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PURPOSE AND SCOPE

Jurnal Sains dan Aplikasi Keilmuan Teknik Industri (SAKTI) is the official publication of the Industrial Engineering Universitas Ma Chung, with an ISSN of 2829-8519 for print and 2829-8748 for electronic versions. Its logo features water, a gear-shaped sun, and nature, with water symbolizing adaptability and a source of life, the sun representing hope, and nature representing the natural world and its living beings. The journal aims to promote ethical research in industrial engineering and engineering management that is constantly evolving and adaptable, with the goal of benefiting all living things, especially in Indonesia. Within the journal, readers can document their ideas, observations, and experiments related to industrial engineering and sustainable practices. Whether developing new systems or analyzing existing ones, SAKTI aims to be a companion in the pursuit of efficiency, productivity, and environmental responsibility.

SAKTI welcomes submissions on the exploration of theoretical concepts or practical applications associated with the study of ergonomic and human factors, systems design and engineering, logistics and supply chain management, operations research, quality, reliability, and maintenance management, production planning and inventory control, sustainability, facilities engineering, and other relevant subjects.

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Production Quality Control Analysis of Pipe Water Inlet EW010 Using Six Sigma and Failure Mode and Effect Analysis (Case Study: PT Wijaya Karya Industri dan Konstruksi)

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Abstract. PT Wijaya Karya Industri dan Konstruksi has businesses in the fields of Steel, Plastic, Pressing and Casting (PPC) Manufacturing and heavy construction equipment. The PPC factory produces various kinds of manufacturing components, one of which is vehicle spare parts made from metal which are produced using a casting process. One of the products produced using a casting process is Pipe Water Inlet EW010. There are many Pipes Water Inlet EW010 defective products with an average of 52% defective products in July-August 2023. The research was conducted to analyze the sigma value and determine the factors of product defects and the impact of the defects to provide suggestions for product quality improvement. In this research, the method applied is the Six Sigma method and FMEA, by implementing DMAIC (Define, Measure, Analyze, and Control). From this research, the results showed that the most common defects were Leaking, Pen/core, and Porous, namely 89% cumulative. Pipe Water Inlet EW010 products are currently at level 2.44 sigma so corrective action needs to be taken to reach the six-sigma level. By applying the FMEA method, it can be seen that the most significant and most frequently occurring product defects are caused by poor core quality and work method errors. Therefore, the recommended alternative repair solution is to improve the quality of the cores used and improve work methods. The results show an increase in the sigma level value from 2.44 to 2.86 and a decrease in average defects from 52% to 23%.

Keywords: Failure mode and effect analysis; Pipe water inlet EW010; Root cause analysis; Six sigma

1. Introduction

The manufacturing industry in Indonesia currently plays an important role in the era of infrastructure development and progress in Indonesia. This gives rise to various kinds of competition in business activities between manufacturing companies which are increasingly creative and generate greater profits.

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The production process is important for a company, because it is the process that can process a product so that it is ready to be marketed. Quality is something that must be paid attention to and is an important aspect for the progress of a company (Masdalifah, 2019). Quality control systems are currently designed and implemented in various industries to anticipate increasing competitive pressures and can reduce quality costs resulting from product nonconformities. The aim of quality control in an industry is to produce consistent products, increase profits and reduce product repair costs by identifying factors that cause defects in products (Ishikawa, 1990). Defective products are products that do not meet specifications or do not reach the specified quality standards so they cannot be reworked (Alfarizi et al., 2023; Andriana et al., 2016; Puspitaloka & Ekawati, 2022). Companies whose main strategy is quality gain competitive advantage in business, because not all companies are able to achieve and maintain high and consistent quality. In this case the company must produce high quality products at prices that can compete with similar companies. One of the objectives of quality control in a company is to reduce the number of defective products so that production costs are not too high and do not disappoint consumers.

Plastic, Pressing and Casting (PPC) factory produces various kinds of manufacturing components, one of which is vehicle spare parts components made from metal which are produced using a casting process. Casting process is the process of making objects by melting metal and pouring it into the mold cavity (Sudjana, 2008). One of the products produced using a casting process by the PPC Factory for use by PT HINO is Pipe Water Inlet EW010. Pipe Water Inlet EW010 product can be seen in Figure 1.

Figure 1 Pipe Water Inlet EW010

In the manufacture of Pipe Water Inlet EW010, defective products were still found, so the company suffered losses due to wasted time and costs, because time that should have been used in the production process was wasted to repair defective products, and it was difficult to achieve the predetermined production targets. The defects in question are defects found in foundry production products, such as leaks, pen/core, porous, cracked, and inappropriate visual shapes.

The maximum average reject standard for Pipe Water Inlet EW010 products set by the PT WIKON PPC factory is 8%. From January 2023 to June 2023, the PT WIKON PPC Factory produces Pipe Water Inlet EW010 with the following reject data:

Table 1 Reject Data on Pipe Water Inlet EW010 Products

No	Month	Number of Goods Production (Pcs)	Number of Reject Items (Pcs)	Total Production Results	Reject Percentage (%)
1	Januari	2007	130	1877	6.48%
2	Februari	2591	163	2428	6.29%
3	Maret	2653	256	2397	9.65%
4	April	2169	253	1916	11.66%
5	Mei	2206	156	2050	7.07%
6	Juni	2095	228	1867	10.88%
Total		13721	1186	12535	8.65%

The reject referred to in the table above is the Pipe Water Inlet EW010 product which has serious defects and cannot be repaired, so the product cannot be distributed to customers and must be melted down again for re-production. The defect factor in the Pipe Water Inlet EW010 product is caused by various aspects, such as mold design, raw material composition, casting method, and factory environment. The casting unit at the PPC factory produces defective products which are quite high causing high costs for repairs. Product quality checks are carried out by the Quality Control (QA/QC) management department through manual product testing. The high number of defective products in the Pipe Water Inlet EW010 product, of course, can be detrimental to the company, therefore the researchers made observations at the PPC factory of PT Wijaya Karya Industri and Construction using the Failure Mode and Effect Analysis (FMEA) method to identify any potential causes defects in products by looking at the Severity, Occurrence and Detection levels to be able to reduce and find alternative ways for the company. Failure Mode and Effects Analysis (FMEA) is a method used to analyze the occurrence of risks or failures in a process and can be applied in various types of manufacturing industries (Susanti, 2015). The DMAIC Six Sigma method is used to help make improvements to the production process so that companies can make improvements to any existing problems (Saputro et al., 2016). To find the root cause of existing problems, the help of Root Cause Analysis (RCA) is needed. Root cause analysis (RCA) is a method for identifying the root causes of functional and operational problems (Jucan, 2005).

2. Method

The flowchart of the steps to address the issue in this study can be seen in Figure 2.

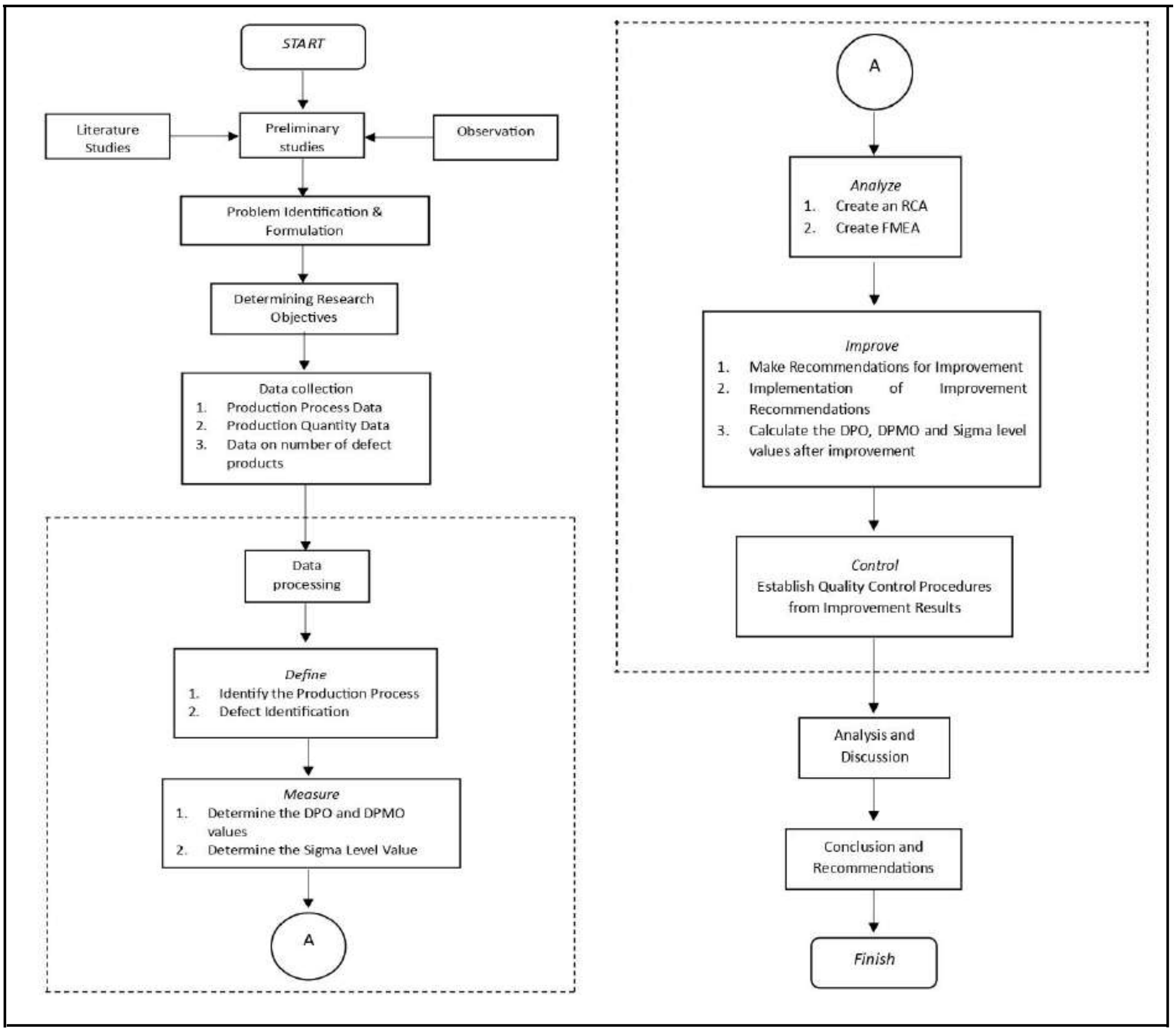


Figure 2 Flowchart

The following are the research stages conducted using the Six Sigma and FMEA methods: The first step is to conduct direct field observations and literature studies. Observations were conduct directly at the Plastic, Pressing and Casting (PPC) Factory Casting unit of PT Wijaya Karya Industri and Construction. Observations were carried out on defects in the Pipe Water Inlet EW010 product, by directly observing the production process starting from the melting of material to the finishing process. After the problem is found, the next step is to determine the topic of the problem that will be researched through literature study. The aim of the literature study is to obtain sources that can support problem solving in a production process. The types of literature used in this research include journals and books regarding Quality Control, Six Sigma, FMEA, RCA and supporting documents from companies.

The next step is collecting data. In this research, the data used is primary data and secondary data. The primary data required for this research is defect data for Pipe Water Inlet EW010 product and data for complete risk analysis, such as data on effects and causes of failure and indicator values from FMEA. This data was obtained by collecting information and conducting interviews with the head of the production engineering department, head of the QA/QC department, and field operators. Secondary data is data that indirectly provides information to researchers through interviews and company documents. The secondary data needed in this research is data on production quantities and the number of defects in Pipe Water Inlet EW010 product and existing FMEA analysis data.

After collecting data, the next step is data processing using the Six Sigma method. The purpose of data processing is to provide solutions and resolve a problem that is a research topic. The implementation of Six Sigma follows the DMAIC cycle (Define, Measure, Analyze, Improve, Control), where these steps are repeated steps or form a quality improvement cycle using the six-sigma methodology.

The defining stage is the first step in the DMAIC Six Sigma cycle, namely identifying the product manufacturing process by determining the SIPOC (Supplier-Input-Process-Output-Customer). After identifying the product manufacturing process described through SIPOC tables and diagrams, the next step is to identify what types of defects are found in the Pipe Water Inlet EW010 product. The second step in the DMAIC cycle is the measure stage, namely calculating process capability. After the process capability results are known, process identification is carried out using a control chart. Then proceed with the calculation of DPO (Defect per Opportunity), DPMO (Defect per Million Opportunities) and sigma level to determine product quality in a production process. The third step in the DMAIC cycle is the analysis stage, namely the phase where researchers try to find out the reasons for a failure. The analysis stage is the stage where the cause of the error is identified. Tools that can be used at this analysis stage are Root Cause Analysis (RCA) and FMEA. This tool is used to explain what factors can cause problems, such as: humans, machines, materials, methods and the environment. To find out the type of defect that has the most impact, you can use the Failure Mode Effect Analysis method, to see the RPN value. So, you can see the impact of failures that occur. The fourth step in the DMAIC cycle is Improvement, namely in this phase measurements and recommendations for improvements are made to product defects found in production results. In this phase, post-repair DPMO and Sigma Level calculations are carried out to see the production quality of the proposed improvements made. The final step in the DMAIC cycle is the control stage. This stage aims to evaluate and monitor the results of improving quality. The results of quality improvement are documented and provided to the company which is useful as a corrective action for future process implementation.

Finally, the researcher needs to conclude the research findings and provide Recommendations. The conclusion will provide the final answers to the analyzed problems according to the problem statement in the introduction. Recommendations will contain suggestions for improvements to be implemented or maintained.

3. Results and Discussion

The process of making the Pipe Water Inlet EW010 using the casting method consists of several stages as in figure 3.

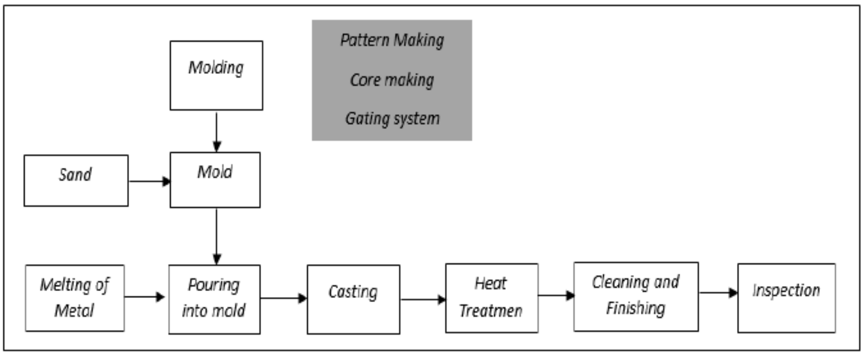


Figure 3 Casting Process Flowchart

The first step in making the Pipe Water Inlet EW010 is making mold. There are two types of molds used for the Pipe Water Inlet EW010 casting process, namely Expendable Mold and Permanent Mold. Expandable mold is a mold that can only be used once during the casting process. The Pipe Water Inlet EW010 has a complex product shape and dimensions, so the manufacturing process requires the help of an additional mold, namely a sand core mold. Sand core is very helpful in the process of making metal products with complex shapes and small dimensions. The PT Wijaya Karya Industri and Construction PPC factory has 7 sand blowing machines for making sand cores. The following is a picture of the sand core making process and casting process as shown in figure 4.

a b c

Figure 4 a. Sand Core Making Process, b. Melting of Metal, c. Casting Process

Permanent Mold is mold used for the metal casting process and can be used repeatedly. In the process of making the Pipe Water Inlet EW010, liquid metal is poured into a permanent mold along with a sand core and flows using gravity to form the desired product, this process is called gravity casting.

The next process in making Pipe Water Inlet EW010 products is melting material. Melting of metal is the initial process in the metal casting process. The material used for the process of making the Pipe Water Inlet EW010 is AC2B, which is a combination of aluminum and silicon. Smelting of AC2B material is generally carried out in an induction melting furnace with a temperature of 650 °C – 900 °C. The material melting process is generally carried out at the same time as the sand core making process. After the material is melted, the melted material is then taken to the holding furnace using a transfer leader to be stored so that the temperature of the molten metal is maintained before the molten metal enters the next process, namely the casting process. After the metal is melted and the mold is ready to be used, the next process is that the liquid material in the holding furnace is poured into the mold with a liquid metal temperature of around 800°C. This process is known as pouring into mold. The pouring speed needs to be paid attention to in order to maintain the temperature and fluidity of the molten metal so that premature cooling (cold shuts) does not occur. The standard pouring time set by the PPC factory is 4-6 seconds. Fourth is the casting process. The liquid metal that has been poured into the mold is then left for several minutes in the machine, generally for 4-5 minutes until solidification occurs. This process is called the casting process. The casting process used to make the Pipe Water Inlet

EW010 is gravity casting, which is a casting process using the help of gravity. After hardening, the cast metal is removed from the mold and then left for some time before the next process is carried out. The gravity casting machine and process can be seen in figure 7. Fifth is heat treatment. Casting products generally do not have hardness that meets standards, so additional processes are needed, namely heat treatment. Heat treatment is a process that uses controlled heating and cooling to modify the structure of a metal. The use of heating or cooling is usually at extreme temperatures to achieve the desired hardening results

The Pipe Water Inlet EW010 castings do not yet have a perfect visual shape, so a cleaning and finishing process needs to be carried out to improve the quality and visual refinement of the product so that it matches the initial design plan. The cleaning process for the Pipe Water Inlet EW010 product includes several stages, namely the process of dismantling the sand core using a bobok drill, cutting off parts that are not needed using a chainsaw, then to get a product that looks clean and neat, the cleaning process is carried out using sand blasting, a grinder and a rotary machine. The final stage is the inspection stage. The final stage of the production process for making the Pipe Water Inlet EW010 is the inspection stage which consists of checking the quality of the castings, measuring dimensions, visual checks, and so on. The purpose of the inspection process is to determine the quality of the cast product and to ensure whether the cast product is suitable for use or not. If a cast product is found to be defective and unfit for use, the cast product will be repaired or re-melted for re-production.

Production data and Pipe Water Inlet EW010 defect data were obtained from the QA/QC (Quality Assurance/Quality Control) department of the PT Wijaya Karya Industri and Construction PPC factory. The available data is weekly data for each type of defect. The data that researchers use is production data and inspection results. Meanwhile, in chapter 1 of the introduction, the researcher describes the number of rejects from January to June 2023 and the reject standards set by the company. The reject data is data obtained from improvement results, namely products that have gone through an improvement process. The following is data on the type and number of defects in the Pipe Water Inlet EW010 product on June 26 – August 25 2023.

Table 1 Data of Types and Number of Defects 26 June-25 August 2023

Date (2023)	Production	A	B	C	D	E	F	G	H	I	J	K	Defect	%
26–30 June	301	15	30	4	92	17	2	0	0	0	0	0	160	53
03–07 July	298	0	27	11	84	57	0	12	2	0	0	0	193	65
10–14 July	285	0	38	20	61	27	0	4	2	7	3	0	162	57
17–21 July	365	5	67	1	106	81	0	0	2	4	1	10	277	76
24–28 July	370	0	31	1	92	46	0	0	2	2	0	0	174	47
31July–4 August	274	0	18	3	43	45	0	13	0	1	0	0	123	45
7–11 August	326	1	28	0	84	46	0	21	0	0	0	0	180	55
14–18 August	300	6	33	0	42	51	0	0	0	0	0	0	132	44
21–25 August	355	0	17	7	37	24	0	0	0	0	0	0	85	24
Total	2874	27	289	47	641	394	2	50	8	14	4	10	1486	52%

Explanation of the type of defect

A. Misrun
B. Porous
C. Lenting
D. Leaking

E. Fungal
F. Cracked
G. stamp
H. Short cut
I. Gmpl
J. Deflates

Data processing stages were carried out using the six-sigma method. The steps taken in implementing the six-sigma method are the DMAIC cycle. The DMAIC stage in six sigma consists of Define, Measure, Analyze, Improve, and Control.

