberapa kategori, yaitu sebagai berikut:

Tabel 3. Kategori Kecocokan Kriteria Terhadap Alternatif

| Parameter | Range | Information |
|---|---|---|
| Sangat Rendah | $x \leq 1$ | Kemampuan sumber daya manusia, teknis, dan biaya yang dimiliki perusahaan sangat rendah dalam melakukan aksi mitigasi. |
| Rendah | $2 \leq x < 3$ | Kemampuan sumber daya manusia, teknis, dan biaya yang dimiliki perusahaan rendah dalam melakukan aksi mitigasi. |
| Sedang | $3 \leq x < 4$ | Kemampuan sumber daya manusia, teknis, dan biaya yang dimiliki perusahaan sedang atau cukup dalam melakukan aksi mitigasi. |
| Tinggi | $3 < x < 5$ | Kemampuan sumber daya manusia, teknis, dan biaya yang dimiliki perusahaan tinggi dalam melakukan aksi mitigasi. |
| Sangat Tinggi | $x \geq 5$ | Kemampuan sumber daya manusia, teknis, dan biaya yang dimiliki perusahaan sangat tinggi dalam melakukan aksi mitigasi. |

**Petunjuk Pengisian**

Jawaban merupakan persepsi Bapak/Ibu terkait bobot kecocokan suatu kriteria terhadap setiap tindakan mitigasi dengan memberikan penilaian berdasarkan keterangan pada setiap table diatas. Atas kerjasama Bapak/Ibu dalam mengisi kuesioner ini, saya ucapkan terima kasih.

## B- Fuzzy Match Degree Questionnaire Questionnaire (Continued)

**TABEL PENILAIAN**

| Rating Kecocokan | | | | |
|---|---|---|---|---|
| **Kode** | **Tindakan Mitigasi** | **Kemampuan Sumber Daya Manusia ($C_1$)** | **Kemampuan Teknis ($C_2$)** | **Kemampuan Biaya ($C_3$)** |
| **$A_1$** | Membuat laporan rekap data downtime. | | | |
| **$A_2$** | Memeriksa dan merawat mesin secara teratur. | | | |
| **$A_3$** | Membuat instruksi kerja yang terperinci. | | | |
| **$A_4$** | Membuat draft laporan penilaian kinerja karyawan. | | | |
| **$A_5$** | Melakukan pengawasan yang ketat terhadap pekerja. | | | |
| **$A_6$** | Memberikan pelatihan teknis kepada pekerja. | | | |
| **$A_7$** | Melakukan pemantauan inventaris secara berkala. | | | |
| **$A_8$** | Membuat *checksheet* dalam pemeriksaan kebersihan gudang. | | | |
| **$A_9$** | Membuat salinan panduan berdasarkan pengaturan mesin yang optimal dan menyimpannya ke dalam dokumen. | | | |
| **$A_{10}$** | Mengawasi proses pengecekan material dan menjaga kualitas material. | | | |

## B- Fuzzy Match Degree Questionnaire Questionnaire (Continued)

| Rating Kecocokan | | | | |
|---|---|---|---|---|
| **Kode** | **Tindakan Mitigasi** | **Kemampuan Sumber Daya Manusia ($C_1$)** | **Kemampuan Teknis ($C_2$)** | **Kemampuan Biaya ($C_3$)** |
| **$A_{11}$** | Memasang CCTV di ruang produksi. | | | |
| **$A_{12}$** | Membuat kontrol visual yang berisi peringatan untuk tetap fokus dalam bekerja. | | | |

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