ISSN 2622-2035 (Online)
ISSN 2622-2027 (Cetak)

TiBuana

Journal of Applied Industrial Engineering

1. The Influence of Occupational Safety for Iron Frame Installation Project Workers Using FMEA Approach in CV. Sinar Surya Abadi Sidoarjo
2. Design and Build of Dacron Pillow Filling Machine to Increase Production Capacity and Reduce Production Costs
3. Analysis of Ovality Deviation of Bending Superheater Tube Boiler Fabrication Process with Six Sigma Method in Manufacturing Company
4. Designing Improvement of Service effectiveness Using M/M/1 and M/M/S Queue Models (Case Study: Customer Arrivals at Jatim Park Tourist Destination During Holidays and Peak Hours)
5. The Effect of Using Crankcase Emission Control System Technology on the Performance of a 160 cc Single Cylinder Four Stroke Engine
6. Quality Matrix-Based Product Innovation in Birkinpet Pet Harness Apparel
7. The Overview Literature Review on Competence-Based Education in The Industrial Engineering Using PRISMA 2020
8. Autoregressive Integrated Moving Average (ARIMA) Simulation Methods In Product Inventory 9969B Printable Splicing Tape
9. Implementation of the Gravity Location Models Method in Determining Regional Warehouse Locations to Minimize Goods Transport Costs at PT X
10. Analysis Of Defects In Laminated Doors Using Failure Mode And Effect Analysis (FMEA) And Fault Tree Analysis (FTA)

Industrial Engineering Department
Faculty of Industrial Technology
University of PGRI Adi Buana Surabaya

JURNAL TEKNIK | VOLUME 7 | NOMOR 02 | JULY 2024 | UNIPA PRESS

Tibuana
Journal of applied Industrial Engineering-University of PGRI Adi Buana
p-ISSN 2622-2027
e-ISSN 2622-2035

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Tibuana
Journal of applied Industrial Engineering-University of PGRI Adi Buana

Publisher:
Program Studi Teknik Industri Universitas PGRI Adi Buana Surabaya

Publisher Address:
Jalan Dukuh Menanggal XII/4 Surabaya
http://jurnal.unipasby.ac.id/index.php/tibuana
e-mail : jurnaltibuana@unipasby.ac.id

Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8773.82-89 *e*-ISSN 2622-2035

The Influence of Occupational Safety for Iron Frame Installation Project Workers Using FMEA Approach in CV. Sinar Surya Abadi Sidoarjo

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Abstract – CV. Sinar Surya Abadi is a company engaged in the installation of iron frames. The manufacture of these products cannot be separated from hazardous equipment such as grinders, plasters, and others. This causes the risk of accidents at work. Thus the application of Occupational Safety and Health (K3) is very important to implement. Based on these problems, a study was made regarding the influence of work safety for project workers including iron with the FMEA approach on CV. Sidoarjo Eternal Sunshine. Occupational Health and Safety is a situation that affects the health and safety of workers or other employees. Occupational accidents can be reduced by implementing occupational safety and health (K3). FMEA is a structured procedure to identify and prevent as many failure modes as possible. FMEA focuses on preventing defects, increasing safety, and increasing customer satisfaction. The advantage of this FMEA is that it can improve the quality of control of the implementation of K3 so that it can prevent work accidents. FMEA serves to determine the actions of prioritized risks. The use of FMEA is also used to find out what potential risks exist in a production process. And also used to analyze failures from human error or the machine used.

Keyword: Refinement of Iron; K3; FMEA; Failure Mode

1. INTRODUCTION

CV. Sinar Surya Abadi is a company engaged in installing iron frames. The products produced by this company are mosque dome roofs, enamel domes, sloping roofs or pyramids, construction pipe construction, and other steel construction. The manufacture of these products certainly cannot be separated from dangerous equipment such as grinders, plasterers, etc. This causes the risk of accidents while working. Thus, the implementation of Occupational Safety and Health (K3) is very important to implement.

Product development and sustainability are important combinations and conditions starting from the design stage, selection of raw materials, typical products, product waste, (Rusdiyantoro, 2015) and especially the risks of such development. With work that is full of risks, the solution to overcome this needs to be research on the impact of work safety for workers on the project to install iron frames on CVs. Sinar Surya Abadi Sidoarjo. This research will focus on what risks will occur and how to overcome or prevent these risks from occurring. Where this risk is closely related to accidents during project work which can be overcome by implementing occupational safety and health (K3) appropriately and appropriately.

Work accidents can be reduced by implementing occupational safety and health (K3). K3 factors and the work environment must be considered, such as employees wearing Personal Protective Equipment, environmental conditions when working so that conditions are comfortable. The influence of K3 can be determined using the FMEA (Failure Mode and Effect Analysis) approach. (Arifuddin, 2022)

FMEA is a structured procedure to identify and prevent as many failure modes as possible. FMEA focuses on preventing defects, improving security, and increasing customer satisfaction. The advantage of FMEA is that it can improve quality control of K3 implementation so that it can prevent work accidents. (Elfira Vidian Paquita, 2022)

2. METHODS

The method used in this research is the Failure Mode and Effect Analysis (FMEA) method. FMEA aims to give weight to the assessment of factors that cause potential

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8773.82-89 *e*-ISSN 2622-2035

failure. In the process, FMEA will observe factors that cause potential failure, where these factors are obtained from identifying the causes of failure. Factors obtained from FMEA identification will be the main priority in handling failures. Data collection in this research was by interviews and using questionnaires. Questions asked during interviews and questionnaires are based on observations made on the CV. Sinar Surya Abadi Sidoarjo.

3. RESULTS AND DISCUSSION

This research data was taken using a questionnaire distributed to several respondents. The selection of respondents was carried out on project managers, safety engineers, safety engineer staff and field staff. From the preliminary survey that was carried out, the results of the risk variables were obtained which were not much different from the variables obtained in the previous stage. The results of this preliminary survey can be seen in table 1.