Define is the first stage in the DMAIC cycle, this stage includes identifying the product manufacturing process, identifying the main process, determining customer needs and CTQ (Critical to Quality). The following is a Pareto diagram of defect data for the Pipe Water Inlet EW010 product. The diagram shown in figure 11 below is defect data resulting from the production of the Pipe Water Inlet EW010 for 2 months, starting from June 26 to August 25, 2023.

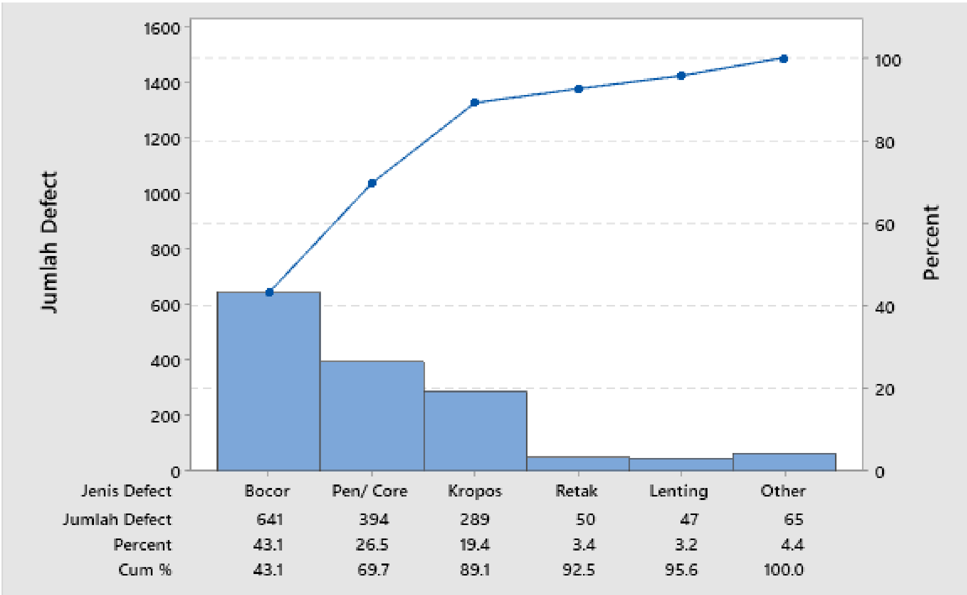


Figure 11 Pareto diagram number of defects 26 June-25 August 2023

From the Pareto diagram above, it is known that there are 3 types of defects that occur most frequently. The types of defects most often found in Pipe Water Inlet EW010 products are leak at 43.1%, pen/core at 26.5%, and porous at 19.4%. Of these three types of defects, they represent 89.1% of the total defects or as many as 1324 defective products found in the Pipe Water Inlet EW010 product contain defects.

The next stage in the DMAIC cycle is the measure stage. At this stage, the Defects Per Million Opportunities (DPMO) value and the sigma level value are calculated. The data calculated is the number of defects in the Pipe Water Inlet EW010 product from 26 June - 25 August 2023. CTQ (critical to quality) in this research is determined based on the type of critical defect in the Pipe Water Inlet EW010 which affects the quality characteristics of the production results. From the research results it can be seen in figure 11, that the response variables which are critical to quality (CTQ) include leaking, porous, and pen/core. To make it easier to analyze table 2 data on the type and number of defects for 26 June-25 August 2023, the author created a table of the percentage of defects per week for the Pipe Water Inlet EW010 product as follows:

Table 3 Percentage of defective products per week

No	Date (2023)	Production	*Defect*	Persentase
1	26 – 30 June	301	160	53%
2	03 – 07 July	298	193	65%

No	Date (2023)	Production	*Defect*	Persentase
3	10 – 14 July	285	162	57%
4	17 – 21 July	365	277	76%
5	24 – 28 July	370	174	47%
6	31 Juli – 4 August	274	123	45%
7	7 – 11 August	326	180	55%
8	14 – 18 August	300	132	44%
9	21 – 25 August	355	85	24%
	Total	2874	1486	52%

The calculation of DPO, DPMO, and Sigma Level on the quality of the Pipe Water Inlet EW010 product is as follows:

I. DPO (Defect per Opportunities):

$$DPO = \frac{Total\ number\ of\ defects}{Number\ of\ units\ \ x\ \ CTQ}$$

$$DPO\ 1 = \frac{160}{301\ x\ 3} = 0.17718715$$

$$DPO\ 2 = \frac{193}{298\ x\ 3} = 0.21588367$$

$$DPO\ 9 = \frac{85}{355\ x\ 3} = 0.07981221$$

II. DPMO calculation

DPMO = DPO x 1000000

DPMO 1 = 0.17718715 x 1000000 = 177187.15

DPMO 2 = 0.21588367 x 1000000 = 215883.67

DPMO 9 = 0.07981221 x 1000000 = 79812.21

III. Level Sigma calculation

$$\text{Level Sigma} = \text{NORMSINV}\left(\frac{1000000 - \text{DPMO}}{1000000}\right) + 1.5 = 2.43$$

$$\text{Level Sigma 1} = \text{NORMSINV}\left(\frac{1000000 - 177187.15}{1000000}\right) + 1.5 = 2.43$$

$$\text{Level Sigma 2} = \text{NORMSINV}\left(\frac{1000000 - 215883.67}{1000000}\right) + 1.5 = 2.29$$

$$\text{Level Sigma 9} = \text{NORMSINV}\left(\frac{1000000 - 79812.21}{1000000}\right) + 1.5 = 2.91$$

Table 4 DPMO and Sigma level value 26 June-25 August 2023

No	Production	Defect	CTQ	DPO	DPMO	Level Sigma
1	301	160	3	0.17718715	177187.15	2.43
2	298	193	3	0.21588367	215883.67	2.29
3	285	162	3	0.18947368	189473.68	2.38
4	365	277	3	0.25296804	252968.04	2.17
5	370	174	3	0.15675676	156756.76	2.51
6	274	123	3	0.14963504	149635.04	2.54
7	326	180	3	0.18404908	184049.08	2.40
8	300	132	3	0.14666667	146666.67	2.55
9	355	85	3	0.07981221	79812.21	2.91
Total	2874	1486	3	0.17249248	172492.48	2.44

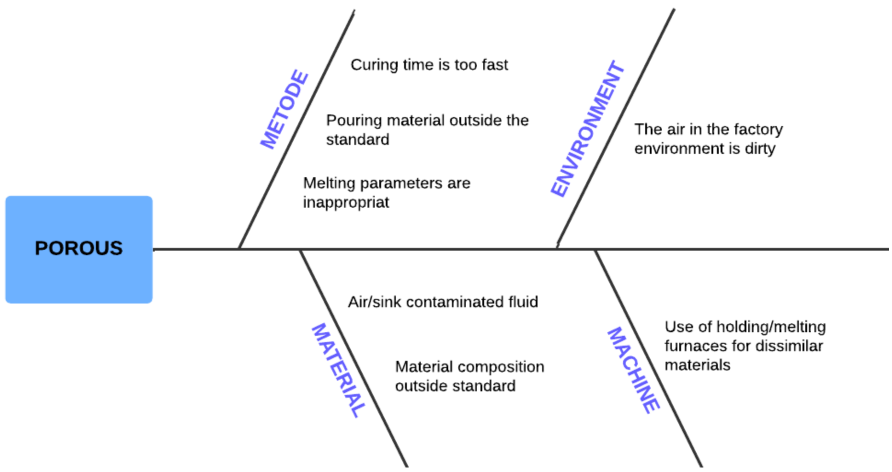
From table 4, it can be seen that the average DPMO value for the quality of the Pipe Water Inlet EW010 product on 26 June-25 August 2023 was 172492.48 with an average sigma level value of 2.44, meaning that this figure is still very far from the 6-sigma level value, so improvements are needed in production quality.

To find out the cause of the high number of leaking, porous and pen/core defects in the Pipe Water Inlet EW010 product, it is necessary to analyze the root cause of the high number of defects. This analysis stage functions to find the root cause of the existing type of disability. Failure analysis and the effects/consequences of failure using the FMEA method can be seen in Table 5 as follows:

Table 5 Failure Analysis Table and Failure Consequences

Activity in process	Failure mode	Effects/consequences of failure
Gravity Casting	Porous	Reject
	Pen/Core	
Leak Test	Leak	Not Good

After knowing the failure that occurred in each process, the next step is to find the root cause of the incident. One method that can be used to find the root causes and causes of defects is Root Cause Analysis (RCA). Analysis of the causes of failure using the RCA method based on each type of failure mode is as follows figure 12:



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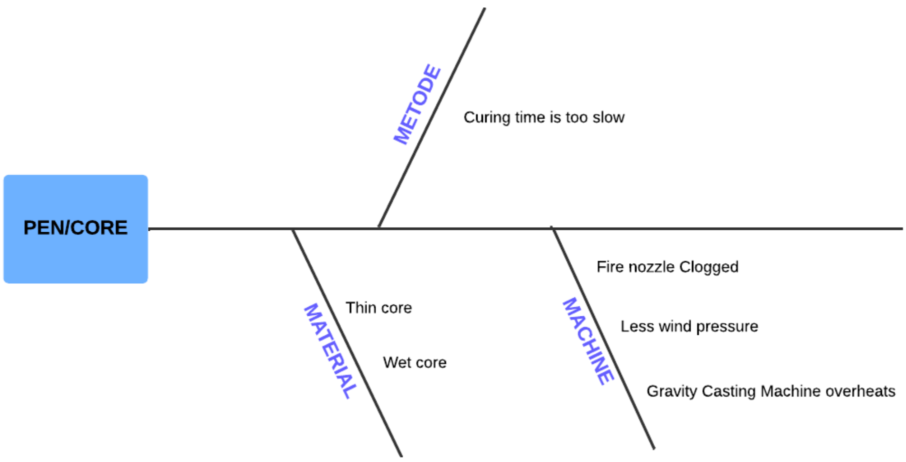

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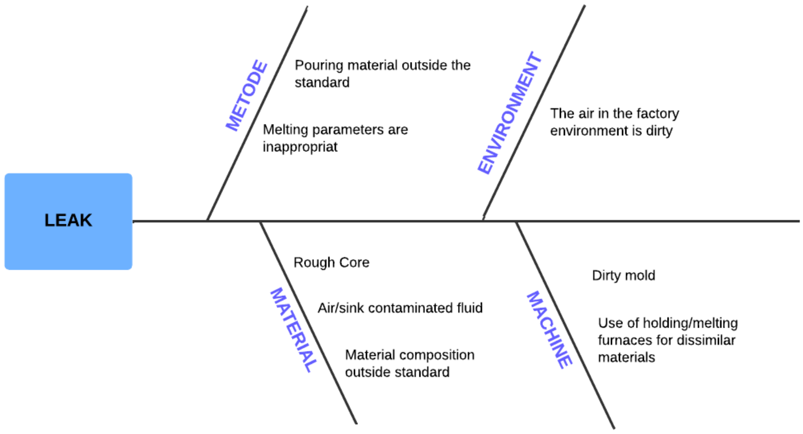

c

Figure 12 a. RCA Porous Defect, b. RCA Pen/Core Defect, c. RCA leaking Defect

The results of the Root Cause Analysis (RCA) that have been made will be input into the FMEA analysis, especially in identifying the root causes of potential failures. The purpose of the FMEA analysis is to find suggestions for improvements that can reduce the number of failures and prevent failures in the Pipe Water Inlet EW010 production process. The scores or weight values used in FMEA analysis are obtained from observations, interviews and company FMEA documents. The results of the FMEA analysis can be seen as below table 6.

Table 6 FMEA Analysis (Porous)

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
Gravity Casting	Porous	Reject	8	The fluid temperature is too high	8	Check the liquid temperature at each melting and maintain the temperature parameters according to standards	6	384
				Air/sink contaminated fluid	8	Visually check the outer surface of the ladle / scoop	7	448
				Material composition outside standard	8	Carry out millsheet and actual inspection of materials to be used	6	384
				Use of holding/melting furnaces for dissimilar materials	7	Check the type of liquid in the furnace with a spectroanalyzer	5	280
				Pouring material outside the standard	7	Workers routinely control the pouring duration	4	224
				Curing time is too fast	7	Setting curing time	4	224

Table 7 FMEA Analysis (Pen/Core)

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
Gravity Casting	Pen/Core	Reject	8	Gravity Casting Machine overheats	7	Check the temperature of the gravity casting machine	3	168
				Thin core	8	Trial use of new sand material	6	384
				Wet core	7	Check the quality of the core to be used	5	280
				Curing time is too slow	7	Setting curing time	4	224
				Fire nozzle Clogged	7	The flame nozzle is cleaned	6	294
				Less wind pressure	7	Check the wind tube	3	147

Table 8 FMEA Analysis (Leak)

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
Leak Test	Leak	Not good Product (NG)	7	Coarse resin core	7	Core inspection by sorting	5	245
				Use of holding/melting furnaces for dissimilar materials	7	Check the type of liquid in the furnace with a spectroanalyzer	5	245
				Material composition outside standard	8	Carry out millsheet and actual inspection of materials to be used	6	336
				Pouring material outside the standard	7	Workers are routinely checked	4	196
				Fluid temperature is too low	8	Check the liquid temperature at each melting and maintain the temperature parameters according to standards	6	336
				Dirty mold	6	Spraying process on the mold surface	3	126
					8	Visually check the outer	7	392

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
						surface of the ladle / scoop		
				Air/sink contaminated fluid		Visually check the outer surface of the ladle / scoop	8	392
						Air vent cleaned / added	5	280

FMEA analysis was carried out on the types of defects that often occur in the Pipe Water Inlet EW010 product. The types of defects in question are leaking, pen/core, and crumbling defects which the researchers then used as failure modes in the FMEA analysis. From the FMEA analysis above, it can be seen that the RPN value for each failure mode in the Pipe Water Inlet EW010 product exceeds the value 100. The higher the RPN value, the higher the risk and impact that can cause defects in the Pipe Water Inlet EW010 product and become a priority for repair. The PT Wijaya Karya Industri and Construction PPC factory has standards for the RPN FMEA assessment. If the RPN value is greater than or equal to 100 (RPN ≥ 100), then the factor causing the problem must be given corrective action. Next, the researcher will follow up on the problem by providing corrective solutions to the problem at the improvement stage.

After knowing the factors that cause defects in the Pipe Water Inlet EW010 product through RCA and FMEA analysis, the next step is to make recommendations for improvements to each existing problem. After providing suggestions for improvement, at this stage the researcher will recalculate the DPMO value and sigma level value after the recommendation for improvement. Recommendations for improvement provided by researchers are based on the types of defects in the high category which can be seen in Table of FMEA Analysis above. There are 3 failure modes that need to be given recommendations for repair, including leaking defects, pen/core and porous. Recommendations for improvement can be seen in table as follows:

Table 9 Improvement Recommendations (Porous)

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
Gravity Casting	Porous	Reject	The fluid temperature is too high	Control over standard liquid temperature limits
			Dip contaminated fluid	Coating ladle before use
			Material composition outside standard	Remove the mixture of screws and materials from suppliers to check cleanliness and material content
			Use of holding/melting furnaces for dissimilar materials	Allocation of transfer furnaces and ladles according to the number of material types
			Pouring material outside the standard	Calculation of work cycle time and application of SOP when pouring material into mold

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
			Curing time is too fast	Curing time increased

Table 10 Improvement Recommendations (Pen/Core)

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
Gravity Casting	Pen/Core	Reject	Gravity Casting Machine overheats	Setting the curing time temperature for the gravity casting machine
			Thin core	Increase resin levels
			Wet core	Maintain humidity in the factory environment
			Curing time is too slow	Curing time is reduced
			The flame nozzle is clogged	Maintenance
			Less wind pressure	Wind valve settings

Table 11 Improvement Recommendations (Leak)

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
Leak Test	Leak	Not Good Product (NG)	Fluid temperature is too low	Control liquid temperature standard limits
			Dirty mold	Molds are cleaned before and after the casting process
			Use of holding/melting furnaces for dissimilar materials	Allocation of transfer furnaces and ladles according to the number of material types
			Material composition outside standard	Remove the screw mixture, and check the material from the supplier again for cleanliness and material content
			Pouring material outside the standard	Calculation of work cycle time and application of SOP when pouring material into mold
			Air/sink contaminated fluid	Coating ladle before use, AC4B material is used immediately after the melting process, and cleaning/adding the air vent
			Coarse resin core	Check the quality of the core to be used

Through the recommendations given, the first corrective action taken by the company was that the casting process was carried out carefully and the production process was supervised by skilled and experienced operators. Casting process engineers routinely control the production process in the field, such as paying attention to curing time on machines.

One of the biggest defects in the Pipe Water Inlet EW010 product is the pen/core defect, which is caused by the sand core being damaged during the casting process. The second recommendation that was implemented was KH 7904 sand with a resin content of 1.75%, increased to 2.0%. This can increase the strength of the sand core, thereby reducing the presence of pen/core defects in the Pipe Water Inlet EW010 production results.

The biggest cause of leak defects is porosity. Products using AC4B material are very susceptible to air contamination, so defective products are often found, such as porosity, shrinkage and leaks. AC4B is a material that is commonly used in automotive products because its quality is quite good, but the failure rate for products cast using this material is very high. The next recommendation that is implemented is to use additional materials, namely Titanium (0.019 wt % and 0.029 wt %) to reduce defects in the casting results. The next recommendation that is implemented is that materials from suppliers are checked again for cleanliness and the material content contained, to ensure that the products used are clean and comply with standards. The next recommendation that is implemented is that workers are routinely monitored for their work. The duration of pouring molten metal into the mold must comply with standards, because this greatly influences production results. The standard for pouring into mold is 4 to 6 seconds. This can be done by calculating the cycle time in the pouring process to see any improvements. The next recommendation that is implemented is to use machines well, efficiently and under control, and routinely provide maintenance to the machines used, so as to improve good production quality.

Through the implementation of improvements made by the researcher, the researcher then observed the production quality and number of defects during September-October 2023. The following is the data and types of defects in the Pipe Water Inlet EW010 product after the improvement:

Table 12 Data of Types and Number of Defects 04 September-27 October 2023

Date (2023)	Production	A	B	C	D	E	F	G	H	I	J	K	Defect	%
04 – 08 Sept	200	6	9	2	15	12	0	0	0	1	1	0	46	23%
11 – 15 Sept	311	0	22	1	26	19	0	0	3	1	0	0	72	23%
18 – 22 Sept	370	2	17	0	31	28	0	0	2	3	5	0	88	24%
25 – 29 Sept	172	2	9	1	18	7	0	0	0	3	0	0	40	23%
02 – 06 Oct	335	1	11	8	29	13	0	0	0	0	1	0	63	19%
09 – 13 Oct	128	0	7	0	52	8	0	0	1	8	1	0	77	60%
16 – 20 Oct	468	10	22	1	19	31	0	0	3	1	0	0	87	19%
23 – 27 Oct	298	2	9	0	21	18	0	2	1	2	0	0	55	18%
Total	2282	23	106	13	211	136	0	2	10	19	8	0	528	23%

Explanation of the type of defect

A. Misrun
B. Porous
C. Lenting
D. Leaking
E. Fungal
F. Cracked
G. stamp
H. Short cut
I. Gmpl
J. Deflates

The calculation of DPO, DPMO and sigma level after implementing improvements uses the same calculation as the previous calculation. Data on DPO, DPMO and Sigma Level values on the quality of the EW010 Water Inlet Pipe product after repairs are as follows:

Table 14 DPMO and Sigma level value 4 September -27 October 2023

No	Production	Defect	CTQ	DPO	DPMO	Level Sigma
1	200	46	3	0.07666667	76666.67	2.93
2	311	72	3	0.07717042	77170.42	2.92
3	370	88	3	0.07927928	79279.28	2.91
4	172	40	3	0.07751938	77519.38	2.92
5	335	63	3	0.06268657	62686.57	3.03
6	128	77	3	0.20052083	200520.83	2.34
7	468	87	3	0.06196581	61965.81	3.04
8	298	55	3	0.06152125	61521.25	3.04
Total	2282	528	3	0.08716628	87166.28	2.86

From table 4.14, it can be seen that the average DPMO value for the quality of the EW010 Water Inlet Pipe product after controlling workers, changing the type of sand and improving work methods is 87166.28 with an average sigma level value of 2.86, meaning there is an increase in production quality from before the repair. It can be seen that in October, weeks 1, 3 and 4, production quality improved with a sigma level value of 3.

After implementing the improvement recommendations, the final stage in the DMAIC cycle is the control stage. The control stage is carried out to control the production process so that it is able to maintain product quality or improve quality. Therefore, it is necessary to take control measures, namely by implementing the QCPC (Quality Control Process Chart) and IK (Special Instructions) standards that have been made by the company. Apart from that, productivity and production quality must always be controlled every day by reviewing check sheets and daily production reports filled in by field operators. This can help the quality control division to review work results and production problems every day, and the engineering division can take corrective action if there are problems in the production process.

4. Conclusion

In the production process of Pipe Water Inlet EW010, there are three types of biggest defects found namely leak defects, pen/core, and porous which are depicted through the Pareto diagram. Analysis of the causes of defects in the Pipe Water Inlet EW010 product was carried out using the DMAIC six sigma method, namely by identifying problems in the process of making the Pipe Water Inlet EW010 product and determining the CTQ (Critical to Quality) value. The results of the implementation of improvements showed a decrease in the DPMO value and an increase in the sigma level value. The initial value of DPMO was 172492.48, decreasing to 87166.28 after implementing the improvements. Meanwhile, the sigma level value was initially 2.44 after implementation, increasing to 2.86. Based on these results, implementing the improvements made can improve the quality of the EW010 Water Inlet Pipe product, although not significantly. This happens because not all proposed improvements can be carried out and the causes of failure in the casting production process are caused by various factors.

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Defect Analysis Using Failure Mode and Effects Analysis and Fault Tree Analysis (Case Study: Secondary Section PT PID Ongkowidjojo)

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Abstract. Quality control is a vital aspect of product manufacturing, ensuring adherence to predefined standards and meeting consumer expectations. This study focuses on quality control within the cigarette production process, specifically in PT PID Ongkowidjojo, a prominent manufacturer located in Malang, Indonesia. Despite meticulous production processes, defects in cigarette sticks persist, leading to waste of resources, time, and potential degradation in product quality. The research employs Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) to identify, analyze, and propose solutions for defects occurring in the maker machine division. Initial analysis reveals common defects such as glue inadequacy, tears in wrappers, and tobacco density inconsistencies, prompting the need for systematic improvements. Through FMEA and FTA methodologies, root causes of defects are pinpointed, and corrective actions are proposed. Implementation of these measures results in a reduction of Risk Priority Number (RPN) values for major defects, indicating a positive impact on production quality. However, limitations in utilizing gate symbols within FTA are acknowledged, suggesting avenues for future research to optimize analytical techniques. This study contributes to the ongoing discourse on quality control in manufacturing industries, particularly in addressing common defects in cigarette production. By integrating FMEA and FTA methodologies, it offers insights into effective defect mitigation strategies, highlighting the importance of continuous improvement in maintaining product quality and operational efficiency.

Keywords: Cigarette production; Defect mitigation; Failure mode and effects analysis (FMEA), Fault tree analysis (FTA); Manufacturing industry; Quality control.

1. Introduction

Quality is the excellence value of a product that reflects a company's ability to meet predetermined quality requirements and qualifications, or even exceed consumer expectations (Razak et al., 2019). Product quality is the ability of a product to perform its functions, such as product durability and reliability, ease of operation and maintenance, taste value, and product

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aesthetics, among others (Napitupulu, 2019). Quality must be continuously maintained and preserved using quality control. This is crucial to consistently maintain products in the market and compete in the business industry (Revita et al., 2021). Quality control is a technical and managerial activity that assesses the quality characteristics of products and services. The measurement results are then compared with predetermined specifications. The comparison results between specifications and measurements will be followed up according to existing SOPs to continually improve productivity in the production process (Shiyami et al., 2021). Quality control is an activity that ensures a product meets specific quality standards set by the company, ranging from the quality of the production process, quality of raw materials, quality of the raw material processing process to finished goods, and also the standards for distribution to consumers in the most effective and efficient manner (Riadi, 2020).

PT PID Ongkowidjojo is one of the cigarette manufacturing companies located in the city of Malang. In the production process of cigarettes, there are two divisions, namely primary and secondary. Primary is the cigarette division that processes raw tobacco into sauced tobacco, while secondary is the division that manages sauced tobacco into packaged and ready-to-distribute cigarettes or Machine-Made Clove Cigarettes (SKM). In the secondary division, there are three types of machines, one of which is the Maker machine (MK). This machine functions to turn sauced tobacco into cigarette sticks or Machine-Made Clove Cigarettes (SKM) ready for consumption (not yet in packaging). These cigarette sticks consist of several components, including filters, wrappers, sauced tobacco, glue, and tipping paper.

The production process is carried out to produce cigarette sticks ready for consumption. However, not all cigarette sticks produced can be consumed or pass the quality check. There are many types of defects obtained from the production of cigarette sticks, such as: glue not adhering between the wrapper and tipping paper, tears in the cigarette wrapper (wrapper), insufficient tobacco density in the cigarette, resulting in a porous appearance, uneven cutting size of the tipping paper, and many more. These types of defective products undoubtedly affect the quality of production. In addition to product quality, this can impact the repetition of processes, leading to ineffective and inefficient production processes. The number of samples and the quantity of defects from July 20, 2023, to July 31, 2023, can be seen in Table 1.

Table 1 Number of Samples and Quantity of Defects in Cigarette

Date (2023)	Number of Sample	Type of Defects							Quantity of Defects
		A	B	C	D	E	F	G	
July, 20	240	5	19						**24**
July, 21	240		37	4					**41**
July, 22	240	9	6	6					**21**
July, 24	240		20						**20**
July, 25	240		27		10	22			**59**
July, 26	240		18			10	15	18	**61**
July, 27	240		11				12	4	**27**
July, 28	240		8		6		21		**35**
July, 30	240	26			50				**76**
July, 31	240	32	8					8	**48**
Total Quantity of Defect		**72**	**154**	**10**	**66**	**32**	**48**	**30**	**412**

Explanation:
A. Tears on Wrapper
B. Porous/Density not appropriate
C. Improper Overlap (2 mm)
D. Wrapper and tipping paper not adhering
E. Varying diameters
F. Varying lengths of tipping paper
G. Absence of filter

Based on the data above, it can be seen that there are 412 defects out of 2400 samples. This will result in excessive use of raw materials and may affect the taste of the cigarettes. Additionally, unnecessary process repetitions can waste time, energy, and costs. The quantity of defective products will be dismantled and reprocessed, requiring additional time, costs, raw materials, and manpower to repeat the process. Moreover, the taste produced from the reprocessed tobacco may be diminished, impacting consumer interest in PT PID Ongkowidjojo's cigarette products. This, in turn, leads to ineffective and inefficient production processes. Therefore, this study conducts a failure analysis based on each process in the maker machine using the FMEA method. Causes, effects, and corrective solutions will be identified using the Fault Tree Analysis (FTA) method by (Alijoyo et al., 2021). Subsequently, the FMEA method will be used as a tool to compare the results of the proposed improvements in the cigarette production process at PT PID Ongkowidjojo, as suggested by (Alijoyo et al., 2017).

According to (Alfarizi et al., 2022), FMEA can be used in conjunction with Six Sigma to reduce the number of defective products, as demonstrated in their study titled "Quality Control Using Six Sigma and FMEA to Reduce Reject Material Preform in Bottled Drinking Water Industry." Additionally, FMEA can be paired with Fault Tree Analysis (FTA) to reduce defective products, as seen in the study titled "Application of Fault Tree Analysis Method to Prevent Failures in the Interior Department at PT X" by (Yolanda et al., 2023). FMEA can also be combined with the SWOT method to enhance quality, as demonstrated in the study titled "Marketing Strategy Design and Improvement of Bird Feed Product Quality at IKM Sinar Mas Malang using SWOT and FMEA" by (Susanto & Purnomo, 2022).

2. Methods

This research focuses on the random sampling of a population consisting of machine-made cigarette sticks. Samples are taken randomly, with 50 sticks sampled every few hours at random times. Typically, researchers conduct sampling five times, totaling 250 cigarette sticks. These samples are then checked for defects. The defects found on the cigarettes are counted and entered into a Google Form as a data collection tool during the research period. Data collection takes approximately three months, with a total sample of 16,000 cigarette sticks. Once the data is gathered, researchers need to analyze it according to the following procedures.

The first analysis conducted is by analyzing the mode and impact of failures using Failure Mode and Effects Analysis (FMEA). Failure mode analysis is done by identifying potential failures in each production process. Next, analyzing the causes of failure, and controlling them with Fault Tree Analysis (FTA). At this stage, each process analyzed with FMEA will be detailed using a failure tree. Each type of failure impact will be analyzed for its causes one by one. The next step is to determine the weights of the Severity, Occurrence, and Detection components. Weight determination is based on the impact resulting from the types of defects. The more severe and impactful the defect, the higher the assigned value. Once the Severity, Occurrence, and Detection weights are assigned, these values will be calculated for the Risk Priority Number (RPN) using the formula S x O x D. The RPN values will be sorted from highest to lowest, and defects with the highest values will be prioritized for correction first.

The prioritization sequence from the RPN values will be used as the basis for proposing improvement recommendations. After each defect receives improvement proposals, these proposals need to be implemented over some time. During the implementation process of improvement proposals, researchers need to measure defect data on the machine makers that have undergone implementation over a certain period. Afterward, this data will be used to calculate the final RPN based on the Severity, Occurrence, and Detection values of the defects after improvement. Once the final RPN value is determined, researchers can conduct a comparative analysis. This comparative analysis contains the results of comparing the initial and final RPN calculations. The analysis results will show whether the implemented improvement proposals can reduce the number of defective products.

3. Results and Discussion

The research data consists of a combination of primary and secondary data obtained from the quality control division of PT PID Ongkowidjojo. The summarized data of the cigarette stick quality checks from August to October can be seen in Table 2.

Table 2 Summary of Defective Quantity Data for the Period of August-October 2023

Type of Defects	Quantity of Defects	Percentage of Defects
Tears on the Wrapper	699	24,96%
Porous/Density not Appropriate	1279	45,66%
Improper Overlap (2 mm)	51	1,82%
Wrapper and Tipping Paper not Adhering	435	15,53%
Varying Diameters	119	4,25%
Varying Lengths of Tipping Paper	121	4,32%
Absence of Filter	97	3,46%
Total	**2801**	**100%**

Based on the summarized data above, it can be observed that the highest defect percentage is attributed to porous defects, accounting for 45.66%. Subsequently, the second-largest defect is tears on the wrapper at 24.96%, and the third-largest defect is the detachment of tipping and wrapper at 15.53%. These three defects collectively constitute over 80% of the overall defect percentage. This indicates that these three defects have the highest frequency factor (O) in their occurrences. The seven types of defects in Table 2 will be analyzed, and their corrective measures will be determined using the FMEA and FTA methods.

Table 3 Failure Analysis and Failure Consequence Table

Activities in the Process	Failure Mode Potential	Impact of Failure Potential
Rolling and Tipping of Cigar Wrapper	*Wrapper roll not straight/there is a bend in the wrapper roll*	Tears on the Wrapper
	The size of the cigarette wrapper folding is not appropriate	Improper Overlap (2 mm)
		Varying Diameters
Filling tobacco in the wrapper	There is crushed tobacco	Porous/Density not appropriate
	The tobacco texture is too wet (moist)	
	The tobacco weight adjustment on the machine has not been set	
	There is other material besides tobacco	Tears on the Wrapper
Cutting the tobacco-filled wrapper	Dirty machine (sharp objects have not been cleaned)	Tears on the Wrapper
Filter cutting	The operator does not arrange the filters according to the cutting machine	Absence of Filter
Combining the tobacco-filled wrapper with the filter and tipping	Dried glue on the machine has not been cleaned	Wrapper and Tipping Paper not Adhering
	Glue is empty and not filled	
	The cutting knife of the tipping is tilted	Varying Lengths of Tipping Paper
	The cutting knife of the tipping has not been cleaned	
Automatic sensor checking	There is a problem with the electrical part	Tears on the Wrapper
		Porous/Density not appropriate
		Varying Diameters
		Wrapper and Tipping Paper not Adhering
		Absence of Filter

After identifying the failures in each process, the next step is to find the root causes of these incidents. One method that can be used to determine the causes of defects is Fault Tree Analysis (FTA). The cause analysis using the FTA method for each type of defect is as follows:

The presence of tears in the wrapper can be caused by one of three factors: human error, machinery, and raw materials. Human error can lead to this defect when operators sometimes forget or fail to check whether the cigar wrapper roll is straight or bent. If the used wrapper is bent, it will result in the wrapper tearing when pulled by the machine. Additionally, operators often neglect to clean the entire machine. Typically, the machine is cleaned only when a defect is detected, and the machine is temporarily stopped for cleaning. Ideally, before the production process begins, operators should thoroughly clean the machine. A solution derived from the human factor is the implementation of a checklist containing specific tasks to be performed in a written format before initiating the production process. This checklist will be provided to the operators and must be completed and filled out before the production process begins.

The second factor contributing to wrapper tears is the machinery. After all production processes are completed, all cigars go through a sensor process that sorts defective and distribution-worthy cigars. If this machine fails to operate, defective cigars can exit the sensor without proper sorting. A corrective solution is the implementation of regular maintenance or checks on the machine's electrical components, conducted on a monthly basis.

The third factor causing wrapper tears is the raw materials. The primary raw materials for cigars are tobacco and cloves. The tobacco used is a mixture of sauces tobacco combined with *koncek* tobacco resulting from the disassembly of defective cigars. Additionally, the wrapper can tear if there are materials other than tobacco and cloves. These materials usually have a sharp shape that can scratch the wrapper, causing it to tear, such as staple contents, sharp pieces of clove stems, and others. A preventive solution is to use foreign object detection devices such as metal detectors or others.

The defect of wrapper tears or inadequate density can occur due to three factors: machinery, raw materials, and environmental conditions. The first factor is machinery. In the maker machine, there is a process of filling the wrapper with tobacco regulated based on the tobacco's weight. The weight regulation machine sometimes does not match the set figure by the operator, requiring frequent checks by the operator. The second issue lies in the process of suctioning tobacco to be inserted into the wrapper. This machine can also get stuck with tobacco, reducing its pulling force. The consequence of reduced pulling force is insufficient tobacco entering the wrapper, causing the cigar to be porous as the wrapper is not fully filled. The corrective solution for operators is the implementation of a checklist containing tasks to be checked and performed before the production process starts.

After cigars experience porosity, they are usually automatically discarded by the sensor machine as defective. However, if the sensor machine malfunctions, porous cigars may proceed to the packaging stage without manual checks by QC and operators. The corrective solution for the sensor machine is regular maintenance by the electrical department once a month.

The factor causing the porosity defect is the raw material, where crushed tobacco exceeding the specified proportion is found among the overall tobacco. If the amount of crushed tobacco exceeds the specification, the tobacco in the cigar will have a very fine texture with a weight similar to other cigars. If the tobacco in the cigar is fine, there is a high likelihood that it can fall out, causing the cigar to be porous. The solution for this factor is thorough mixing of crushed and sauces tobacco with the right proportions.

The third factor causing porosity is unpredictable temperature and weather changes. Tobacco is stored in a cool room in the WIP warehouse using air conditioning. However, the secondary production process takes place in an open area with a temperature dependent on the weather. This exposes the tobacco to moisture during rain, making it damp and heavier. Excessive weight will make the cigar porous because the tobacco is filled based on its weight. On the other hand, hot weather can make the tobacco drier, resulting in lighter tobacco weight. Therefore, when dry tobacco is filled into the cigar, it becomes denser than a regular cigar. The solution is to have an enclosed space with temperature control to maintain humidity in the secondary SKM production area.

The defect of misaligned overlap refers to an overlap that is more or less than 2 mm. This can occur due to the operator's negligence in adjusting the size of the cigar wrapper folding machine. The size of the wrapper roll used usually varies, depending on the supplier of the wrappers. When there is a change in the type of wrapper, the folding machine must be adjusted to the new size to achieve a 2 mm overlap. This issue can be addressed by providing a checklist to the operator as a reminder of the tasks to be completed before the production process starts.

The defect of the wrapper and tipping paper not adhering originates from human and machine factors. This can be caused by dried adhesive from the previous production process that hasn't been cleaned by the operator. Additionally, it can occur if the operator fails to check the availability of adhesive on the machine, causing the machine to operate without adhesive. This can be addressed by providing a checklist outlining tasks for the operator to perform before the production process begins.

A machine-related factor that can contribute to this issue is the failure of the sensor machine to detect defective cigars. If the sensor machine malfunctions, defective cigars may proceed to the packaging stage without manual checks by QC and operators. The corrective solution for the sensor machine is to conduct monthly maintenance by the electrical department.

The defect of varying diameters refers to diameters that are either more or less than 8 mm. This can occur due to the operator's negligence in adjusting the size of the cigar wrapper folding machine. The size of the wrapper roll used usually varies, depending on the supplier of the wrappers. When there is a change in the type of wrapper, the folding machine must be adjusted to the new size to achieve an 8 mm diameter. This issue can be addressed by providing a checklist to the operator as a reminder of the tasks to be completed before the production process starts.

The defect of varying lengths of tipping paper originates from human factors. This can be caused by a slightly tilted knife that goes unchecked by the operator. Additionally, it can occur due to a knife that is dirty from tobacco but hasn't been cleaned by the operator. This can be addressed by providing a checklist outlining tasks for the operator to perform before the production process begins.

The defect of the absence of filters can be caused by human or machine factors. Human factors may result from the operator's negligence in arranging the filter's position. Thus, when the filter is inserted into the machine, it gets stuck at the entrance of the cutting machine. This causes the machine for filling the wrapper with tobacco to continue running while the filter cutter stops. Consequently, it leads to the production of cigarettes without filters. This can be rectified by providing a checklist to the operator that includes tasks to be done and checked before initiating the production process.