Table 1 Preliminary Survey Results

No	Potential risk	Relevant	Not Revelant
	Material and labor risks		
1	Long delivery of tools and materials	√	
2	Increase in material prices	√	
3	The volume of material sent is incorrect	√	
4	Damage and loss of materials in the field	√	
5	Lack of material storage space	√	
6	Lack of competent workforce	√	
7	Poor material quality	√	
	Implementation risk		
8	Incompatibility of foundation design	√	
9	Weakness of the dome foundation	√	
10	Incomplete and limited equipment	√	
11	Equipment that is no longer suitable	√	
12	Errors in structural calculations and analysis	√	
13	Problem with implementation coordination	√	
14	Heavy equipment accidents	√	
15	Heavy equipment is not working properly	√	
	Job management		
16	Lack of project manager experience	√	
17	Lack communication and coordination between parties involved in the project	√	
18	Poor implementation methods	√	

Apart from assuming that the risk is likely to occur or not, the preliminary survey assessment is also carried out by looking at and observing conditions in the field directly. Because if it is only done by assuming without looking at the conditions in the field, the results will likely be different from the actual conditions in the field. Based on this preliminary survey, a risk ranking can be carried out for each variable. The severity value in FMEA can be calculated in table 2.

Table 2 Failure Mode Effect and Analysis (Severity)

No	Potential risk	Failure mode	Effect	Risk event	Severity scale					SI	Category	Scale
1	Long delivery of tools and materials	Delivery of goods is late due to travel constraints	Work is delayed	Work is not completed on time	1	2	3	4	5	76	T	4
					0	0	2	2	1			
2	Increase in material prices	Price increase due to increase in fuel prices	Work costs become inflated	Prices do not match the agreement	1	2	3	4	5	28	R	2
					3	2	0	0	0			

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8773.82-89 *e*-ISSN 2622-2035

3	The volume of material sent is incorrect	There is not enough/excess material	If it is not enough then you have to buy more material	The work takes longer because you have to buy less material	1	2	3	4	5	24	R	2
					4	1	0	0	0			
4	Damage and loss of materials in the field	Reduced work materials	Reduces materials must be purchased immediately	Buy missing materials so that the price becames higher	1	2	3	4	5	52	C	3
					0	2	3	0	0			
5	Lack of material storage space	Materials will be easily stolen	Materials will decrease	Buy materials again	1	2	3	4	5	60	T	3
					0	0	5	0	0			
6	Lack of competent workforce	An error occurred during project work	Correcting the error	Work exceeded the target time	1	2	3	4	5	52	C	4
					0	2	1	2	0			
7	Poor material quality	Products become damaged more quickly	Products become of lower quality	Customer will no longer trust the company	1	2	3	4	5	44	C	3
					0	4	1	0	0			
8	Incompatibility of foundation design	Disappointed customers	There are complaints from customers	Cancellation of cooperation	1	2	3	4	5	32	R	2
					2	2	1	0	0			
9	Weakness of the dome foundation	There was damage to the dome	There were complaints	Customer no longer trusted the company	1	2	3	4	5	76	T	4
					0	0	2	2	1			
10	Incomplete and limited equipment	Companies renting equipment	Rental costs are expensive	Costs can be a bit inflated	1	2	3	4	5	68	T	3
					0	0	3	2	0			
11	Equipment that is no longer suitable	Equipment is not working properly	Work is delayed	Work is not completed on time	1	2	3	4	5	28	R	2
					3	2	0	0	0			
12	Errors in structural calculations and analysis	Project not suitable	Project failed	Customer disappointed	1	2	3	4	5	68	T	3
					0	0	3	2	0			
13	Problem with implementation coordination	Miscommunication occurs	Project becomes a mess	Work id delayed	1	2	3	4	5	48	C	2
					0	3	2	0	0			
14	Heavy equipment accidents	Worker injured	Work delayed	Work not completed on time	1	2	3	4	5	64	T	3
					0	0	4	1	0			
15	Heavy equipment is not working properly	Tool becomes damaged	Work is delayed	It takes time to repair the tool	1	2	3	4	5	80	T	4
					0	0	2	1	2			
16	Lack of project manager experience	Managers find it difficult to organize workers	Work is messy	Work is not completed on time	1	2	3	4	5	72	T	3
					0	0	2	3	0			
17	Lack communication and coordination between parties involved in the project	Miscommunication occurs	Work is messy	Work is not completed on time	1	2	3	4	5	68	T	4
					0	1	2	1	1			
18	Poor implementation methods	Work is less organized	Work is delayed	Work is not completed on time	1	2	3	4	5	56	C	4
					0	3	1	0	1			

Severity is the first step to analyze risk by calculating how much impact/intensity the event affects the process output. Here is how to calculate the severity index.

$$S = \frac{\sum_{i=0}^{5} a_i x_i}{\sum_{i=0}^{4} x_i} \times 100\%$$

$$S = \frac{\sum_{i=0}^{5} (1\times 0)+(2\times 0)+(3\times 2)+(4\times 1)+(5\times 2)}{(5\times 5)} \times 100\%$$

$$S = \frac{2}{2} \times 100\% = 80\%$$

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8773.82-89 *e*-ISSN 2622-2035

From the severity index results of 80%, it is obtained that the failure mode at the project location is included in the "T" category. The following classification categories from the assessment scale on severity, occurrence and detection are as follows:

- Very low / very small(SR/SK) = $0.00 \leq S \leq 12.5$
- Low/small (R/K) = $12.5 \leq S \leq 37.5$
- Fair/moderate (C) = $37.5 \leq S \leq 62.5$
- Height/large (T/B) = $62.5 \leq S \leq 87.5$
- Very height/very large= $87.5 \leq S \leq 100$

Based on this preliminary survey, a risk ranking can be carried out for each variable. The Occurance value in FMEA can be calculated in table 3.