The second factor causing the absence of filters is the poor performance of the sensor machine. This is often due to inadequate maintenance from the electrical department. Therefore, the corrective solution provided is to conduct monthly maintenance.

The results of the Fault Tree Analysis (FTA) created will serve as input for Failure Mode and Effect Analysis (FMEA), particularly in identifying potential root causes of failures. The goal of FMEA analysis is to identify improvement suggestions that can reduce the number of failures and prevent failures in the production process of SKM cigarettes. The scores or weight values used in the FMEA analysis are obtained from observations and interviews with the QC supervisor. The results of the FMEA analysis can be seen in Table 4.

Table 4 FMEA Analysis

					Before Improvement				
Activities in the Process	**Failure Mode**	**Impact of Failure**	**Causes**	**Control**	**S**	**O**	**D**	**RPN**	**Recommendations for Improvement**
Rolling and Tipping of Cigar Wrapper	*Wrapper roll not straight/there is a bend in the wrapper roll*	Tears on the Wrapper	The operator has not checked before the production process	Checking the bends in the wrapper roll	7	6	4	168	Creating a checklist containing a 'To-Do List' before production
	The size of the cigarette wrapper folding is not appropriate	Improper Overlap (2 mm)	The operator did not set the size before the production process	Setting the folding size before starting production	2	5	3	30	Creating a checklist containing a 'To-Do List' before production
		Varying Diameters	The operator did not set the size before the production process	Setting the folding size before starting production	2	5	3	30	Creating a checklist containing a 'To-Do List' before production
Filling tobacco in the wrapper	There is crushed tobacco	Porous/Density not appropriate	The mixing process of crushed and sauces tobacco is not be spread evenly	Mixing at the right location	7	7	8	392	Mixing crushed tobacco in the primary section
	The tobacco texture is too wet (moist)		Unpredictable changes in temperature and weather	Closing the storage and production room to maintain temperature	7	7	6	294	Providing temperature control (AC) in the Secondary SKM section
	The tobacco weight adjustment on the machine has not been set		The operator did not check the machine before the production process	Ensuring the tobacco weight is correct	7	7	4	196	Creating a checklist containing a 'To-Do List' before production
	There is other material besides tobacco	Tears on the Wrapper	The operator is less meticulous in the inspection process	Double-checking sharp objects on the tobacco	7	6	9	378	Providing sharp object detection tools
Cutting the	Dirty machine	Tears on the Wrapper	The operator	Conducting	7	6	5	210	Scheduling periodic

					Before Improvement				
Activities in the Process	**Failure Mode**	**Impact of Failure**	**Causes**	**Control**	**S**	**O**	**D**	**RPN**	**Recommendations for Improvement**
tobacco-filled wrapper	(sharp objects have not been cleaned)		did not clean the machine thoroughly	thorough cleaning of the machine parts					thorough cleaning
Filter cutting	The operator does not arrange the filters according to the cutting machine	Absence of Filter	The operator is not meticulous in the pre-production inspection	Ensuring the correct position of the filter before starting the production machine	8	5	4	160	Creating a checklist containing a 'To-Do List' before production
Combining the tobacco-filled wrapper with the filter and tipping	Dried glue on the machine has not been cleaned	Wrapper and Tipping Paper not Adhering	The operator is less meticulous in machine inspection	Conducting a more thorough cleaning of the machine	7	6	4	168	Scheduling periodic thorough cleaning
	Glue is empty and not filled		The operator is less meticulous in machine inspection	Conducting a more thorough cleaning of the machine	7	6	4	168	Creating a checklist containing a 'To-Do List' before production
	The cutting knife of the tipping is tilted	Varying Lengths of Tipping Paper	The operator is less meticulous in machine inspection	Conducting a more thorough cleaning of the machine	4	5	4	80	Creating a checklist containing a 'To-Do List' before production
	The cutting knife of the tipping has not been cleaned		The operator is less meticulous in machine inspection	Conducting a more thorough cleaning of the machine	4	5	4	80	Scheduling periodic thorough cleaning
Automatic sensor checking	There is a problem with the electrical part	Tears on the Wrapper	The machine lacks maintenance	Establishing a regular maintenance schedule	7	6	4	168	Scheduling maintenance with the electrical section every month
		Porous/Density not appropriate	The machine lacks maintenance	Establishing a regular maintenance schedule	7	7	4	196	Scheduling maintenance with the electrical section every month
		Varying Diameters	The machine lacks maintenance	Establishing a regular maintenan	2	5	4	40	Scheduling maintenance with the electrical

					Before Improvement				
Activities in the Process	**Failure Mode**	**Impact of Failure**	**Causes**	**Control**	**S**	**O**	**D**	**RPN**	**Recommendations for Improvement**
				ce schedule					section every month
		Wrapper and Tipping Paper not Adhering	The machine lacks maintenance	Establishing a regular maintenance schedule	7	6	4	168	Scheduling maintenance with the electrical section every month
		Absence of Filter	The machine lacks maintenance	Establishing a regular maintenance schedule	8	5	4	160	Scheduling maintenance with the electrical section every month

Based on the FMEA table above, a summary of the average RPN values for each type of defect is obtained, as shown in Table 5.

Table 5 Average RPN for Type of Defects

No	Type of Defects	Average RPN	Categories
1	Tears on the Wrapper	231	High
2	Porous/Density not Appropriate	269,5	High
3	Improper Overlap (2 mm)	30	Low
4	Wrapper and Tipping Paper not Adhering	168	Medium
5	Varying Diameters	35	Low
6	Varying Lengths of Tipping Paper	80	Low
7	Absence of Filter	160	Medium

The type of defect with the highest RPN is porosity. The recommended handling proposed by the researcher is the implementation of a Checklist Form for the Production Operator's "To-Do List." This checklist form is expected to prevent operator errors and address machine performance issues during production. The form will be filled out by the supervisor by placing a checkmark after the operator completes the procedures outlined in the checklist. The checklist provided to the SKM cigarette production supervisor can be seen in Table 6.

Table 6 Operator Pre-Production Checklist Form

Tanggal/ shift Cth: (1/11/23) / 1	Cek kondisi *Roll* Ambri	Mengatur ukuran *overlap*/ diameter rokok di maker	Mengatur ukuran berat tembakau maker	Mengecek posisi *filter* rokok	Mengecek jumlah lem dalam mesin	Membersihkan mesin, pisau, dan lem yang ada pada mesin	Memeriksa posisi mesin pemotong ambri	Memeriksa posisi mesin pemotong *filter*	Memeriksa posisi mesin pemotong *tipping*	Ttd Mandor

Another recommended improvement to prevent porous cigarettes is to reprocess the crushed tobacco so that it has the same weight as regular sauces tobacco. This improvement involves reprocessing the crushed tobacco in the primary section by adding sauce and alcohol to it. The researcher also suggests an improvement recommendation in the form of adding a room temperature control device in the production area to maintain the humidity stability of sauces tobacco during processing. Another recommendation that can be implemented to reduce porosity in cigarettes is a general cleaning of the machines.

For the second highest average RPN defect, which is tears in the wrapper, the researcher recommends implementing a sharp object detection tool to prevent wrapper tears. For defects categorized as medium and low, a general improvement that can be made is to establish a regular maintenance schedule, typically on a monthly basis. In addition to maintenance, measures to prevent defects in the production process can include socializing complaints from QC about failed products, which will then be conveyed by supervisors to operators. This socialization should be conducted whenever defects are identified by QC. In addition to socialization, supervisors or production managers should also conduct briefings at the beginning of each shift before production.

Not all recommended measures can be implemented due to budget limitations of the company. Some feasible recommendations include creating a checklist form to prevent operator negligence before the production process begins. Another recommended measure is to conduct more detailed cleaning at the start of each shift to reduce the possibility of defective cigarettes due to dirty machine factors. The third recommended measure is to mix crushed tobacco in the primary section so that it acquires flavor and can be evenly mixed with sauces tobacco. This is done to reduce the type of defect related to porosity. The fourth recommendation is to conduct socialization with operators before starting production. This is done to help operators remember what needs to be done and to evaluate the shifts from previous days. It helps reduce operator negligence in the production process of cigarettes and ensures uniform information to all operators. The implementation of these improvements took place over two weeks with data as shown in Table 7.

Table 7 Table of Measurement Final Type of Defects

Date	Number of Sample	Type of Defects							Quantity of defects
		A	B	C	D	E	F	G	
20/11/2023	250	25			10	8			43
21/11/2023	250	10	25		4	5			44
22/11/2023	250		11	6					17
23/11/2023	250						8		8
24/11/2023	250					6	5		11
27/11/2023	250	12	25	5	20		6	10	78
28/11/2023	250	18					2	3	23
29/11/2023	250		16						16
30/11/2023	250		9	7					16
01/12/2023	250	14					4		18
04/12/2023	250	20	16		14	5			55
Total	**2750**	**99**	**102**	**18**	**48**	**24**	**25**	**13**	**329**

Explanation:
A. Tears on Wrapper
B. Porous/Density not appropriate
C. Improper Overlap (2 mm)
D. Wrapper and tipping paper not adhering
E. Varying diameters
F. Varying lengths of tipping paper
G. Absence of filter

After the data collection following the implementation was conducted, the RPN values after the implementation also need to be evaluated, as shown in Table 8.

Table 8 FMEA Analysis Before dan After Improvement

			Before Improvement					After Improvement			
Activities in the Process	**Failure Mode**	**Impact of Failure**	**S**	**O**	**D**	**RPN**	**Recommendations for Improvement**	**S**	**O**	**D**	**RPN**
Rolling and Tipping of	*Wrapper roll not straight/ther*	Tears on the Wrapper	7	6	4	168	Creating a checklist containing a 'To-	7	6	3	126

			Before Improvement					After Improvement			
Activities in the Process	**Failure Mode**	**Impact of Failure**	**S**	**O**	**D**	**RPN**	**Recommendations for Improvement**	**S**	**O**	**D**	**RPN**
Cigar Wrapper	*e is a bend in the wrapper roll*						Do List' before production				
	The size of the cigarette wrapper folding is not appropriate	Improper Overlap (2 mm)	2	5	3	30	Creating a checklist containing a 'To-Do List' before production	2	5	3	30
		Varying Diameters	2	5	3	30	Creating a checklist containing a 'To-Do List' before production	2	5	3	30
Filling tobacco in the wrapper	There is crushed tobacco	Porous/Density not appropriate	7	7	8	392	Melakukan pecampuran tembakau *koncek* di bagian *primary*	7	6	3	126
	The tobacco texture is too wet (moist)		7	7	6	294	Melakukan pecampuran tembakau *koncek* di bagian *primary*	7	6	3	126
	The tobacco weight adjustment on the machine has not been set		7	7	4	196	Creating a checklist containing a 'To-Do List' before production	7	6	2	84
	There is other material besides tobacco	Tears on the Wrapper	7	6	9	378	Melakukan sosialisasi sebelum memulai produksi	7	6	3	126
Cutting the tobacco-filled wrapper	Dirty machine (sharp objects have not been cleaned)	Tears on the Wrapper	7	6	5	210	Scheduling periodic thorough cleaning	7	6	3	126
Filter cutting	The operator does not arrange the filters according to the cutting machine	Absence of Filter	8	5	4	160	Creating a checklist containing a 'To-Do List' before production	8	5	3	120
Combining the tobacco-filled wrapper with the filter and tipping	Dried glue on the machine has not been cleaned	Wrapper and Tipping Paper not Adhering	7	6	4	168	Scheduling periodic thorough cleaning	7	6	3	126
	Glue is empty and not filled		7	6	4	168	Creating a checklist containing a 'To-Do List' before production	7	6	3	126

Activities in the Process	Failure Mode	Impact of Failure	Before Improvement S	O	D	RPN	Recommendations for Improvement	After Improvement S	O	D	RPN
	The cutting knife of the tipping is tilted	Varying Lengths of Tipping Paper	4	5	4	80	Creating a checklist containing a 'To-Do List' before production	4	5	4	80
	The cutting knife of the tipping has not been cleaned		4	5	4	80	Scheduling periodic thorough cleaning	4	5	4	80
Automatic sensor checking	There is a problem with the electrical part	Tears on the Wrapper	7	6	4	168	Scheduling maintenance with the electrical section every month	7	6	4	168
		Porous/Density not appropriate	7	7	4	196	Scheduling maintenance with the electrical section every month	7	6	4	168
		Varying Diameters	2	5	4	40	Scheduling maintenance with the electrical section every month	2	5	4	40
		Wrapper and Tipping Paper not Adhering	7	6	4	168	Scheduling maintenance with the electrical section every month	7	6	4	168
		Absence of Filter	8	5	4	160	Scheduling maintenance with the electrical section every month	8	5	4	160

Table 9 Table of Comparison RPN Value Before dan After Improvement

No	Type of Defects	Before Improvement Average RPN	Categories	After Improvement Average RPN	Categories
1	Tears on the Wrapper	231	High	136,5	Medium
2	Porous/Density not Appropriate	269,5	High	126	Medium
3	Improper Overlap (2 mm)	30	Low	30	Low
4	Wrapper and Tipping Paper not Adhering	168	Medium	140	Medium
5	Varying Diameters	35	Low	35	Low
6	Varying Lengths of Tipping Paper	80	Low	80	Low
7	Absence of Filter	160	Medium	140	Medium

Table 9 is the summary of the average RPN before and after the improvements. Defects with the highest initial RPN were porosity or inappropriate density with an RPN value of 269.5. Then, for defects with the second-highest RPN, there were tears in the wrapper with a value of 231. Both types of defects became top priorities for improvement during the implementation phase. After the improvements, the RPN value for porosity decreased to 126, while tears in the wrapper decreased to 136.5. The implemented improvements proved effective in reducing defects and failures in the production process of PT PID Ongkowidjojo cigarettes, although the resulting decrease was not significant due to some recommended improvements that couldn't be implemented due to budget constraints.

4. Conclusions

The research has a limitation, namely the underutilization of gate symbols in FTA. Therefore, for further research, it is hoped that the full potential of gate symbols in FTA can be maximally utilized. Defects with the highest initial RPN were porosity or inappropriate density with an RPN value of 269.5. Then, for defects with the second-highest RPN, there were tears in the wrapper with a value of 231. Both types of defects became top priorities for improvement during the implementation phase. After a two-week implementation of improvements, the RPN value for porosity decreased to 126, while tears in the wrapper decreased to 136.5. The implemented corrective measures were able to reduce the RPN values, although the resulting decrease was not significant. This could be attributed to some recommended improvements that couldn't be implemented due to budget constraints.

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Analisis Efektivitas Mesin Cetak Flexo menggunakan Metode Overall Equipment Effectiveness Berbasis Six Big Losses (Studi Kasus: Industri Corrugated Box)

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Abstract. PT X is a manufacturing company operating in the integrated cardboard industry, utilizing various machines, including flexography machines. This study aims to analyze the primary causes of production deficiencies in the flexography process and provide improvement recommendations using the Six Big Losses-based Overall Equipment Effectiveness (OEE) method. The OEE analysis revealed that the average availability ratio is 88.8%, falling short of the world-class standard of 90%. A deeper analysis using the Six Big Losses methodology identified that the primary cause for not achieving the desired availability ratio is the high percentage of setup and adjustment losses, which stands at 7%. To address these issues, several recommendations are proposed. Firstly, conducting comprehensive training for operators on the proper and correct operation of flexography machines is essential. This training will enhance their technical skills and reduce the time lost during setup and adjustments. Secondly, implementing daily briefings for operators before shifts begin, coupled with regular supervision, will ensure consistent adherence to operational standards. Moreover, establishing a routine and time-limited cleaning schedule for machines and work locations will minimize unexpected downtimes due to maintenance issues. Finally, developing and enforcing standardized machine operation protocols will promote discipline among operators, ensuring that all procedures are followed meticulously. These recommendations aim to improve the overall efficiency of flexography machines, thereby increasing the availability ratio to meet or exceed the world-class standard. By addressing the root causes of production inefficiencies, PT X can enhance its operational performance and maintain its competitive edge in the cardboard industry.

Keywords: Availability ratio; Overall equipment effectiveness; Performance efficiency; Quality ratio; Six big losses

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1. Pendahuluan

Industri manufaktur karton adalah sektor yang sangat kompetitif dengan tekanan yang signifikan untuk mengurangi biaya dan meningkatkan efisiensi. Perusahaan dalam industri ini harus terus berinovasi dan memperbaiki proses produksi mereka untuk tetap kompetitif. Persaingan yang semakin ketat menuntut peningkatan produktivitas perusahaan, yang dapat dicapai melalui analisis dan perbaikan yang tepat sasaran (Sayuti *et al*., 2019; Pribadi *et al*., 2023; Septa & Putrianto, 2023; Soejanto *et al*., 2023; Aurelia *et al*., 2023).

PT X, sebagai salah satu produsen kotak karton terkemuka, menghadapi tantangan untuk mengoptimalkan kinerja mesin dan proses produksinya guna mempertahankan posisi kompetitif di pasar yang semakin ketat. Salah satu masalah utama yang dihadapi adalah kurang efektifnya mesin cetak flexo, yang disebabkan oleh berbagai faktor seperti kerusakan mesin, keterlambatan material, dan peralatan yang kotor atau aus. Permasalahan ini menyebabkan produksi terlambat, waktu yang lebih panjang untuk memulai proses produksi, kemungkinan produk cacat yang tinggi, dan keterlambatan pengiriman barang jadi kepada pelanggan.

Mesin cetak flexo di PT X memiliki kapasitas produksi maksimum sebesar 50 ton per hari, namun sering kali produksi melebihi kapasitas ini. Hal ini mengakibatkan nilai *availability* yang tidak mencapai standar kelas dunia. Oleh karena itu, diperlukan metode perbaikan untuk meningkatkan efektivitas Total Productive Maintenance (TPM) mesin cetak flexo. Metode yang dipilih adalah *Overall Equipment Effectiveness* (OEE) berbasis *Six Big Losses*, yang mampu mengidentifikasi dan mengelompokkan enam jenis kerugian utama yang mempengaruhi efektivitas peralatan: *breakdown, setup and adjustment, small stops, reduced speed, startup rejects*, dan *production rejects*.

OEE merupakan indikator kinerja mesin yang mencakup tiga aspek utama: *availability, performance*, dan *quality*. Menurut *Japan Institute of Plant Management* (JIPM), nilai sasaran kelas dunia untuk *availability* adalah di atas 90%, *performance* di atas 95%, dan *quality* di atas 99% (Dal *et al*., 2000). PT X telah mencapai nilai OEE kelas dunia sebesar 85%, namun nilai *availability ratio* belum mencapai target. Implementasi metode OEE berbasis *Six Big Losses* diharapkan dapat mengidentifikasi akar penyebab masalah dan mengusulkan strategi perbaikan yang tepat, sehingga nilai *availability ratio* dapat ditingkatkan sesuai dengan sasaran kelas dunia.

Penelitian sebelumnya oleh Sayuti *et al*. (2019), Pribadi *et al*. (2023), Septa & Putrianto (2023), Soejanto *et al*. (2023), Aurelia *et al*. (2023) dan Jessika *et al*. (2019) telah menyoroti pentingnya evaluasi kinerja fasilitas produksi dalam meningkatkan produktivitas perusahaan. Namun, masih terdapat gap dalam literatur terkait implementasi metode OEE berbasis *Six Big Losses* di sektor manufaktur karton. Penelitian ini bertujuan untuk mengisi gap tersebut dengan mengevaluasi kinerja mesin cetak flexo di PT X dan mengusulkan strategi perbaikan yang berbasis pada analisis *Six Big Losses*.