Table 3 Failure Mode Effect and Analysis (Occurance)

No	Potential risk	Failure mode	Couse	Occurance scale					OI	category	Scale
1	Long delivery of tools and materials	Delivery of goods is late due to travel problems	Delivery is stuck in traffic jams, roads are too narrow, roads are damaged	1	2	3	4	5	68	T	4
				1	0	2	0	2			
2	Increase in material prices	Simultaneous price increase	Fuel prices rise, dollar prices rise	1	2	3	4	5	40	C	2
				0	2	3	0	0			
3	The volume of material sent is incorrect	Material is insufficient/excessive	Supplier sends the wrong quantity	1	2	3	4	5	48	C	2
				0	4	0	1	0			
4	Damage and loss of materials in the field	Work materials are reduced	Materials are not tidied up when workers rest or return from work	1	2	3	4	5	52	C	2
				0	2	3	0	0			
5	Lack of material storage space	Materials will be easily stolen	Materials are left on the side of the road without being covered in plastic or tied	1	2	3	4	5	44	C	3
				2	0	3	0	0			
6	Lack of competent workforce	Errors occur during project work	Recruitment of worker does not match competency, there is no training period	1	2	3	4	5	84	T	4
				0	0	1	2	2			
7	Poor material quality	Product become damaged more quickly	In order to meet insufficient funds	1	2	3	4	5	28	R	2
				4	0	1	0	0			
8	Incompatibility of foundation design	Disappointed customer	Miscommunication occured between customer and worker	1	2	3	4	5	32	R	3
				2	2	1	0	0			
9	Weakness of the dome foundation	Damage to the dome	The material is of poor quality	1	2	3	4	5	36	R	2
				3	0	2	0	0			
10	Incomplete and limited equipment	Company rents equipment	Rental costs are expensive	1	2	3	4	5	68	T	3
				0	0	3	2	0			
11	Equipment that is no longer suitable	Equipment does not work properly	Equipment has been used for long time and is outdated	1	2	3	4	5	64	T	3
				0	2	0	3	0			
12	Errors in structural calculations and analysis	Project do not match	Miscommunication occurs between customers and workers	1	2	3	4	5	60	T	3
				1	0	2	2	0			
13	Problem with implementation coordination	Miscommunication occurs	Inexperienced manager	1	2	3	4	5	48	C	2
				0	3	2	0	0			
14	Heavy equipment accidents	Workers injured	Lack of implementation of K3 and work SOPs	1	2	3	4	5	64	T	3
				0	0	4	1	0			
15	Heavy equipment is not working properly	The equipment is damaged	The equipment is old and worn out	1	2	3	4	5	64	T	3
				0	1	2	2	0			
16	Lack of project manager experience	Managers find it difficult to manage workers	Managers are inexperienced	1	2	3	4	5	72	T	3
				0	0	2	3	0			
17	Lack communication and coordination between parties involved in the project	Miscommunicatiion occurs	Work is messy	1	2	3	4	5	68	T	4
				0	1	2	1	1			
18	Poor implementation methods	Work is less organized	Workers do not apply SOPs when working	1	2	3	4	5	56	C	4
				0	3	1	0	1			

Tibuana
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Based on this preliminary survey, a risk ranking can be carried out for each variable. The detection value in FMEA can be calculated in table 4.

Table 4. Failure Mode Effect and Analysis (Detection)

No	Potential risk	Failure mode	Design control	Skala detection					DI	Kategori	Skala
1	Long delivery of tools and materials	Delivery of goods is late due to travel problems	Ordering materials must be several days before the work day	1	2	3	4	5	76	T	4
				0	0	2	2	1			
2	Increase in material prices	Simultaneous price increase	Minimize funds for other things	1	2	3	4	5	56	C	3
				0	2	2	1	0			
3	The volume of material sent is incorrect	Material is insufficient/excessive	Ensure the volume of materials with the supplier before delivery	1	2	3	4	5	64	T	3
				0	0	4	1	0			
4	Damage and loss of materials in the field	Work materials are reduced	Materials are tied and covered in plastic before being left home by workers	1	2	3	4	5	28	R	2
				3	2	0	0	0			
5	Lack of material storage space	Materials will be easily stolen	Create a simple materials warehouse	1	2	3	4	5	52	C	4
				2	0	2	0	1			
6	Lack of competent workforce	Errors occur during project work	Conduct competency training for workers	1	2	3	4	5	68	T	3
				0	0	3	2	0			
7	Poor material quality	Product become damaged more quickly	Look for suppliers who sell higher quality materials	1	2	3	4	5	36	R	2
				3	0	2	0	0			
8	Incompatibility of foundation design	Disappointed customer	Immediately make improvements to the design	1	2	3	4	5	48	C	2
				0	4	0	1	0			
9	Weakness of the dome foundation	Damage to the dome	Make sure the basic foundation is strong before cementing	1	2	3	4	5	44	C	2
				2	0	3	0	0			
10	Incomplete and limited equipment	Company rents equipment	Renting goods of good quality	1	2	3	4	5	72	T	3
				0	0	2	3	0			
11	Equipment that is no longer suitable	Equipment does not work properly	Rent equipment that is still suitable	1	2	3	4	5	44	C	3
				0	2	2	1	0			
12	Errors in structural calculations and analysis	Project do not match	Perform structural calculations repeatedly and ensure they are correct before the project is carried out	1	2	3	4	5	68	T	2
				0	0	3	2	0			
13	Problem with implementation coordination	Miscommunication occurs	Carry out more detailed coordinated communication so that there are no misunderstandings	1	2	3	4	5	72	T	3
				0	0	2	3	0			
14	Heavy equipment accidents	Workers injured	Workers must be stricter about K3 and apllicble sops	1	2	3	4	5	64	T	3
				0	0	4	1	0			
15	Heavy equipment is not working properly	The equipment is damaged	Use and store the equipment according to the applicable SOP, so that equipment maintanance is better maintained	1	2	3	4	5	60	C	2
				1	0	2	2	0			
16	Lack of project manager experience	Managers find it difficult to manage workers	Choose managers who are experienced and familliar with other workers	1	2	3	4	5	72	T	3
				0	0	2	3	0			
17	Lack communication and coordination between parties involved in the project	Miscommunicatiion occurs	Work in accordance with applicable K3 and SOP	1	2	3	4	5	72	T	4
				0	1	2	0	2			
18	Poor implementation methods	Work is less organized	Apply sops when applicable	1	2	3	4	5	64	T	4
				0	2	1	1	1			

Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana
p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8773.82-89 *e*-ISSN 2622-2035

Based on the FMEA calculation, the risk priority number (RPN) can be calculated. The RPN value in FMEA can be calculated in table 5.