Penelitian ini bertujuan untuk mengidentifikasi faktor-faktor yang mempengaruhi efektivitas mesin cetak flexo di PT X, mengevaluasi kinerja mesin tersebut menggunakan metode OEE berbasis *Six Big Losses*, dan mengusulkan strategi perbaikan yang dapat meningkatkan nilai *availability ratio* sehingga mencapai sasaran kelas dunia.

2. Metode

2.1. Pengumpulan Data

Langkah pertama dalam penelitian ini adalah melakukan pengamatan langsung di PT X. Data yang dibutuhkan meliputi: *planned downtime*, *set-up and adjustment*, *failure and repair*, hasil produksi per hari, dan jumlah produk *reject setup* dan *reject and rework*. Data ini diperoleh melalui pengamatan langsung serta wawancara dengan operator mesin flexo, kepala bagian produksi, dan staf terkait.

2.2. Perhitungan OEE dan *Six Big Losses*

Setelah data terkumpul, langkah selanjutnya adalah melakukan perhitungan *Overall Equipment Effectiveness* (OEE) dan analisis *Six Big Losses*. OEE dihitung untuk mengetahui tingkat efektivitas mesin dengan menggunakan tiga komponen utama: *availability ratio, performance efficiency*, dan *quality ratio* (Affan, 2021; Blanchard, 1997)

2.3. Analisis Penyebab Ketidaktercapaian Target

Setelah nilai OEE dan *Six Big Losses* diperoleh, dilakukan analisis mendalam untuk mengidentifikasi penyebab ketidaktercapaian target pada: *availability ratio*, *performance efficiency*, *quality ratio* (Chikwendu, 2020). Analisis ini mencakup identifikasi faktor-faktor yang menyebabkan rendahnya nilai pada ketiga komponen tersebut.

2.4. Analisis *Six Big Losses*

Analisis lebih lanjut dilakukan pada *Six Big Losses*, yang meliputi: *equipment failure*, *set-up and adjustment losses, idle and minor stoppages losses, reduced speed, process defect losses*. Analisis ini bertujuan untuk menemukan akar penyebab dari kerugian-kerugian yang mempengaruhi performa mesin.

3. Hasil dan Pembahasan

Langkah pertama adalah perhitungan *Overall Equipment Effectiveness* dengan menghitung presentase *availability ratio, performance efficiency,* dan *quality ratio.* Data yang diambil dari bulan Agustus 2022 hingga Januari 2023. Berikut merupakan hasil dari perhitungan *availability ratio, performance efficiency,* dan *quality ratio:*

1. *Availability Ratio*

Tabel 1 Rata-Rata Nilai Availability Ratio

Jenis Mesin	Bulan	*Availability Ratio*
Flexo 1	Agustus	89,8%
	September	84,5%
	Oktober	87,4%
	November	92,0%
	Desember	95,0%
	Januari	94,5%
Flexo 2	Agustus	87,1%
	September	87,4%
	Oktober	85,1%
	November	87,9%
	Desember	93,1%
	Januari	90,3%
Flexo 3	Agustus	89,8%
	September	86,3%
	Oktober	82,4%
	November	89,4%
	Desember	92,9%
	Januari	91,1%
Rata-rata		88,8%

Tabel 1 menunjukan bahwa rata-rata nilai *availability ratio* flexo 1, flexo 2, dan flexo 3 bulan Agustus 2022 hingga Januari 2023 adalah 88,8% yang berarti belum mencapai target *availability ratio* kelas dunia, yaitu 90%.

2. *Performance Efficiency*

Tabel 2 Rata-Rata Nilai *Performance Efficiency*

Jenis Mesin	Bulan	*Performance Efficiency*
Flexo 1	Agustus	94,9%
	September	96,7%
	Oktober	97,2%
	November	96,7%
	Desember	97,5%
	Januari	97,1%
Flexo 2	Agustus	97,0%
	September	95,4%
	Oktober	95,5%
	November	97,7%
	Desember	97,8%
	Januari	97,8%
Flexo 3	Agustus	96,8%
	September	97,3%
	Oktober	96,6%
	November	97,5%
	Desember	97,4%
	Januari	97,6%
Rata-rata		96,8%

Pada tabel 2 terlihat bahwa rata-rata nilai *performance efficiency* dari flexo 1, flexo 2, dan flexo 3 bulan Agustus 2022 hingga Januari 2023madalah 96,8% yang berarti sudah mencapai target nilai kelas dunia, yaitu 95%.

3. *Quality Ratio*

Tabel 3 Rata-Rata Nilai *Quality Ratio*

Jenis Mesin	Bulan	*Quality Ratio*
Flexo 1	Agustus	99,6%
	September	99,7%
	Oktober	99,7%
	November	99,7%
	Desember	99,7%
	Januari	99,7%
Flexo 2	Agustus	99,7%
	September	99,7%
	Oktober	99,6%
	November	99,7%
	Desember	99,6%
	Januari	99,7%
Flexo 3	Agustus	99,6%
	September	99,6%
	Oktober	99,6%
	November	99,7%
	Desember	99,6%
	Januari	99,7%
Rata-rata		99,7%

Pada tabel 3 terdapat nilai rata-rata nilai *quality ratio* dari flexo 1, flexo 2, dan flexo 3 bulan Agustus, September, Oktober, November, Desember, dan Januaru adalah 99,7% yang berarti sudah sesuai dengan target nilai kelas dunia, yaitu 99%.

Setelah dilakukan perhitungan nilai *availability ratio, performance efficiency, dan quality ratio*, maka tahap berikutnya yaitu menghitung nilai *Overall Equipment Effectiveness* (OEE). Perhitungan nilai OEE menggunakan rumus sebagai berikut:

$$OEE = availability(\%) \times performance(\%) \times quality(\%)$$

$$OEE = 88{,}8\% \times 96{,}8\% \times 99{,}7\% = 85{,}7\%$$

Dari nilai OEE tersebut, maka dapat disimpulkan bahwa OEE sudah mencapai nilai target dunia, yaitu 85%, tetapi masih diperlukan usulan perbaikan pada nilai *availability ratio* karena masih belom mencapai nilai standar nya, yaitu 90%.

Langkah kedua adalah menghitung *Six Big Losses.* Data diambil dari bulan Agustus 2022 hingga Januari 2023. Berikut adalah hasil perhitungan *Six Big Losses:*

1. *Equipment Failure Losses*

$$Equipment\ failure\ losses = \frac{failure\ and\ repair}{loading\ time} \times 100\%$$

$$Equipment\ failure\ losses = \frac{6012}{167620} \times 100\% = 3{,}6\%$$

2. *Setup and Adjustment Losses*

$$Setup\ and\ adjustment\ losses = \frac{setup\ and\ adjustment}{loading\ time} \times 100\%$$

$$Setup\ and\ adjustment\ losses = \frac{11777}{167620} \times 100\% = 7\%$$

3. *Idle and Minor Stoppages*

$$Idle\ and\ minor\ stoppages = \frac{(jumlah\ target - jumlah\ produksi) \times ideal\ CT}{loading\ time} \times 100\%$$

$$Idle\ and\ minor\ stoppages = \frac{(11113454 - 10759086) \times 0{,}016}{167620} \times 100\% = 3{,}4\%$$

4. *Reduce Speed Losses*

$$Reduce\ speed\ losses = \frac{(actual\ CT - ideal\ CT) \times jumlah\ produksi}{loading\ time} \times 100\%$$

$$Reduce\ speed\ losses = \frac{(0{,}017 - 0{,}016) \times 10759086}{167620} \times 100\% = 3{,}1\%$$

5. *Defect Losses*

$$Defect\ losses = \frac{total\ reject \times ideal\ cycle\ time}{loading\ time} \times 100\%$$

$$Defect\ losses = \frac{27658 \times 0{,}016}{167620} \times 100\% = 0{,}3\%$$

6. *Reduce Yield*

$$Reduce\ yield = \frac{total\ reject \times ideal\ cycle\ time}{loading\ time} \times 100\%$$

$$Reduce\ yield = \frac{7829 \times 0{,}016}{167620} \times 100\% = 0{,}07\%$$

Hasil perhitungan nilai OEE, didapatkan nilai rata-rata OEE 85,7% yang berarti sudah mencapai nilai target dunia yang telah ditetapkan JIPM, antara lain 85%. Nilai yang cukup mempengaruhi perhitungan nilai OEE adalah nilai *availability ratio* dengan rata-rata sebesar 88,8%. Setlah melakukan perhitungan *Six Big Losses* dapat diketahui bahwa kerugian terbesar terdapat pada kerugian *setup and adjustment losses* dengan nilai sebesar 7%, kedua tertinggi *equipment failure losses* dengan nilai 3,6%, ketiga *idling and minor stoppages* dengan nilai 3,4%, keempat *reduce speed* dengan nilai 3,1% kelima *defect losses* dengan nilai 0,3%, dan yang terakhir nilai terendah terdapat pada *reduce yields* dengan nilai 0,07%. Dari perhitungan di atas dapat disimpulkan bahwa kerugian utama yang dialami dan sangat berdampak pada kinerja mesin flexo adalah *setup and adjustment losses dan equipment failure losses.* Sehingga keduanya menjadi prioritas utama dalam upaya perbaikan agar dapat meningkatkan nilai OEE.

4. Kesimpulan

Metode OEE berbasis *Six Big Losses* telah digunakan untuk menganalisis dan meningkatkan persentase nilai OEE. Langkah pertama adalah melakukan perhitungan terhadap OEE, dilanjutkan dengan perhitungan *Six Big Losses* untuk mengidentifikasi permasalahan lebih detail. Berdasarkan penelitian yang telah dilakukan, ditemukan bahwa masalah utama terletak pada *setup and adjustment losses* dan *equipment failure losses*. Tingginya waktu *setup and adjustment losses* dan *equipment failure losses* disebabkan oleh beberapa faktor, yaitu perbaikan pisau kupingan, listrik padam, perbaikan sensor conveyor, perbaikan pisau plong, masalah pada lem, perbaikan slotter, cuci karet, *setup* mesin, *adjust* tinta, sambung belting, *setting* karet, dan ganti roll conveyor.

Hasil perhitungan dan analisis menunjukkan nilai *availability ratio* dengan rata-rata sebesar 88,8%, *performance efficiency* dengan rata-rata sebesar 96,7%, dan *quality ratio* dengan rata-rata sebesar 99,7%. Berdasarkan nilai *availability ratio, performance efficiency,* dan *quality ratio*, diperoleh nilai OEE rata-rata sebesar 85,7%. Nilai ini sudah mencapai target kelas dunia OEE yang ditetapkan oleh JIPM, yaitu sebesar 85%. Namun, nilai *availability ratio* masih berada di bawah target kelas dunia, yaitu 90%.

Oleh karena itu, diperlukan beberapa usulan perbaikan untuk mencapai target *availability ratio* yang diharapkan, yaitu memberikan pelatihan kepada operator terkait pengoperasian mesin flexo yang baik dan benar, melakukan briefing harian kepada operator sebelum shift dimulai dan mengadakan pengawasan secara berkala, melakukan pembersihan mesin dan lokasi kerja secara rutin dengan pembatasan waktu, membuat standar operasional mesin, sehingga operator lebih disiplin dalam menjalankan tugas.

Dengan menerapkan usulan perbaikan tersebut, diharapkan nilai *availability ratio* dapat meningkat, sehingga keseluruhan nilai OEE juga dapat mencapai atau bahkan melampaui target kelas dunia. Implementasi perbaikan ini akan berdampak positif pada efisiensi operasional dan kualitas produk yang dihasilkan.

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Usability Test Using the System Usability Scale in the Industrial Engineering Laboratory at Universitas X Indonesia

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Abstract. In a quality education system, services are integral to delivering quality education. Providing excellent, effective, and efficient services to students is crucial for their success at the university, including laboratory services to support student practicum. However, the laboratory services in the Industrial Engineering Program Study at Universitas X in Indonesia seem to fall short of expectations and do not fully meet student needs. This study aims to assess the usability of the Industrial Engineering Laboratory services at Universitas X. The System Usability Scale (SUS) method is employed to gauge the service scale's effectiveness. The SUS score obtained in this study is 53, indicating that the services at the Industrial Engineering Laboratory Universitas X are categorized as acceptable but require improvement. Therefore, while the system created is deemed acceptable by its users, it needs enhancement to positively impact Industrial Engineering laboratory services.

Keywords: System usability scale, Services, Laboratory

1. Introduction

Educational institutions at both secondary and tertiary levels must possess quality and qualified human resources (HR). This includes not only teachers or lecturers but also competent educational staff to ensure maximum satisfaction among the stakeholders we serve. In higher education, stakeholders may include students, parents, or collaborating parties. However, since most activities in higher education revolve around students, excellent service must prioritize their needs. Miftah & Sari (2020) define service as the process of fulfilling needs directly through the activities of others.

It's crucial to realize that services to students should be executed excellently, efficiently, and in accordance with established procedures and quality standards. This ensures that the output of these services effectively addresses the problems faced by students on campus. Service quality, being the essence of service, must be evaluated based on the quality of the service itself. Abdullah Adzan (2022) identifies two factors influencing service quality: expected service and perceived

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service. Balancing these factors is essential to ensure good service quality and alignment between expectations and perceived performance. Service quality, a crucial indicator of organizational effectiveness, must be integrated into services provided to students on campus (Maulana et al., 2023).

The significance of laboratory service quality in student satisfaction is supported by various studies. Susanto et al. (2021) found that good service quality positively impacts customer satisfaction, echoed by Shofa et al. (2019) who suggest that customer satisfaction predicts loyalty in the education sector. Mahapatra & Kiran (2018) emphasize the role of service quality in shaping students' perceptions of university quality and loyalty to the institution. Thus, Universitas X must prioritize the quality of its laboratory services to enhance student satisfaction, perceptions of the university, and loyalty to the institution (Girsang, 2019).

This study employs the System Usability Scale (SUS) analysis (Miftah & Sari, 2020) to assess the usability of the Industrial Engineering Laboratory at Universitas X. SUS is chosen for its effectiveness in evaluating usability, as supported by Welda et al. (2020), Kosim et al. (2022), Tuloli et al. (2022), and Kaban et al. (2020). It is particularly suitable for evaluating service systems like laboratory services, focusing on factors such as learnability, efficiency, memorability, errors, and satisfaction (Defriani et al., 2021). Additionally, SUS requires a relatively small sample size, reducing costs and time (Shofa et al., 2019). This approach aligns with the need for verification and validation testing to ensure that laboratory services meet their objectives. However, further exploration is needed to address the research gap in the specific application of usability testing for service systems like laboratory services.

2. Methods

The study employs the field research method for data collection, involving physical visits to the research location. This method encompasses interviews, discussions, observations, and distribution of questionnaires. The focus of this study is the Industrial Engineering Laboratory at Universitas X. Data collection utilizes a questionnaire comprising various aspects. Researchers extract diverse data corresponding to the questionnaire items. The research was conducted during January-February 2023.

This study utilized a questionnaire based on the System Usability Scale (SUS) method, comprising 10 items. The instrument was distributed through Google Forms. Each question in the questionnaire consists of a five-point scale: 1 for "strongly disagree," 2 for "disagree," 3 for "undecided," 4 for "agree," and 5 for "strongly agree."

Respondents in this study are Industrial Engineering students at Universitas X who have utilized the laboratory facilities. The study aims to involve 60 respondents, including 44 males and 16 females. Below is a table 1 displaying the translation of items in the SUS Questionnaire instrument:

Table 1 System Usability Scale (SUS) item translation results

Item	Question	Scale
1	I think that I would like to use the Industrial Engineering Lab more often for practicum.	1 – 5
2	In my opinion, access to the use of the Industrial Engineering Lab does not need to be complicated/complex for practicum.	1 – 5
3	In my opinion, the Industrial Engineering Lab is easy to use for practicum.	1 – 5
4	I need help from someone who is an expert/understands how to use the Industrial Engineering Lab for practicum.	1 – 5
5	In my opinion, the facilities available in the Industrial Engineering Lab are sufficient for practicum.	1 – 5
6	In my opinion, many of the facilities available in the Industrial Engineering Lab do not support practicum.	1 – 5
7	In my opinion, ordinary people will quickly understand and easily use the Industrial Engineering Lab for practicum.	1 – 5
8	In my opinion, the Industrial Engineering Lab is too difficult to use for	1 – 5

Item	Question	Scale
	practicum.	
9	I feel that there are no obstacles when practising in the Industrial Engineering Lab.	1 – 5
10	I need to adapt first before using the Industrial Engineering Lab for practicum.	1 – 5

The SUS analysis utilizes a rating scale from 1 to 5 (x), with each question assigned a weight from 0 to 4, based on 10 given questions. These questions are categorized into two types: positive questions (numbered 1, 3, 5, 7, and 9) and negative questions (numbered 2, 4, 6, 8, and 10). Scores for positive questions (1, 3, 5, 7, and 9) are calculated by subtracting 1 from the rating scale (x-1), while scores for negative questions (2, 4, 6, 8, and 10) are calculated by subtracting the rating scale from 5 (5 - x). The sum of these scores is then multiplied by 2.5 to determine the SUS value. The range of assessment results for this study will be interpreted using an adjective scale, as illustrated in Figure 1.

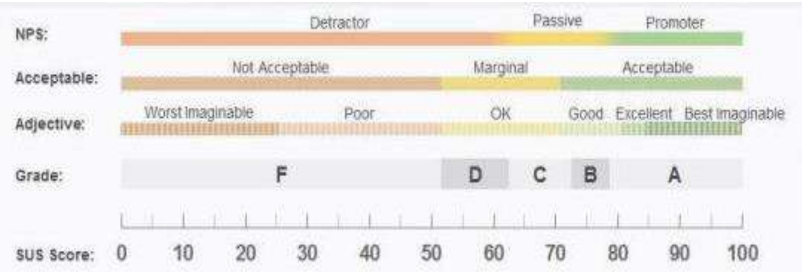

Figure 1 SUS Value Interpretation

3. Results and Discussion

In this study, the validity and reliability of the System Usability Scale (SUS) are determined using the two-tailed Pearson correlation test. This test is chosen to evaluate the relationship between the total scores of all questionnaire items and the desired validity measure. The two-tailed Pearson test offers insight into both the direction and strength of the relationship between the total questionnaire score and the validity measure. By analyzing the correlation value, this study ascertains the extent to which the questionnaire meets expected validity standards. Therefore, the decision to utilize the two-tailed Pearson test establishes a robust framework for assessing the validity of the SUS (table 2).

Table 2 Questionnaire Data Validity Test Results

	R_{count}	R_{table}	Description
Q1	0,324	0,2144	Valid
Q2	0,639	0,2144	Valid
Q3	0,434	0,2144	Valid
Q4	0,476	0,2144	Valid
Q5	0,546	0,2144	Valid
Q6	0,614	0,2144	Valid
Q7	0,561	0,2144	Valid
Q8	0,648	0,2144	Valid
Q9	0,551	0,2144	Valid
Q10	0,699	0,2144	Valid

This study conduct reliability testing on each question collectively using the Cronbach's Alpha (α) method. This selection is based on the necessity to gauge the internal consistency of the questionnaire items. The Cronbach's Alpha method specifically evaluates the level of consistency or reliability of a measurement instrument consisting of multiple items or questions. Through this reliability test, researchers can ascertain the extent to which the questionnaire questions are consistent in measuring the same variable, thus ensuring the reliability and accuracy of the research findings.

Table 3 Reliability Test Results of Questionnaire Data (Reliability Statistics)

Method (a)	Item Number	Description
0.741	10	Reliable

The reliability test results (Table 3) yield a coefficient alpha of 0.741 for the 10 questionnaire statements, indicating a high level of reliability. Generally, when the alpha value exceeds 0.60, the questionnaire items are considered reliable.

Regarding the System Usability Scale assessment results, they are categorized as follows:

a. Grade

This type of grading system for categorising SUS scores is in the A-F grade range. At grade A which indicates superior performance, grade B indicates excellent, grade C indicates average, grade D indicates poor, to F to indicate failed performance.

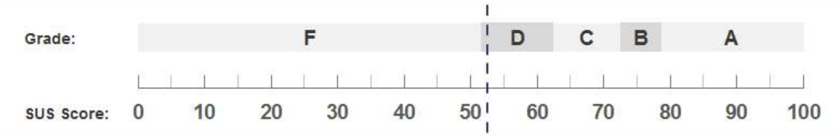

Figure 2 SUS Score in Grade Scale

With a SUS score of 53, correlating with a grade D on the scale (Figure 2), the findings suggest a low assessment of laboratory service quality. This indicates inadequate performance in areas such as equipment availability, staff effectiveness, and responsiveness to user needs. The link between this outcome and the questionnaire lies in users' evaluations of the usability and satisfaction regarding the provided laboratory services.

b. Adjectives

The adjective scale includes adjectives such as good, OK, and poor to categorize users broadly based on the usability of a product. For instance, an SUS score above 85 is associated with the Excellent category.

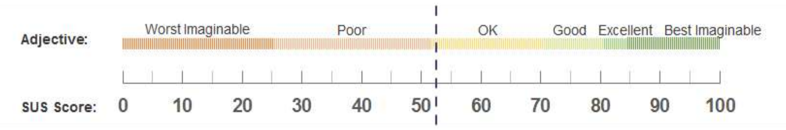

Figure 3 SUS Score in Adjectives Scale

In figure 3, with an SUS score of 53, the service at the Industrial Engineering Laboratory Universitas X is considered "OK" according to the adjective scale. However, respondents perceive a lack of utility, indicating that the service may not be deemed effective in achieving user goals. This could stem from inadequate equipment availability, complex procedures, or insufficient staff support. Improvements in these aspects may be necessary to enhance user perception of utility.

c. Acceptability

Another way to describe SUS is through statements of acceptability or unacceptability. According to Bangor (2009), these terms are defined when the SUS score is well above average or well below average. SUS scores above 70 (which is higher than the average SUS score of 68) are categorized as acceptable, while scores below 50 are deemed unacceptable (closely related to scores lower than 51.6 with an F value). Scores falling within the range of 50-70 are considered marginally acceptable or acceptable but in need of improvement.

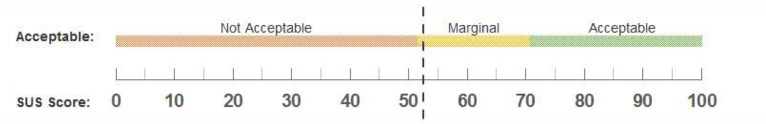

Figure 4 SUS Score in Acceptability Scale

In Figure 4, with a SUS score of 53, the services of the Industrial Engineering Laboratory Universitas X are categorized as marginally acceptable on the Acceptability scale, indicating the need for improvement. This suggests that although meeting minimum standards, the service quality does not fully satisfy users, resulting in hesitancy in recommending it. Critical areas for improvement include equipment availability and quality, staff competency and responsiveness, as well as the effectiveness of the communication and feedback system. Enhancements in these areas are expected to elevate user satisfaction and loyalty, while also enhancing the laboratory's image and reputation.

d. Net Promoter Score (NPS)

NPS classifies recommenders into three categories based on their responses to potential points (ranging from 0 to 100). Promoters are those scoring between 90 and 100, passives fall within the range of 70 to 80, and detractors score 60 or below. Promoters are highly likely to recommend the product/website/app/service to others, while passives find it acceptable but may not actively promote it, and detractors are inclined against recommending it.

The diagram in figure 5 illustrates the correlation between NPS and SUS scores. Achieving a promoter classification typically necessitates an average SUS score close to 81. On the other hand, a detractors classification aligns with an average SUS score of 53 or lower, while passive falls in between with an average score of approximately 70.

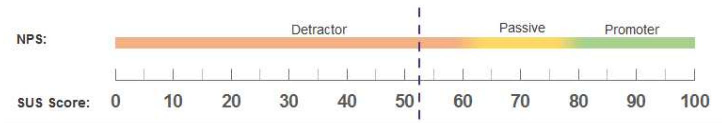

Figure 5 SUS Score in NPS Scale

The SUS score in this study is 53, indicating placement in the detractor category according to NPS. Respondents generally refrain from recommending Universitas X's Industrial Engineering Laboratory services. To address this issue, proposed solutions include enhancing equipment quality and availability, instituting regular staff training, and improving communication and responsiveness to user feedback. Implementation strategies may involve upgrades to equipment, more effective inventory management, comprehensive training programs, and the establishment of a transparent feedback mechanism. The responsibility for these improvements should be assigned to the lab management, with support from the industrial engineering department and the university's quality assurance unit, ensuring cohesive coordination and continuous enhancement.

4. Conclusions

This research contributes to the general improvement of laboratory services by identifying areas in need of enhancement using the SUS (System Usability Scale) method. With a SUS score falling in the D range and categorized as "OK," along with a classification on the acceptability scale as "marginal" and acceptable, the study reveals that while laboratory services meet minimum standards, there remains significant room for improvement. Correlating these results with the NPS (Net Promoter Score) classification in the detractor category emphasizes the necessity of enhancing services to elevate user satisfaction levels. These findings hold relevance not only for the industrial engineering laboratory at Universitas X but also offer valuable guidance to other laboratories seeking to enhance their service quality and achieve optimal user satisfaction.

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Cycle Time Study in Improving Production Output in the Garment Industry Sewing Line

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Abstract. The garment industry is one of the fastest-paced production environments, where speed and accuracy are crucial for meeting global customer demand. Cycle time plays an important role in satisfying the speed factor as it represents the overall time needed to produce a single piece of a product. Maintaining an appropriate cycle time is key to achieving production line balance. This study aims to analyze the cycle time of men's jacket production on a sewing line in an Indonesian garment industry by comparing the actual cycle time with the standard cycle time based on the operation breakdown for each production process step. Four significant discrepancies in actual cycle time are identified, ranging from 16% to 95%, indicating that the actual cycle time was significantly longer than the standard cycle time. The root cause of the highest cycle time is analyzed using Fishbone and 5 Whys analysis to understand the problem from each factor and sub-factor. Six improvement action plans are proposed and implemented, resulting in a 57.81% reduction in actual cycle time, from 127.66 seconds to 53.85 seconds, making it 17.66% faster than the standard cycle time. Furthermore, the total output per hour increased by approximately 216.67%, from 12 pieces to 38 pieces. This result implies that the study successfully identified the root of the problem on the sewing line and managed to increase production output.

Keywords: Cycle time; Fishbone diagram; Five whys analysis; Garment industry; Production output

1. Introduction

The garment industry in Indonesia is one of the sectors that absorb a significant amount of labor. According to data from the Central Bureau of Statistics in 2022, the garment industry employs 2% of the workforce in the manufacturing sector. This industry plays an important role in national revenue and global competition. As of early 2024, the textile and garment industry

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contributes 5.8% to the non-oil and gas GDP. Additionally, the growth rate of the textile and garment industry in the first quarter of 2024 is 5.92% compared to the fourth quarter of 2023. The rapid development of the garment industry in Indonesia requires companies to compete in both product quality and production efficiency. The challenge of production efficiency is constantly faced by the garment industry, especially in the sewing line, which is the main area in garment manufacturing. Therefore, studies to improve efficiency and productivity in the sewing line, such as focusing on cycle time, are still needed.

PT Garmen is one of the garment industries producing ready-to-wear clothing such as men's shirts, pants, kids' wear, dresses, jackets, and more. These products are marketed both domestically and internationally. For international markets, PT Garmen must compete in terms of quality, production speed, and timely delivery according to buyer demands and standards. One of the products marketed internationally is the men's jacket with the Kurabo San style.

To meet the demands for production speed and timely delivery, PT Garmen establishes a standard production cycle time outlined in the operation breakdown. The operation breakdown is a method of preparing a sequential list of operations on a single page. This operation breakdown includes information such as sewing and non-sewing operations, the name of the machines used, and estimated time for each operation (Puranik & Patel, 2021). Cycle time is the interval required to produce one unit of product from start to finish. The condition for this cycle time is that it must not be shorter than the slowest workstation's production time (Alam et al., 2022). If this condition is not met, the production line balance will not be achieved. Variations in cycle time calculation can be influenced by the differing skills of operators in performing the production process (Larasati & Laksono, 2022).

Based on observations in line B1, there is a discrepancy between the cycle time in the operation breakdown and the actual cycle time in the field. The highest discrepancy occurs in the "Attaching sleeve lining" process, with the operation breakdown stating 65.40 seconds while the actual field value is 127.95 seconds. The actual output is 12 pieces per hour, whereas according to the operation breakdown, the output should be 31 pieces per hour with a production period of 5 days for a total production of 1000 pieces.

Several studies on cycle time and standard time in the garment industry have been conducted. The standard time as an analysis of actual processes in garment preparation was conducted using the stopwatch method by the Industrial Engineering Department (Yudhistira et al., 2022). Cycle time can also be predicted using neural networks, as applied by Cao and Ji (2022). Cycle time is used by Oktyajati et al. (2023) as a reference in calculating throughput time to analyze productivity in garment production using a one-piece flow system. One-piece flow is a lean manufacturing method focusing on completing one item before starting another. Kurnianingtias et al. (2021) also analyzed bottlenecks in waistband production in the textile industry. The study found that bottlenecks occur because one production process has a cycle time longer than the takt time. Takt time is the time needed to produce one unit of product based on customer demand speed (Sugiyarto et al., 2021). Improvements were made using Kaizen, reducing the cycle time by 30%, thus achieving production line balance. Jadav et al. (2017) used time study as a basis for productivity improvement in making leggings and shirts.

This study analyzes the cycle time differences in producing the men's jacket Kurabo San style between the operation breakdown and actual cycle time. The factors causing cycle time differences in the sleeve lining attachment process are analyzed, and recommendations are made to reduce the actual cycle time, bringing it closer to the operation breakdown time. The objective of this study is to analyze cycle time differences and propose problem-solving recommendations to improve efficiency and strengthen the garment industry's competitiveness in the global market.

2. Methods

This study observes and analyzes the cycle time in the production process of Men’s Jackets at PT Garmen. The cycle time in this production process is divided into two categories: the cycle time established in the Operation Breakdown (OB) and the actual cycle time occurring on the production line. The OB cycle time is determined by the Engineering Prepare Department during the creation of the men's jacket product sample before mass production is undertaken by the Sewing Department. This OB cycle time value serves as the standard cycle time that must be met for each stage of the production process. Observations are then made on the actual cycle time during the mass production of men's jackets. The cycle time for each production stage is calculated and then compared with the OB cycle time to determine the percentage difference. The four highest cycle time discrepancies in the men's jacket production process are identified. The percentage differences in cycle time are calculated using the method described in Formula 1.

$$Percentage\ difference = \frac{actual\ cycle\ time\ value}{operation\ breakdown\ cycle\ time\ value} \times 100\% \quad (1)$$

The process with the highest cycle time discrepancy between the operation breakdown (OB) and the actual time will be further analyzed using one of the seven tools methods, the Fishbone Diagram. The Fishbone Diagram is used to identify the causes of a problem based on man, machine, method, material, and environment (Neyestani, 2017). The Fishbone Diagram is also frequently used to solve production process issues, particularly in the textile and garment industry, such as in yarn production (Afifuddin, 2020) and women's sportswear production (Kurnianingtias et al., 2022). To deepen the analysis, the 5 Whys analysis will be employed, continually asking "why"—typically five times—to determine the cause of nonconformity (Kasanah & Suryadini, 2021). This 5 Whys analysis will reveal the root cause of each failure or contributing factor (Khairunnisa et al., 2022). The 5 Whys analysis will be conducted for each factor: man, machine, method, material, and environment, analyzing each sub-factor until the root cause is identified. Improvement actions will be proposed for each identified root cause. These corrective actions will be implemented in the production line, followed by a recalculation of the cycle time after the improvements. The production output and process cycle time post-improvement will be compared to the cycle time before the improvements to measure the effectiveness of the proposed solutions.

3. Result and Discussion

The issue addressed in this study occurs in the production process of men's jackets. Observations over a period of 7 days reveal a significant discrepancy between the predetermined cycle time (cycle time from the operation breakdown) and the actual cycle time in the production line. The four most significant time discrepancies in the men's jacket production process are presented in Table 1.

Table 1 Cycle time

No	Process	Operation Breakdown (second)	Actual condition (second)	Difference (%)
1	Stik Pasang Lapisan Lengan *k/k*	65,40	127,66	95%
2	Stik Krah	22,31	39,12	75%
3	Blabar Lapisan Zipper + Jepit Zipper	39,60	62,07	56%
4	Blabar Pasang Zipper Pada Lapisan	74,94	87,58	16%

Source: *Engineering Preparation Department*, 2022

The cycle time in the operation breakdown is predetermined by the Engineering Preparation Department. The percentage differences shown in Table 1 were calculated using the formula mentioned in the methods section. The output recorded during data collection was 12 pieces per hour, whereas the operation breakdown data indicates that the output should be 31 pieces per hour over a five-day production period. Table 1 reveals that the highest discrepancy occurs in the “Stitch Sleeve Lining” process, with a calculated cycle time of 127.66 seconds. This results in a time difference of 95% from the predetermined cycle time of 65.40 seconds. This significant discrepancy must be addressed promptly to ensure smooth production line output.

The "Stitch Sleeve Lining" process involves sewing the lining fabric to the sleeve fabric. In this case, the men's shirt is made from 65% polyester and 35% cotton for the main fabric and 100% cotton for the lining. The stitching process for the sleeve lining is depicted in Figure 1. The actual cycle time observed by Engineering Preparation for the "Stitch Sleeve Lining" process was 127.66 seconds, as detailed in Table 2.

Source: Data *Sewing Line* B1, 2022

Figure 1 Stitching on Sleeve Lining

Table 2 Cycle time calculation for sleeve lining stitch installation

Time Observation **(second)**						***Rate*** **(*x*) second**	**Performance (*P*)+1point**	***Normal Time*** **(*x.P*) second**
1	**2**	**3**	**4**	**5**	**6**			
169,6	169,88	164,84	168,40	167,2	167,92	167,97	0,76	127,66

Source: *Engineering Preparation Department*, 2022

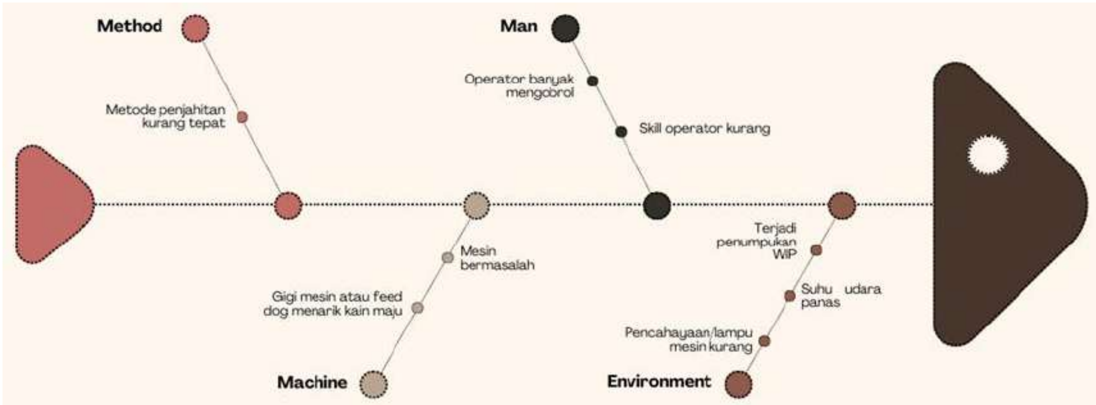
To obtain the time observation, Engineering Preparation conducted six cycle observations. The cycle time calculation starts when the operator picks up the component and ends when they pick up the next one. The average rate of the "Stitch Sleeve Lining" process is derived from these six cycles. This rate is then multiplied by the performance value. At PT Garmen, the Engineering Preparation Department uses the Westinghouse method with an additional 1-point rating to determine the performance value. Multiplying the average rate by the performance value yields the normal time for the process in seconds. The calculation method used at PT Garmen to determine normal time is shown in Table 3.

Table 3 Determining normal time

	Formula
Nilai *Rate*	$\frac{Sum\ of\ 6\ Cycle\ Observations}{Number\ of\ Cycles}$
Normal Time	*Rating value × Rating performance*

Source: *Engineering Preparation Department,* 2022

The observations indicate that the issue arises from the operator taking too long to handle the fabric. The handling involves adjusting the lining fabric while sewing to ensure neat stitching and prevent twisting. Several other factors influencing this issue include method, man, machine, and environment. A fishbone diagram in Figure 2 illustrates the root causes of this problem.



Source: Personal data, 2022

Figure 2 Fishbone diagram

The factors causing the cycle time calculation difference in the "Sleeve Lining Stitch" process are shown in Table 4. Root cause analysis using the 5 Whys tool for each contributing factor is detailed in Table 5.

Table 4 Factors contributing to issues

Factors	Factors Contributing to Issues
Method	**Improper Stitching Method:** During the initial production of sleeve lining stick installation, the guide was placed on the left side of the machine foot, 10mm away from the machine needle. This caused the final stitch size to differ from the sample. The sample stitch size was 10mm, but due to the incorrect method used by the operator, the stitch size became 12mm-15mm. Before correction, the operator took a long time to adjust the stitch size to match the sample.
Man	**Lack of Operator Skill:** The operator is new and not accustomed to sewing jacket styles, as the B1 line is specialized in Blazer production. This caused the operator to take longer to complete the Kurabo-San style. Additionally, the operator was slow and cautious during the sewing process due to inexperience. **Excessive Talking:** Operators often engaged in conversations during the sewing process, leading to inefficient time usage and impacting the line's target output.
Machine	**Incorrect Machine Setting:** During the first sewing attempt, the machine feed dogs pulled the fabric, resulting in twisted stitches. Before the machine was adjusted, the operator had to handle the fabric carefully to avoid twisting, which took additional time.
Environment	**Work In Process (WIP) Accumulation:** The accumulation of WIP restricted the operator's movement, requiring careful handling of the lining and sleeve fabric. The raglan sleeve type used in this style added complexity as the sleeve was already attached to the jacket. **Insufficient Machine Lighting:** The production of this men's jacket involved white fabric, necessitating higher light levels to see the stitches clearly. Poor lighting made the operator spend more time ensuring accurate stitching to avoid mistakes. **Hot Room Temperature:** The B1 line at PT Garmen is adjacent to the finishing area with pressing machines, causing the air to be warm due to steam from the boiler. This discomfort caused operators to frequently stop to wipe sweat, leading to motion waste that affected the cycle time.