Table 5. Risk Priority Number (RPN)

No	Potential risk	Failure mode	Effect of failure	Cause of failure	Current control	Existing conditions			
						S	O	D	RPN
1	Long delivery of tools and materials	Delivery of goods is late due to travel problems	Work is delayed	Delivery is stuck in traffic jams, roads are too narrow, roads are damaged	Ordering materials must be several days before the work day	4	4	4	64
2	Increase in material prices	Simultaneous price increase	Work costs become inflated	Fuel prices rise, dollar prices rise	Minimize funds for other things	2	2	3	12
3	The volume of material sent is incorrect	Material is insufficient/excessive	If it is not enough then you have to buy more material	Supplier sends the wrong quantity	Ensure the volume of materials with the supplier before delivery	2	2	3	12
4	Damage and loss of materials in the field	Work materials are reduced	Reduces materials must be purchased immediately	Materials are not tidied up when workers rest or return from work	Materials are tied and covered in plastic before being left home by workers	3	2	2	12
5	Lack of material storage space	Materials will be easily stolen	Materials will decrease	Materials are left on the side of the road without being covered in plastic or tied	Create a simple materials warehouse	3	3	4	36
6	Lack of competent workforce	Errors occur during project work	Correcting the error	Recruitment of worker does not match competency, there is no training period	Conduct competency training for workers	4	4	3	48
7	Poor material quality	Product become damaged more quickly	Products become of lower quality	In order to meet insufficient funds	Look for suppliers who sell higher quality materials	3	2	2	12
8	Incompatibility of foundation design	Disappointed customer	There are complaints from customers	Miscommunication occured between customer and worker	Immediately make improvements to the design	2	3	2	12
9	Weakness of the dome foundation	Damage to the dome	There were complaints	The material is of poor quality	Make sure the basic foundation is strong before cementing	4	2	2	16
10	Incomplete and limited equipment	Company rents equipment	Rental costs are expensive	Rental costs are expensive	Renting goods of good quality	3	3	3	27
11	Equipment that is no longer suitable	Equipment does not work properly	Work is delayed	Equipment has been used for long time and is outdated	Rent equipment that is still suitable	2	3	3	18
12	Errors in structural calculations and analysis	Project do not match	Project failed	Miscommunication occurs between customers and workers	Perform structural calculations repeatedly and ensure they are correct before the project is carried out	3	3	2	18
13	Problem with implementation coordination	Miscommunication occurs	Project becomes a mess	Inexperienced manager	Carry out more detailed coordinated communication so that there are no misunderstandings	2	3	3	18
14	Heavy equipment accidents	Workers injured	Work delayed	Lack of implementation of K3 and work SOPs	Workers must be stricter about K3 and apllicble sops	3	3	3	27
15	Heavy equipment is not working properly	The equipment is damaged	Work is delayed	The equipment is old and worn out	Use and store the equipment according to the applicable SOP, so that equipment maintanance is better maintained	4	3	2	24

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8773.82-89 *e*-ISSN 2622-2035

16	Lack of project manager experience	Managers find it difficult to manage workers	Work is messy	Managers are inexperienced	Choose managers who are experienced and familliar with other workers	3	3	3	27
17	Lack communication and coordination between parties involved in the project	Miscommunicatii on occurs	Work is messy	Work is messy	Work in accordance with applicable K3 and SOP	4	4	4	64
18	Poor implementation methods	Work is less organized	Work is delayed	Workers do not apply SOPs when working	Apply sops when applicable	4	4	4	64

To calculate the RPN value, the following formula is used.

$$R = s \times o \times d$$

$$S = 4 \times 4 \times 4$$

$$S = 64$$

Based on the risk priority number value above, the priority improvements that must be carried out first are obtained from the mode of accident that occurred, namely material and labor risks and work management. This is because the RPN failure mode value for the potential risk of long delivery of tools and materials is 64, lack of communication and coordination between parties involved in the project is 64, and poor implementation methods are 64. From the results of the calculated RPN values, the highest failure mode values obtained in the mosque dome construction project are:

1. Long delivery of tools and materials
2. Lack of communication and coordination between parties involved in the project
3. Poor implementation methods

4. CONCLUSION

The conclusions obtained from the processing and analysis that have been carried out are as follows:

1. From the severity index results, the highest severity value was obtained, namely 80%, which is included in the "T" (High) category at project locations where heavy equipment is not working properly, which can cause the effects/impact of the equipment to be damaged. To avoid this, maintenance of work tools must be paid very strict attention to, so that the tools can function properly.
2. From the results of the occurrence index, the highest occurrence value was obtained, namely 84%, which is included in the "T" (High) category in handling failure modes in employment where there is a lack of competent workers, which is caused by the recruitment of workers not in accordance with competence and no training period. . To avoid this, the recruitment of workers must be in accordance with the worker's competency and skills required, then basic training is held as a training period for new workers so that workers can understand better when they enter the field.
3. From the results of the detection index, 76% is included in the "T" (High) category in handling failure modes for long delivery of tools and materials. To overcome this, material orders must be made several days before the work is carried out so that the material does not experience delays in delivery because the material has arrived at the project site earlier.
4. From the results of the RPN calculation, the highest value is 64. Based on these results, the priority improvements that must be made first regarding the mode of accident that occurred are material risks from the workforce and work management. This is caused by the RPN failure mode value for the potential risk of long delivery of tools and materials of 64, lack of communication and coordination between parties involved in the project of 64, and poor implementation methods of 64.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8773.82-89 *e*-ISSN 2622-2035

5. Form the calculated RPN results, the highest failure mode value obtained in the mosque dome constructing project is:
   a. Long delivery of tools and materials
   b. Lack of communication and coordination between parties involved in the project
   c. Poor implementation methods

5. ACKNOWLEDGEMENT

The author would like to thank friends who have helped the author in this research as well as the lecturers who have guided the author so that this paper can be completed. completed in a timely manner.

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Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana
p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8889.90-97 *e*-ISSN 2622-2035

Design and Build of Dacron Pillow Filling Machine to Increase Production Capacity and Reduce Production Costs

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Abstract- This research was conducted at Mr. Khambali's SME. Mr. Khambali's pillow SME is engaged in producing pillows and bolsters with an average daily production of 140 units. The problem in Mr. Khambali's pillow SME is that the production output often does not meet demand because the process of stuffing the dacron into the pillow sack takes 8 minutes. This research aims to increase production capacity and reduce production costs. The method used in this research is Anthropometry, which is a reference for designing the machine to ensure its safe and comfortable use. Then, work time measurement is conducted using the time study method, and the calculation of production costs is compared before and after the design process. The results obtained from the design process are an increase in production from 140 units to 230 units per day and a reduction in production costs from IDR. 23,801 to IDR. 14,705. This research concludes that after designing the Dacron pillow-filling device, production increased by 90 units, and production costs decreased by IDR. 9,096.