Table 5 *Whys analysis*

Factors	Sub factors	Why 1	Why 2	Why 3	Why 4	Why 5
Method	Improper stitching method	Stitch size does not match the sample	Incorrect guide placement distance	No tool to determine guide placement	No specific SOP for guide placement	Lack of awareness of stitching method details

Factors	Sub factors	Why 1	Why 2	Why 3	Why 4	Why 5
			Incorrect sewing foot type	No SOP for sewing foot type for different fabrics	Lack of awareness of stitching method details	
Man	Insufficient operator skill	Operator's sewing speed is slower	Operator is not used to sewing jacket styles	Operator previously worked more on Blazer styles	Operator is new	
	Exccesive talking	Lack of operator discipline	Incomplete implementation of sewing SOPs by operators	Insufficient SOP supervision and evaluation by team leader	Inadequate SOP dissemination and guidance on proper sewing processes	
Machine	Machine problems	Feed dogs pulling the fabric, causing twisted stitches	Improper feed dog setting	Insufficient routine machine maintenance	Mechanics are not thorough in ensuring all feed dogs function properly	
Environment	Insufficient machine lighting	The fabric being sewn is white, requiring higher light levels to see the stitches	Operator did not promptly request a mechanic to replace the light	Uniform machine lighting for all fabric colors	No standards and specifications for lighting levels for different fabric colors	
	Hot room temperature	Air mixed with steam from the boiler in the finishing area next to the sewing line	No specific temperature control for the area around the finishing section	No additional cooling devices like AC or fans	Room temperature is not well-standardized	
	WIP accumulation	Many components are not yet sewn	Components require extra handling, taking longer to process	Components being sewn are raglan sleeves (extending fully to the collar)		

After identifying and analyzing the root causes of the cycle time discrepancy in the sleeve lining stitch process, improvement suggestions are provided in Table 6. Implementing these suggestions led to a reduction in cycle time for the sleeve lining stitch process, as shown in Table 7.

Table 6 Corrective actions analysis

Factor	Sub factor	Cause	Resolution
Method	Improper Stitching Method	Lack of method detail awareness	Change the guide placement from the left to the right side of the presser foot, 10mm from the needle, using the CR 3/8 sewing foot for this style and material.
Man	Insufficient Operator Skill	New operator	New operators should undergo training and receive guidance from sewing staff, leaders, engineering prepare, and sample team on efficient stitching methods.
	Excessive Talking	Lack of SOP awareness and guidance	Issue warnings and emphasize the importance of following sewing SOPs and staying focused to meet output targets.
Environment	Insufficient Machine Lighting	No specific lighting standards	Develop standards for lighting levels for different fabric colors and ensure operators promptly request lighting adjustments.
	Hot Room Temperature	Unregulated room temperature	Monitor and adjust room temperature according to set standards, adding fans to cool the B1 line area if necessary.
Machine	Machine issues	Inadequate mechanical adjustments	Mechanics should adjust the feed dogs to prevent fabric pulling and twisting.

Source: Personal data, 2022

Table 7 presents the cycle time data for the sleeve lining stitch process after implementing the improvement suggestions in Table 6. The cycle time decreased from 127.66 seconds to 53.85 seconds, a reduction of 57.85%. This improved cycle time is also 17.66% faster than the standard cycle time from the operation breakdown. Implementing the solutions in Table 6 took three days and resulted in a significant increase in hourly output on line B1, from 12 pieces per hour to 38 pieces per hour, a 216.67% increase.

Table 7 Final cycle time calculation data

Time Observation (second)						Rate (x) second	Rating Perform (p) +1	Normal time ($x.p$) second
1	2	3	4	5	6			
57,91	59,21	58,80	58,22	58,81	58,29	58,54	0,92	53,85

Source: Personal data, 2022

4. Conclusions

This study observes and analyzes the production cycle time of men's jackets on the sewing line of a garment industry. Four stages of the production process were examined, with the most significant discrepancies between the standard cycle time and the actual cycle time ranging from 16% to 95%. The actual cycle time was substantially longer than the standard cycle time, indicating issues within the production line. Fishbone and 5 Whys analyses were utilized to identify the causes and root problems of the high actual cycle time, particularly in the sleeve attachment process. Six corrective actions were proposed and implemented, resulting in a 17.66% reduction in cycle time for the sleeve attachment process, achieving faster than the standard cycle time. Additionally, the hourly output of the production line increased by 216.67%. This demonstrates that addressing production line issues by identifying root causes can not only reduce cycle time but also enhance productivity. The findings of this study are expected to serve as a reference for reducing production cycle time and resolving issues in garment production lines specifically, and in other industrial sectors generally. However, the corrective actions in this study focused solely on one production stage with the most significant cycle time discrepancy, without considering the entire production process. Therefore, further studies are recommended to conduct a comprehensive assessment of all stages of the process, considering value-added and non-value-added activities, as well as waste found in the production process. Implementing lean manufacturing techniques throughout all production stages could be done to identify and reduce waste.

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Determination of Physical Enviroment Factor Levels to Improve Productivity in the Filleting Process (Case study: PT Bumi Menara Internusa Surabaya)

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Abstract. PT Bumi Menara Internusa Surabaya is a producer of processed frozen seafood products, which uses a lot of human resources in its production. The use of human resources in the production process is closely related to productivity which will ultimately affect work efficiency and effectiveness. PT Bumi Menara Internusa itself has many products from various types of fish, one of which is salmon. The production process for frozen salmon products has several processing stages, one of which is the filleting process. The filleting process is a process where the fish flesh is separated from the fish backbone. To determine employee productivity in the production of frozen salmon products, employee output will be recorded every hour. Based on observations, records held by the company and interviews that have been conducted, it was found that employees in the fillet section were often unable to achieve the daily output targets that had been planned and calculated by the department concerned. Therefore, study was carried out using the Taguchi method to increase the productivity of salmon fillet employees. The results of the study carried out were an increase in productivity value of 3.556.

Keywords: Physical work environment; Productivity; Salmon fillet; Taguchi

1. Introduction

Work productivity is something that describes the results or outcomes of a person's activities by considering the resources/capital (time, land, money, etc.) to produce these outcomes. Productivity is a comprehensive measurement of the quantity and quality of goods or services produced by workers or machines and raw materials or resources as inputs (Nugroho, 2021). The work environment itself is divided into two, namely the non-physical work environment and the physical work environment (temperature, noise, light, and so on). The physical work environment means all the conditions that exist around the workplace, which will affect employees either directly or indirectly (Sedarmayanti, 2011). Increasing productivity is one way to increase profits (Sijoatmodjo & Hadi, 2021), increasing productivity is also a solution when the price of raw materials/inputs has increased (Hadi et al., 2018).

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PT Bumi Menara Internusa Surabaya is one of the producers of frozen seafood products, which in its production uses a lot of human resources. The use of human resources in the production process is closely related to productivity which will ultimately affect the efficiency and effectiveness of work. PT Bumi Menara Internusa itself has many products from various types of fish, one of which is salmon. The production process of frozen salmon products has several processing stages, one of which is the filleting process. The filleting process is a process where the fish meat will be separated from the fish backbone. To determine employee productivity in the production of frozen salmon products, employee output records will be made every hour. Based on observations, records owned by the company and interviews that have been conducted, it is often found that employees in the fillet section cannot achieve the daily output targets that have been planned and calculated by the section concerned.

Based on this description, the studyer wants to conduct a study with the title "Determination of Physical Environment Factor Levels to Increase Productivity in the Filleting Process at PT Bumi Menara Internusa" to determine the effect of physical environment factors on the work productivity of filleting employees of PT Bumi Menara Internusa Surabaya and the optimal physical environment tuning design. This study will use 3 physical environmental factors and each of these factors has 3 levels, the 3 factors are the type / genre of songs, light intensity, and sound intensity (production room noise combined with song sounds). After selecting the factors, the following levels are also determined for the song type factor: dangdut, pop, and jazz, then for the light intensity factor: 100-250 lux, 500-800 lux, and 850-1050 lux, then for the sound intensity factor: 75-80 dB, 80-85 dB, and 85-90 dB. The selection of factors and levels above is based on several previous studies and government regulations, namely study conducted by (Setiyanto, 2011), (Puspitaratna & Dwiyanti, 2013), (Khomariah et al., 2016), (Yusuf, 2013), (Andriyanti, 2007), Peraturan Menteri Ketenagakerjaan No. 5 Tahun 2018, Keputusan Menteri Negara Lingkungan Hidup No. 48 tahun 1996, (Padmanaba, 2006), and (Yusuf ,2013).

The experimental design method that studyers will use in this study is the taguchi method, the use of this method is because the taguchi method is a more efficient method than the full factorial method which suits the needs of studyers who need efficient study methods due to relatively short study time. The efficiency of the taguchi method can be seen from the number of trial combinations that are less than the full factorial method so that it can save study time.

This study aims to determine the physical work environment factors that affect the productivity of the filleting section of the production of frozen salmon products at PT Bumi Menara Internusa Surabaya. This study also aims to find the best setting level of each of these influential factors, then further this study also wants to analyse the results of implementing the optimal setting level of these influential factors on the productivity of the filleting section.

2. Methods

2.1 Experimental Design

Experimental Design is a systematic effort in designing a design through the action of conditioning several factors (Montgomery, 1997). According to Iriawan & Astuti (2006), experimental design aims to determine input variables (factors) that can influence the response, determine factors that make the response approach or reach the desired value, and determine input variables that cause small variations in the response.

2.2 Taguchi Method

The Taguchi method is divided into three main stages that cover all experimental approaches. The three stages are planning, implementation and analysis (Pranogyo, 2020). Then the three stages can be described in more detail into problem formulation, determination of experimental objectives, determination of independent variables, identification of factors, separation of control factors and disturbance factors, determination of the number of levels and level values of factors, calculation of degrees of freedom, selection of orthogonal arrays, forging columns for factors in the interaction into orthogonal arrays, conducting experiments, analysis stage, and confirmation experiments.

The study method describes the activities carried out during the study at PT Bumi Menara Internusa Surabaya. Figure 1 is a flowchart of this study:

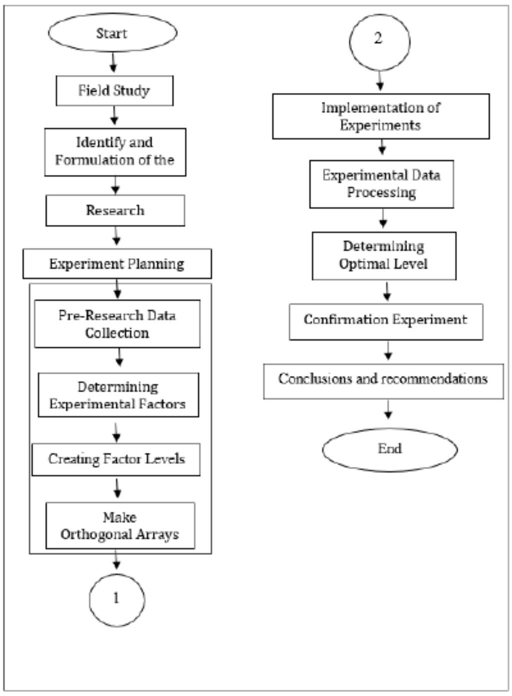

Figure 1 Study Flowchart

3. Results and Discussion

3.1 Experiment Implementation

The experimental implementation stage is carried out in accordance with the planning that has been made. In accordance with the previous stages of the experiment to be carried out is as many as 9 experiments and will be replicated twice. The combination of experiments to be carried out will be made with the help of Minitab software version 19. The combination of nine physical work environment experiments at PT Bumi Menara Internusa Surabaya can be seen in Table 1.

Table 1 Experiment Combinations $L_9(3^4)$

Eksperiment	Factors		
	Light Intensity	Sound Intensity	Type of Music
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	3	1	3
7	3	2	3
8	3	2	1
9	3	3	2

With a description of the level of each factor, namely for the light intensity factor level 1 is 100-250 Lux, level 2 is 500-800 lux, level 3 is 850-1050 lux, then for the sound intensity factor level 1 is 75-80 dB, level 2 is 80-85 dB, 85-90 dB, and for the music type factor level 1 is dangdut, level 2 is pop, and level 3 is jazz.

Experiments were run according to table 1 above. For example, when running the first experiment, the first level of each factor will be used which is 100-250 lux light, 75-80 dB sound intensity, and dangdut music. The implementation of the experiment will begin with setting the lighting, music and sound intensity at the station that has been provided. Then the employees for fillets will alternately go to the station to carry out salmon fillet activities, data collection of fillet output will be taken per hour and will be repeated twice, the implementation of the experiment will be carried out at 09.00-12.00 and continued again at 13.00-14.00.

Because the study situation was carried out directly when the production process in the factory was running, so that it had to pay attention so that the production process was not disrupted during the experiment, the implementation of the experiment (as described in the previous paragraph) was not ideal. Where the ideal experimental process is the collection of data on the output of fillet division employees in each combination should be carried out by all fillet division employees simultaneously instead of alternately as was done in this experiment.

3.2 Experiment Result Data

After the experiment implementation stage is carried out, a record of the fillet results of each employee in each experimental combination will be obtained, which will then be used to calculate the average output of the fillet division employees or in this study will be equated with the productivity (output / input) of the fillet division. The productivity of the salmon fillet division can be seen in Table 2.

Table 2 Productivity Data of Fillet Division

Combination	Fillet Division Productivity	
	R1	R2
1	93.333	94.667
2	87.000	84.000
3	90.667	91.333
4	86.000	84.000
5	84.000	86.667
6	100.000	100.667
7	81.667	83.333
8	95.333	90.667
9	92.000	94.00

3.3 Data Processing of Experiment Results

3.3.1 Calculation of Means and Signal to Noise Rasio (SNR)

At this stage, the average value and signal to noise ratio of the fillet output of each experimental combination will be calculated. The mean and SNR calculation data for each experiment can be seen in Table 3.

Table 3 Calculation Results of Mean and SNR

Combination	Fillet Division Productivity		SNR	Mean
	R1	R2		
1	93.333	94.667	39.4619	94.000
2	87.000	84.000	38.6353	85.500
3	90.667	91.333	39.1807	91.000
4	86.000	84.000	38.5866	85.000
5	84.000	86.667	38.6192	85.333
6	100.000	100.667	40.0288	100.333
7	81.667	83.333	38.3277	82.500
8	95.333	90.667	39.3615	93.000

Combination	Fillet Division Productivity		SNR	Mean
	R1	R2		
9	92.000	94.000	39.3682	93.000

3.3.2 ANOVA Calculation for Mean Values

At this stage, the ANOVA calculation will be carried out for the average value. This calculation will use formulas 2.2 to 2.16. This ANOVA calculation is done using the Minitab version 19 application. The results of the ANOVA calculation for the average value can be seen in Table 4.

Table 4 ANOVA Resluts for Mean Values

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Light Intensity	2	0.969	0.969	0.4846	0.32	0.760
Sound Intensity	2	105.228	105.228	52.6142	34.37	0.028
Type of Music	2	155.784	155.784	77.8920	50.88	0.019
Residual Error	2	3.062	3.062	1.5309		
Total	8	265.043				

In interpreting the results of ANOVA calculations, hypothesis testing will be carried out. The F table value is determined through the F table based on the free degree of treatment, namely 6 as F1 and the free degree of error, namely 2 as F2. The F table values for free degrees 6 and 2 (F1=6 and F2=2) at the 5% and 1% levels are 19.33 and 99.33, respectively. If you want to use the formula in Microsoft Excel, the formula used is FINV(α;df1:df2).

After obtaining the value of the F table, the next step is to compare this value with the results of F count. This comparison is done by hypothesis testing on each factor used in the experiment. The following hypothesis test is used for decision making in this study.

1. Light Intensity
   H0 : There is no effect of light intensity on the productivity of fillet employees
   H1 : Light intensity affects the productivity of fillet employees
   α : 0.05 or 5%
   CR : F count > F table 5% or F count > F table 1%
   F count : 0,32
   F table : 19.33 (5% level) and 99.33 (1% level)
   Decision : Accept H0, because F count < F table 5% or 0.32 < 19.33
   Conclusion: F count < f table at the 5% level, then H0 is accepted, meaning that light intensity has no effect on the productivity of fillet section employees.
2. Sound Intensity
   H0 : There is no effect of sound intensity on the productivity of fillet employees
   H1 : Sound intensity affects the productivity of fillet employees
   α : 0.05 or 5%
   CR : F count > F table 5% or F count > F table 1%
   F count : 34,37
   F table : 19.33 (5% level) and 99.33 (1% level)
   Decision : Reject H0, because F count > F table 5% or 34.37 > 19.33
   Conclusion: F count > F table at 5% level, then H0 is rejected, meaning that sound intensity has an influence on the productivity of fillet section employees and the difference between treatments is real.
3. Type of Music
   H0 : There is no effect of music type on fillet employee productivity
   H1 : Music type affects the productivity of fillet employees
   α : 0.05 or 5%
   CR : F count > F table 5% or F count > F table 1%
   F count : 50,88
   F table : 19.33 (5% level) and 99.33 (1% level)

Decision : Reject H0, because F count>F table 5% or 50.88>19.33

Conclusion: F count > F table at 5% level, then H0 is rejected, meaning that the type of music has an influence on the productivity of fillet section employees and the difference between treatments is real.

It can be seen from the results of the hypothesis test above, it can be concluded that the factors of sound intensity and music type have a significant influence on the productivity that can be produced by fillet employees and the differences between the effects of treatments are real. This is based on the calculated F value of the two factors which is greater than the F table at the 5% level. The results of the Main Effect Plot for the average value can be seen in Figure 2.

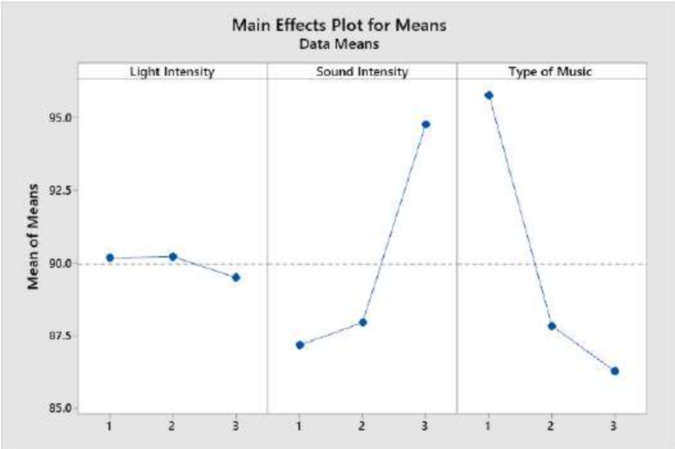

Figure 2 Main Effect Plot of Means Values

Based on Figure 4, it can be seen that when the sound intensity is at level 3, it produces the highest productivity value which can reach 94.7778 tails. In the music type factor, the productivity value of the fillet division is at level 1, which is 95.7778 tails. So it can be determined that the optimal level for influential factors based on the average experimental results is level 3 sound intensity factor (85-90 dB) and level 1 music type factor (dangdut).

3.3.3 ANOVA Calculation for SNR Value

Signal To Noise Ratio is a value of how well a process maintains consistency or accuracy with respect to relevant factors. The SNR calculation is performed to select the largest factor level to optimise the quality characteristics of the experiment. The SNR calculation formula depends on the characteristics of the desired results, where in this study using the larger is better characteristic. The way to interpret the SNR value is always the same in all characteristics, namely the greater the SNR value, the better. The steps taken are the same as the ANOVA calculation of the average value. ANOVA calculation of SNR aims to identify the effect of the level of the factor on the variability of productivity of fillet division employees. ANOVA calculations were performed using the Minitab version 19 application. The results of ANOVA calculations for SNR values can be seen in Table 5.