Keywords: Anthropometry, Production capacity, Production cost

I. INTRODUCTION

Mr. Imam Khambali's Pillow SME was established in 2017 and is located in Simonggirang Village, Prambon District, Sidoarjo Regency. This SME specializes in the production of pillows and bolsters. Mr. Imam Khambali's Pillow SME operates with both Make To Order (MTO) and Make To Stock (MTS) production systems. The MTS system is applicable when customers place orders for 400 units or more. The products manufactured by this SME include foam pillows, foam bolsters, dacron bolsters, and mattresses, and one of the products studied in this research is dacron pillows.

Dacron pillows are items used to support the head during sleep, made from dacron (a silk fiber extracted from cotton plants). The dacron pillows produced by this SME are rectangular and weigh between 600 and 700 grams. These products are popular among consumers due to their soft and comfortable nature.

The UMKM Bantal Pak Imam Khambali employs seven workers, including two pillow fabric sewers, two pillow fluffers, two pillow fillers, and one final sewing worker. In the production of dacron pillows, there are four processes with different processing times. As shown in the OPC (Operation Process Chart) below:

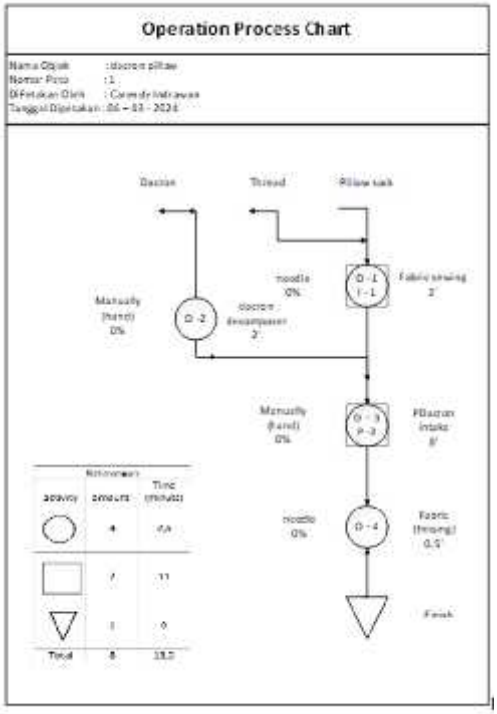

Figure 1. OPC pillow production

Mr. Khambali's Pillow SME produces pillows from Monday to Saturday. The daily production of dacron pillows amounts to approximately 140 units, and on average, it can reach 350 units per month, as shown in the table below:

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8889.90-97 *e*-ISSN 2622-2035

Table 1. Demand

Month	Production Data (Units)	Demand data (Units)
August	3.562	3.551
September	3.534	3.562
October	3.570	3.561
November	3.553	3.542
Desember	3.520	3.552

Based on the data, there is unmet demand at Mr. Khambali's Pillow SME. To fulfill this demand, the SME often resorts to overtime work, which increases operational costs. Additionally, the SME frequently rejects orders and refuses to accept orders from other customers. This is because they need to meet production targets and complete existing orders before taking on new ones, causing other customers to seek products elsewhere. Another issue is the frequent accumulation of raw materials (dacron), which disrupts workflow and reduces production efficiency.

Observations and interviews revealed that the primary reason for the unmet production demand is the low production capacity due to a time-consuming process: stuffing dacron into pillow sacks, which takes 8 minutes per unit. This process consumes significant time, resulting in low product output and causing a backlog of dacron, further hindering production efficiency.

To address these challenges, the researcher proposes a solution: the creation of a Dacron pillow-stuffing machine. The introduction of this machine is expected to increase production capacity and reduce production costs associated with dacron stuffing, enabling the SME to meet customer demand.

II. METHOD

In conducting the research, several stages were undertaken as follows:

1. Problem Formulation The first stage involves identifying the problem statement at Mr. Khambali's Pillow SME. The problem statement addressed in this research is the failure to meet customer demand.
2. Literature Review The literature review aims to gather data by searching for information from references or literature. In this research, the literature review involved gathering information from books such as Product Design, Design and Development of Manufacturing Products, Anthropometry for Work Systems, Ergonomics, Analysis and Design of Work Systems, and Engineering Economics. These books served as references for data management.
3. Field Study The field study aims to obtain direct data conducted at Mr. Khambali's Pillow SME, specifically focusing on the Dacron pillow product. Data acquisition was carried out through observation processes at the SME and interviews conducted with the SME owner and employees.
4. Data Collection Data collection in this research included gathering data on production capacity, production process times, number of employees, employee work hours, and anthropometric data of employees.

Table 2. Body dimensions

body dimensions	Purpose of measurement
Elbow height	To determine the height of the machine frame.
Shoulder height	To determine the height of the hopper support to the floor.
Hand Leght	To determine the reach of the hand to the machine.
Vertical grip reaches height	To determine the height of the output pipe.

This calculation is performed by 2 workers during the dacron pillow stuffing process.

5. Data Management The data obtained from anthropometric data collection undergoes data management, which involves testing data uniformity, adequacy, standard deviation, precision degree, and percentile calculation with sizes of 5th, 50th, and 95th. The results of data management are used to determine the ergonomic size of the Dacron pillow stuffing machine. The percentile calculation is formulated with the following equation.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8889.90-97 *e*-ISSN 2622-2035

$P = \bar{x} - .F\,\sigma$.....(1)

6. Machine Design Machine design is the stage of creating a tool according to the calculation data from anthropometry.
7. Analysis and Discussion Analysis and discussion are stages following the machine design. The results of the machine design are analyzed and compared. The first analysis involves analyzing the time calculation in producing one dacron pillow. The measurement is conducted using the stopwatch time study method. The calculations in this method include testing data uniformity, finding standard deviation, calculating control limits, testing data adequacy, determining performance rating, determining allowance, determining standard time, and establishing standard output. Additionally, the calculation of Production Cost (HPP) will be compared before and after the machine design.
8. Conclusion and Recommendations Conclusion is the final stage in conducting the research. The conclusion should be relevant to the objectives of this research. Meanwhile, recommendations are suggestions or inputs provided by the researcher to Mr. Khambali's Dacron pillow SME.

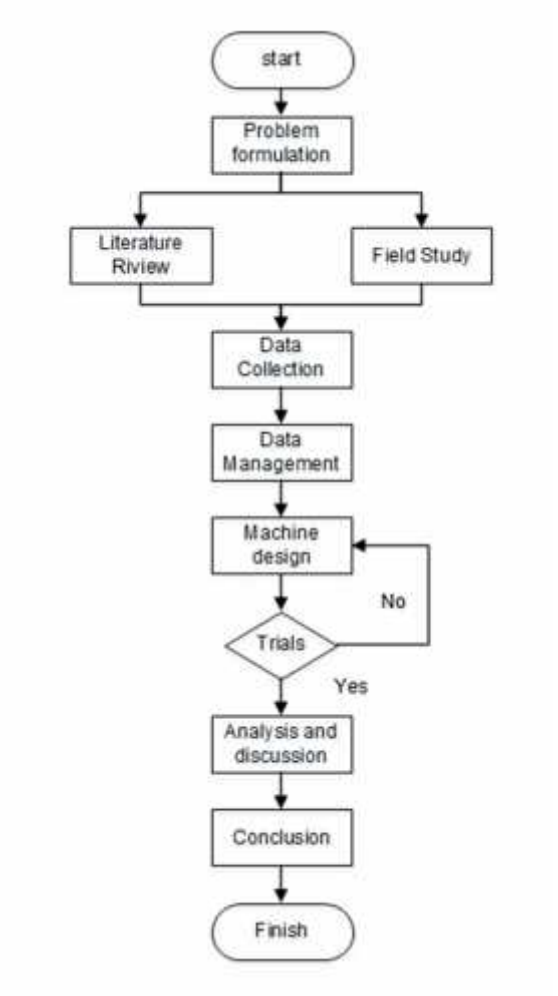

Figure 2. Flow Chart Study

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8889.90-97 *e*-ISSN 2622-2035

III. ANALYSIS

3.1. Data collection and processing

Anthropometry is a combination of Greek terms, "Anthro" meaning human, and "Metri" meaning measurement. It means measuring humans. From the aspect of physical anthropology, it refers to a process resulting from the measurement of the need to understand human physical variations (Kusnawa, 2015).

Table 3. Anthropometric data

Name	Anthropometric data of the body (cm)			
	Elbow Height (cm)	Shoulder height (cm)	Hand Leghtt (cm)	Vertical grip reaches height
kambali	92	146	75	78
Lastri	89	143	73	77
khotimah	90	144	74	77
binti	89	143	73	78

After obtaining the data in the table above, anthropometric data management will be conducted to calculate the standard deviation. Subsequently, percentile calculations will be performed, which will later be used for determining the appropriate size of the dacron pillow filling machine according to human body dimensions for comfortable and safe

Table 4. Employee body size

body dimensions	average	Standard deviation
Elbow height	90	1.414
(Shoulder height)	145	1.414
Hand Leght	71.75	0.957
Vertical grip reach height	76.5	0.577

Based on Table 4, each standard deviation is known and will be used for percentile calculations. Percentile calculations are performed using equation (1). Then, each percentile value will be determined as shown in the table below.

Table 5. Percentile Result

body dimensions	Percentile results		
	5-th	50-th	95-th
Elbow height	87	90	92
Shoulder height	141	145	146
Hand Leght	70	71.75	73
Vertical grip reach height	75.5	76.5	77.4

Based on Table 5, the percentile results for the 5th, 50th, and 95th percentiles are known. From these results, the percentile results for each body dimension will be chosen. For the Elbow height dimension, the 50th percentile result with a size of 90 cm is selected. This choice is made to determine the frame of the Dacron pillow-filling machine so that workers can comfortably use it because the size is neither too tall nor too short. For the Shoulder height body dimension, the 50th percentile result with a size of 145 cm is chosen. This selection is made to determine the height of the hopper to the ground of the dacron pillow filling machine so that workers can comfortably use it to fill raw materials because the size is neither too tall nor too short. For the Hand Leght body dimension, the 5th percentile result with a size of 67 cm is chosen. This selection is made to determine the area of the machine. For the Vertical grip reach height body dimension, the 50th percentile result with a size of 76 cm is chosen. This selection is made to determine the height of the output pipe to the ground of the dacron pillow filling machine so that workers can comfortably use it because the size is neither too tall nor too short.

The values of each body dimension will be used to determine the design size of the Dacron pillow-filling machine, as shown in the image below.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8889.90-97 *e*-ISSN 2622-2035