Table 5 Anova Results for SNR Values

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Light Intensity	2	0.00910	0.00910	0.004550	0.25	0.802
Sound Intensity	2	0.97236	0.97236	0.486181	26.46	0.036
Type of Music	2	1.41710	1.41710	0.708549	38.56	0.025
Residual Error	2	0.03675	0.03675	0.018374		
Total	8	2.43531				

In interpreting the results of ANOVA calculations, hypothesis testing will be carried out. The F table value is determined through the F table using the treatment free degree of 6 as F1 and the error free degree of 2 as F2. The F table values for free degrees 6 and 2 (F1 = 6 and F2 = 2) at the 5% and 1% levels are 19.33 and 99.33, respectively. If you want to use the formula in Microsoft Excel, then the formula entered is FINV (α;df1;df2).

After obtaining the value of the F table, the next step is to compare this value with the results of F count. This comparison is done by making a hypothesis test on each factor used in the experiment. The following hypothesis test is used in making decisions in this study.

1. Light Intensity
   H0 : There is no effect of light intensity on the productivity of fillet employees
   H1 : Light intensity affects the productivity of fillet employees
   α : 0.05 or 5%
   CR : F count > F table 5% or F count > F table 1%
   F count : 0,25
   F table : 19.33 (5% level) and 99.33 (1% level)
   Decision : Accept H0, because F count < F table 5% or 0.25 < 19.33
   Conclusion: F count < F table at 5% level, then H0 is accepted, meaning that light intensity has no influence on the variability of productivity of fillet section employees.
2. Sound Intensity
   H0 : There is no effect of sound intensity on the productivity of fillet employees
   H1 : Sound intensity affects the productivity of fillet employees
   α : 0.05 or 5%
   CR : F count > F table 5% or F count > F table 1%
   F count : 26,46
   F table : 19.33 (5% level) and 99.33 (1% level)
   Decision : Reject H0, because F count > F table 5% or 26.46 > 19.33
   Conclusion: F count > F table at 5% level, then H0 is rejected, meaning that sound intensity has an influence on the variability of productivity of fillet section employees and the difference between treatments is significant.
3. Type of Music
   H0 : There is no effect of music type on fillet employee productivity
   H1 : Type of music affects the productivity of fillet employees
   α : 0.05 or 5%
   CR : F count > F table 5% or F count > F table 1%
   F count : 38,56
   F table : 19.33 (5% level) and 99.33 (1% level)
   Decision : Reject H0, because F count > F table 5% or 38.56 > 19.33.
   Conclusion: F count > F table at 5% level, then H0 is rejected, meaning that the type of music has an influence on the variability of employee productivity in the fillet section among the real treatments.

As can be seen from the results of the hypothesis testing above, it can be concluded that the factors of sound intensity and music type have a significant influence on the variability of fillet productivity and the differences between the treatment effects are significant. This is based on the calculated F value of the two factors which is greater than the F table at the 5% level. The Main Effect Plot results for the average value can be seen in Figure 3.

The SNR value has a function to show how well the desired signal compares to unwanted noise in a system or process. The higher the SNR value, the better the quality or performance of the system. Based on Figure 5, the largest factor level value for each factor will be selected. The factor level that has the best SNR value is the sound intensity factor level 3 and the music type factor level 1.

3.4 Determination of Optimal Level Setting

After performing ANOVA calculations on the average value and SNR, the optimal level setting can be determined to increase the productivity of the fillet section. Determination of the optimal level setting is done using Minitab version 19. The results of the optimal level setting can be seen in Tables 6 and 7.

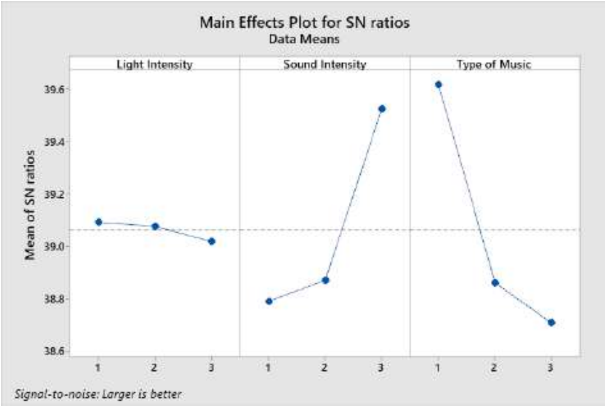

Figure 3 Main Effect Plot of SNR Values

Table 6 Optimal Setting Level

Faktor	Level	Setting Level
Intensitas Cahaya	2	500-800
Intensitas Suara	3	85-90 dB
Jenis Musik	1	Dangdut

Table 7 SNR and *Mean* Value of Optimal level Setting

S/N *Ratio*	Mean	StDev	Ln(StDev)
40.0948	100.852	0.680918	-0.598501

3.5 Calculation of Confidence Interval for Optimal Condition

1. Calculation of the confidence interval for the optimal condition of the average value. In this section there are two calculations, namely the calculation of $\mu_{prediction}$ and CI_{mean}. Here are the two calculations to get the confidence interval for the average optimal condition:
   - Calculation of $\mu_{prediction}$ or estimate of optimal conditions

     $\mu_{prediction} = \bar{y} + (\overline{A_2} - \bar{y}) + (\overline{B_3} - \bar{y}) + (\overline{C_1} - \bar{y})$ (1)

     $\mu_{prediction} = \overline{A_2} + \overline{B_3} + \overline{C_1} - 2\bar{y}$

     $\mu_{prediction} = 90{,}2222 + 94{,}7778 + 95{,}7778 - 2x89{,}963$

     $\mu_{prediction} = 100{,}852$
   - Calculation of CI_{mean}

     Before calculating CI_{mean}, it is necessary to calculate the value of n_{eff}. he following is the calculation of the value using the formula:

     $n_{eff} = \frac{Total\ Number\ Experiment}{1+Number\ of\ DF\ in\ the\ average\ estimate}$ (2)

     $n_{eff} = \frac{9\ x\ 2}{1+DF_A+DF_B+DF_C}$

     $n_{eff} = \frac{9\ x\ 2}{1+2+2+2} = 2{,}571$

   After getting the n_{eff} value, it is necessary to calculate the CI_{mean} value as follows:

   $CI_{mean} = \pm\sqrt{F_{(\alpha,v1,v2)} x\ MS_e x \frac{1}{n_{eff}}}$ (3)

   $CI_{mean} = \pm\sqrt{F_{(0{,}05,1,2)} x\ 1{,}5309 x \frac{1}{2{,}571}}$

   $CI_{mean} = \pm\sqrt{18{,}51 x\ 1{,}5309 x 0{,}3889}$

$CI_{mean} = \pm\sqrt{11{,}02}$

$CI_{mean} = \pm\ 3{,}319$

Based on the calculation results of $\mu_{prediction}$ and CI_{mean}, the optimal average value confidence interval is obtained as follows:

$$\mu_{prediction} - CI_{mean} \leq \mu_{prediction} \leq \mu_{prediction} - CI_{mean}$$

$$100{,}852 - 3{,}319 \leq \mu_{prediction} \leq 100{,}852 + 3{,}319$$

$$97{,}533 \leq \mu_{prediction} \leq 104{,}171$$

2. Calculation of the confidence interval for the optimal condition of the SNR value. In this section there are two calculations, namely the calculation of SNRprediksi and CISNR. Here are the two calculations to get the confidence interval for the average optimal condition:
   - Calculation of $SNR_{predictoni}$ or estimated optimal conditions
     $SNR_{prediction} = \overline{SNR} + (\overline{A_2} - \overline{SNR}) + (\overline{B_3} - \overline{SNR}) + (\overline{C_1} - \overline{SNR})$ (4)
     $SNR_{prediction} = \overline{A_2} + \overline{B_3} + \overline{C_1} - 2\ \overline{SNR}$
     $SNR_{prediction}$ = 39,0926 + 39,5259 + 39,6174 – 2x39,063
     $SNR_{prediction}$ = 40,1099
   - Calculation of n_{eff}
     Before calculating CI_{SNR}, it is necessary to calculate the value of n_{eff}. The following is the calculation of the n_{eff} value using formula 2:
     $n_{eff} = \frac{Total\ Number\ Experiment}{1+Number\ of\ DF\ in\ the\ average\ estimate}$
     $n_{eff} = \frac{9}{1+DF_A+DF_B+DF_C}$
     $n_{eff} = \frac{9}{1+2+2+2} = 1{,}286$

After obtaining the neff value, it is necessary to calculate the CI_{SNR} value as follows:

$CI_{SNR} = \pm\sqrt{F_{(\alpha,v1,v2)} x\ MS_e x \frac{1}{n_{eff}}}$ (5)

$CI_{SNR} = \pm\sqrt{F_{(0{,}05,1,2)} x\ 0{,}018374 x \frac{1}{1{,}286}}$

$CI_{SNR} = \pm\sqrt{18{,}51 x\ 0{,}18374 x 0{,}7776}$

$CI_{SNR} = \pm\sqrt{2{,}607}$

$CI_{SNR} = \pm\ 1{,}6146$

Based on the calculation results of $SNR_{prediksi}$ and CI_{SNR}, the optimal average value confidence interval is obtained as follows:

$$SNR_{prediction} - CI_{SNR} \leq SNR_{prediction} \leq SNR_{prediction} - CI_{SNR}$$

$$40{,}1099 - 1{,}6146 \leq SNR_{prediction} \leq 40{,}1099 + 1{,}6146$$

$$38{,}4953 \leq SNR_{prediction} \leq 41{,}7245$$

3.6 Confirmation Experiment

The data from the confirmation experiment can be seen in Table 8.

Table 8 Productivity Results of Fillet Division in the Confirmation Experiment

Day	Hours	Output	Input (Number of Workers)	Productivity Value
1	3	296	3	98.66667
1	4	300	3	100
1	5	296	3	98.66667
2	4	292	3	97.33333
2	5	306	3	102
2	7	290	3	96.66667
3	3	300	3	100
3	7	306	3	102

After getting the data from the confirmation experiment results, the average value (mean) and SNR will be calculated with the lager the better classification. The following is the calculation of the average value and SNR of the work environment of the confirmation experiment results:

1. Average score calculation (*mean*)

$$\mu = \frac{1}{n}\sum_{i=1}^{n} yi \quad (6)$$

$$\mu = \frac{1}{8}(98{,}667 + 100 + 98{,}667 + 97{,}333 + 102 + 96{,}667 + 100 + 102)$$

$$\mu = \frac{1}{8}(795{,}333) = 99{,}41667$$

2. SNR value with larger is better classification using the formula using formula 2.19

$$SNR = -10 \log\left(\frac{1}{n}\sum_{t=0}^{n}\frac{1}{Y_i^2}\right) \quad (7)$$

$$SNR = -10 \log\left(\frac{1}{8}\left(\frac{1}{98{,}667^2} + \frac{1}{100^2} + \frac{1}{98{,}667^2} + \frac{1}{97{,}333^2} + \frac{1}{102^2} + \frac{1}{96{,}667^2} + \frac{1}{100^2} + \frac{1}{102^2}\right)\right)$$

$$SNR = -10 \log\left(\frac{1}{8}(0{,}00010272+0{,}0001+0{,}00010272+0{,}00010555+0{,}00009611+0{,}000107+0{,}0001+0{,}00009611\right)$$

$$SNR = -10 \log\left(\frac{1}{8}(0{,}00071391\right)$$

$$SNR = -10 \log (0{,}00008923875)$$

$$SNR = 40{,}494$$

Furthermore, a confidence interval calculation will be carried out to determine whether the experimental design fulfils the existing requirements. The calculation of the confidence interval will be carried out on the average value and SNR. The following is the calculation of the confidence interval for the average value and SNR.

1. Calculation of the confidence interval for the mean value using formula 3:

$$CI_{mean} = \pm\sqrt{F_{(\alpha,v1,v2)} x\ MS_e x \left|\frac{1}{n_{eff}} + \frac{1}{r}\right|}$$

$$CI_{mean} = \pm\sqrt{F_{(0{,}05,1,2)} x\ 1{,}5309 x \left|\frac{1}{2{,}571} + \frac{1}{8}\right|}$$

$$CI_{mean} = \pm\sqrt{18{,}51 x\ 1{,}5309 x 0{,}05139}$$

$$CI_{mean} = \pm\sqrt{14{,}5638}$$

$$CI_{mean} = \pm\ 3{,}816$$

Based on the calculation of the mean (μ) dan CI_{mean}, the confidence interval of the confirmation experiment for the mean value is:

$$\mu_{confirmation} - CI_{mean} \leq \mu_{confirmation} \leq \mu_{confirmation} - CI_{mean}$$

$$99{,}41667 - 3{,}816 \leq \mu_{confirmation} \leq 99{,}41667 + 3{,}816$$

$$95{,}6 \leq \mu_{confirmation} \leq 102{,}8$$

2. Calculation of confidence interval for SNR value using formula 4

$$CI_{SNR} = \pm\sqrt{F_{(\alpha,v1,v2)} x\ MS_e x \left|\frac{1}{n_{eff}} + \frac{1}{r}\right|}$$

$$CI_{SNR} = \pm\sqrt{F_{(0,05,1,2)} x\ 0{,}018374x \left|\frac{1}{1{,}286} + \frac{1}{5}\right|}$$

$$CI_{SNR} = \pm\sqrt{18{,}51x\ 0{,}18374x0{,}9776}$$

$$CI_{SNR} = \pm\sqrt{3{,}3248}$$

$$CI_{SNR} = \pm\ 1{,}8234$$

Based on the calculation results of $SNR_{prediksi}$ and CI_{SNR}, the optimal average value confidence interval is obtained as follows:

$$SNR_{confirmation} - CI_{SNR} \leq SNR_{confirmation} \leq SNR_{confirmation} - CI_{SNR}$$

$$40{,}494 - 1{,}8234 \leq SNR_{confirmation} \leq 40{,}494 + 1{,}8234$$

$$38{,}67 \leq SNR_{confirmation} \leq 42{,}31$$

After obtaining the results of the confidence interval calculation for the confirmation experiment, the results will be compared with the optimal condition confidence interval. The following is a comparison of the optimal confidence interval with confirmation for each average value and SNR.

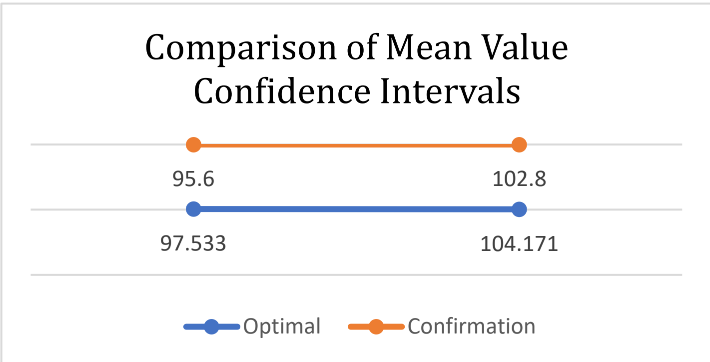

Figure 4 Comparasion of Mean Value Confidence Intervals

Based on Figure 4 above, it can be concluded that the results of the confirmation experiment for the average value are acceptable. It can be seen that the confirmation experiment confidence interval line intersects with the optimal condition confidence interval line.

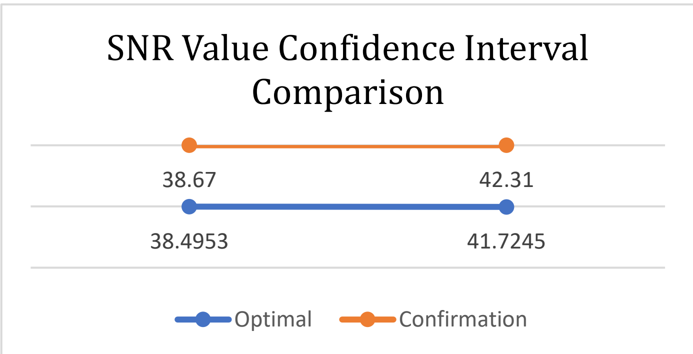

Figure 5 Comparison of SNR Value Confidence Intervals

Figure 5 above also shows that the results of the confirmation experiment for the SNR value are acceptable. It can be seen that the confirmation experiment confidence interval line intersects with the optimal condition confidence interval line.

After conducting the confirmation experiment stage, this comparison is carried out to determine whether there is an increase in productivity value or not, and whether there is a decrease in variation in productivity value after the experimental design is carried out with the optimal level combination. The following tables and graphs show the comparison of the productivity values of the initial and proposed fillet divisions.

Table 9 Comparison of Initial and Proposed fillet Division Productivity

Hour	Initial Productivity (Pre Study Data)	Proposed Productivity
3	98,96471	99,33334
4	92,36364	98,66667
5	92,84848	100,33334
7	99,26471	99,33334
Average	95,86	99,416

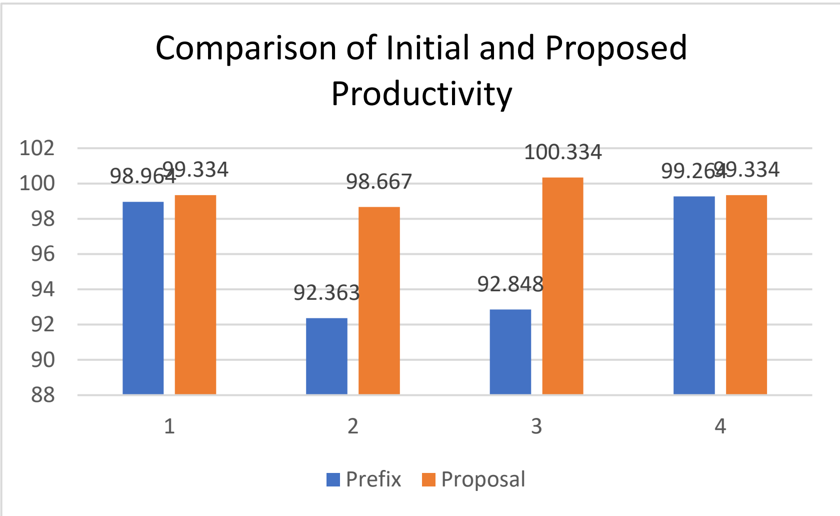

Figure 6 Comparison of Initial and Proposed Productivity

It can be seen in Table 9 and Figure 6 after the confirmation experiment, the average productivity value of the fillet division in the confirmation experiment is 99.416 which was previously only 95.86 which means an increase of 3.556. It can be concluded that the level setting in this confirmation experiment is considered to increase the productivity of the salmon fillet division at PT Bumi Menara Internusa.

4. Conclusions

From the Taguchi experiments conducted, an optimal physical environment tuning design was obtained for filleting activities in the production of frozen salmon products. The tuning design is a combination of levels and factors that can produce productivity values that are close to the target value and have the minimum variation possible. It can be seen from the comparison of initial and proposed productivity which has increased by 3.556. From the analysis that has been done, it is concluded that the factors that have a significant effect on the productivity of salmon fillet employees are sound intensity and song type. The optimal tuning design for these factors is sound intensity set at level 3 (85-90 dB), and music type at level 1 (dangdut).

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