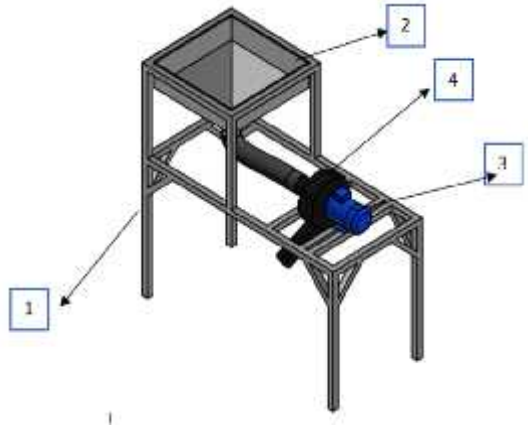

Figure 3. Dacron Machine

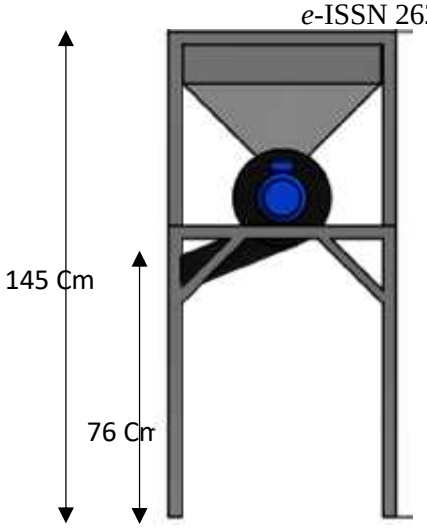

Figure 4. Side view machine

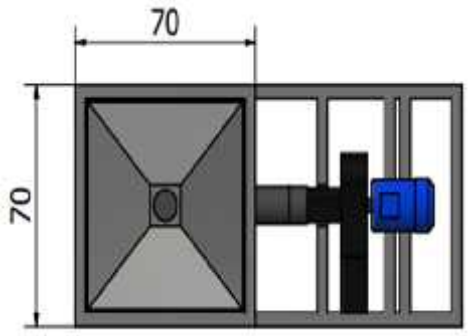

Figure 5. Machine top view

1. Frame The machine frame component consists of several parts:
   - Machine frame The machine frame is made of 4x4 hollow iron with a thickness of 2 mm, serving as the legs of the table measuring 150 cm in length, 90 cm in height, and 70 cm in width.
   - Dynamo holder The dynamo holder is made of 4x4 hollow iron with a thickness of 2 mm, serving as the dynamo support with a length of 70 cm.
2. Machine Drive
   - Electric motor The electric motor used to drive the fan is a single-phase electric motor, 2800 RPM, and 1 HP.
   - Drive fan The drive fan is made of PVC material with a diameter of 26 cm
3. Hopper
   - Hopper The hopper is made of iron plate with dimensions of 70 cm in length, 70 cm in width, and 40 cm in height, and it is funnel-shaped.
   - Hopper support The hopper support is made of angle iron with dimensions of 70 cm in length, 70 cm in width, and 40 cm in height, and it is funnel-shaped.
4. blower snail
   - Auger The auger is made of an iron plate with a diameter of 30 cm.
   - Suction hose The suction hose is made of pipe with a pipe diameter of 2.5 inches.

After designing the tool by incorporating anthropometric measurements of the workforce, the implementation of the Dacron pillow-filling machine will be carried out. This implementation aims to ensure that the design aligns with the research objectives. Below is the machine that has been successfully implemented, as depicted in the image below.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8889.90-97 *e*-ISSN 2622-2035

Figure 6. Machine dacron

After implementation, a trial will be conducted. The result obtained from the trial indicates that the time taken to fill the Dacron pillows using the Dacron pillow filling machine is 3.5 minutes. This marks a reduction in production time compared to the previous method of manual filling, which took 8 minutes. With this decrease, it is expected to increase the production output at Mr. Khambali's SME.

IV. DISCUSSION

4.1. Analysis of productivity and standard output

The productivity and standard output analysis aims to provide a comparison before and after the design of the Dacron pillow-filling machine. Productivity measurement is conducted by collecting data through observation 25 times during the process of filling dacron into sacks. This process involves 2 workers, each obtaining a daily output before design of 70 units with an 8-hour working time. Standard output measurement is done using the stopwatch time study method. The calculations in this method involve testing data uniformity, finding standard deviation, calculating control limits, conducting data sufficiency tests, determining performance rating, determining allowance, determining standard time, and determining standard output. The results obtained from these measurements are as follows, shown in the table below.

Table 6. Ratio Output

Ratio	Output per day	Output per O'clock
Before planning	140	8,7
After Planning	230	20.1

After implementation, a trial will be conducted. The result obtained from the trial indicates that the time taken to fill the Dacron pillows using the Dacron pillow filling machine is 3.5 minutes. This marks a reduction in production time compared to the previous method of manual filling, which took 8 minutes. With this decrease, it is expected to increase the production output at Mr. Khambali's SME.

$$P = \frac{f \quad s_i \quad -t \quad s_i}{t \quad a} \; x\,100\%$$

$$P = \frac{2 \quad -1}{1} \text{ x } 100\ \%$$

$$P = 64\ \%$$

4.2. Analysis of Production cost before and after planning.

Production cost analysis aims to determine the comparison of the price of polyester pillow products before and after planning. In the production cost analysis, costs are collected for the daily production process of polyester pillows. These costs include material costs, labor costs, machining costs, and overhead costs. The costs are as shown in the table below."

Table 7. Ratio Cost

Type of cost	Before planning	After Planning
Cost raw material	IDR. 2.754.000	IDR. 2.754.000
Labor cost	IDR.480.000	IDR.480.000
Cost machine cost	-	IDR. 20.050
overhead	IDR.962.300	IDR.962.300

After collecting cost data from Table 7 above, we will then calculate Production cost. Production cost is calculated by dividing the total overall costs by the daily capacity. The result of the Cost of Goods Manufactured calculation is shown in the table below.

Table 8. Ratio Production cost

Activity	Output per day	Production cost
Before planning	140	IDR.23.801
After Planning	230	IDR. 14.705

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.8889.90-97 *e*-ISSN 2622-2035

Looking at Table 8 above, it can be seen that the cost of goods manufactured before planning is IDR. 23,801, while after planning it is IDR. 14,705. The decrease in the cost of goods manufactured after planning the polyester pillow filling machine is."

Production cost Now = Production cost Before – Production cost After

Production cost New = IDR. 23.801 – IDR. 14.705

Production cost New = IDR. 9.310

IV. CONCLUSION

The results of the ergonomic design using anthropometric methods for Mr. Khambali's MSME polyester pillow filling machine are as follows: a frame height of 90 cm, a height of the hopper to the floor of 145 cm, a frame width of 70 cm, and an output height to the floor of 76 cm.

Analyzing the standard output calculation results after designing the polyester pillow filling machine, it yielded 230 units, while before the design, it produced 140 units per day. The presence of the polyester pillow filling machine increases productivity by 64% compared to the previous condition.

The results and analysis of the comparison of the production cost before the design amounted to IDR. 23,801, while after the design, it is IDR. 14,705. From these results, the design of the polyester pillow-filling machine is considered profitable and worthwhile to enhance production output at Mr. Khambali's MSME.

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Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106 *e*-ISSN 2622-2035

Analysis of Ovality Deviation of Bending Superheater Tube Boiler Fabrication Process with Six Sigma Method in Manufacturing Company

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Abstract - Quality control in fabrication is critical to the success of the production process. In this study, key factors in production quality control were identified by analyzing the influence on the tube bending process in fabrication work. Ovality deviations occur during the tube bending process that exceeds 9 percent. 30 boiler superheater tube elements had to go through the repair process. The causes of tube bending deviations were analyzed using the Six Sigma approach with the DMAIC (Define, Measure, Analyze, Improve, and Control) methodology. The causes of failure were analyzed using FMEA, and the highest RPN of 320 was obtained due to design planning and manufacturing of bending dies that are by the OD tube and the placement of clamp die and pressure die distances that are not too far apart. In addition, an RPN value of 294 was obtained due to the bending speed being too high. The recommendation for the next project is to consider using a C-Frame machine with better control to make it easier for operators to adjust the pressure, temperature, and speed of a good machine to better maintain ovality.

Keyword : Quality Control, Six Sigma, Superheater Tube Boiler, Failure Mode and Effect Analysis (FMEA)

I. INTRODUCTION

Progress in the industrial sector in Indonesia has increased every year. Research is needed on how to realize a product with the best quality that is expected to be used efficiently and effectively in the long term.

Quality control in fabrication is an absolute requirement for the success of a production process. This study aims to determine the things that need to be considered in controlling the quality of production by analyzing the things that hinder the bending process in fabrication work. So that the fabrication work can take place properly without disturbing the delivery schedule and preventing excessive production costs.

One of the manufacturing companies runs production with the fabrication process. One of the products produced is a boiler superheater tube for the needs of an industrial company. Fabrication was carried out in November 2022-January 2023. This manufacturing company is a fabrication service company, especially for pressure part products. With most employees who have decades of competence in their fields, this company has succeeded in becoming a trusted partner of large industrial companies in Indonesia.

During fabrication, there was a discrepancy in tube ovality from the customer specification. During a dimensional inspection by QC after the bending process, tube ovality of more than 9 percent was found. 30-element superheater tube boiler that has been produced must go through the repair process first in various ways. After that, the new tube ovality is obtained by the standard.

Based on the above problems, the company needs an improvement in product quality control, so that in this study is focused on reducing the level of non-conformity in the bending tube process which will be analyzed using a Six Sigma approach with the DMAIC (Define, Measure, Analyze, Improve & Control) stages, namely by measuring the defect rate of a product or DPMO (Defect Per Million Opportunities) and sigma value.

Six Sigma is the right method to prove the success of achieving quality improvement. With levels of numbers that show the current level of production quality to achieve targets for a company regarding product quality. So that with the Six Sigma method, an improvement proposal is obtained for the company to prevent the possibility of product discrepancies with standards again in the future to save time, effort, and costs, and the company can produce the best quality products.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106 *e*-ISSN 2622-2035

II. RESEARCH METHODOLOGY

According to (Montgomery, 1990) quality control is a process control activity to measure product quality characteristics, compare them with existing specifications or requirements, and take appropriate remedial action if there is a difference between actual appearance and predetermined standards.

2.1 Quality Control

Control is an activity carried out to ensure that production and operation activities are carried out according to what has been planned so that if there is a deviation, the deviation can be corrected and the specified expectations can be achieved (Buffa, 1999). Meanwhile, quality according to Assauri (1999) is the invoices contained in an item or result that causes the item or result to be by the purpose for which the item or result is needed. So quality control is a tool for management to maintain, improve, and maintain quality by reducing the number of defective products to provide benefits and satisfy customer desires (Mizuno, 1994). Quality can be interpreted as a product that has the maximum ability to include durability, reliability or progress, strength, ease of packaging, and when the product is damaged it is easy to repair or reparate it according to Luthfia (Razalie, 2019). According to Gasperz opinion in (Anjayani, 2011) is a way of continuously improving performance at the operation or process level, from any functional area of an organization, using available resources and existing capital.

2.2 Six Sigma

The Six Sigma method is one of the tools commonly used in product quality control. This method has the concept of setting quality standards to reach 3.4 deviations per one million possibilities. The Six Sigma method is divided into several stages to achieve product quality improvement. The use of the Six Sigma method can be used to determine the causes and factors that affect deviation to reduce defective production (Salomon, Ahmad, & Limanjaya, 2017).

The Six Sigma method is a method or way to achieve operating performance of 3.4 defects for every one million activities or opportunities. Six Sigma also provides proven benefits, which include cost reduction, productivity improvement, market share growth, defect reduction, and production or service development (Pande, 2002). So that using the Six Sigma method can provide suggestions for improvements (improve) to the company to reduce the level of defects in the product. (Gasperz, 2002).

2.3 DMAIC

Six Sigma DMAIC is often described as a methodology for solving problems (De Mast & Lokkerbol, 2012), (R. Krishnan & Prasath, 2013). Six Sigma requires tools that are used systematically (Naeem et al., 2016). The methods and techniques used in the Six Sigma DMAIC analysis can be seen in Table 1 (Thanhdat et al., 2016), (B. R. Krishnan & Prasath, 2014) and (Girmanová et al., 2017).

Table 1. Six Sigma DMAIC Methods and Techniques

Project Phase	Description	Tools and Technique
Define	1. Define the target of the improvement activity 2. Define the current state 3. Define the problem and identify defects	Project charter, stakeholder analysis, process flowchart, SIPOC diagram, CTQ definitions, Voice of the customer gathering, DMAIC Work breakdown structure
Measure	1. Data collection 2. Identifying possible causes of defects 3. Measuring the validity and reliability of the existing system	Process flowchart, Data collection plan, benchmarking, measurement system analysis, Voice of Customer gathering, process sigma calculation
Analyze	1. Analyze the system to identify measures to eliminate the gaps that arise 2. Perform identification based on the data owned 3. Identify the relationship between variables owned	Histogram, Pareto chart, time series/run chart, scatter plot, regression analysis, Cause and effect/fishbone diagram, 5 whys, process map review and analysis, statical analysis
Improve	1. Assess the causes of the biggest problems 2. Improve the system	Brainstorming, mistake proofing, design of experiment, QFD/House of Quality, Failure Modes and Effects Analysis (FMEA), Simulation Software
Control	Control the new system	Process sigma calculation, Control chart, Control plan

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106 *e*-ISSN 2622-2035

2.4 SIPOC Diagram

The SIPOC diagram is a tool used in the Six Sigma methodology, which is a visual image that describes how the process can provide services to customers. According to Anthony, Vinodh, & Gijo (2015: 83) in a book entitled Lean Six Sigma for Small and Medium Sized Entreprises. SIPOC (Supplier, Input, Process, Output, Customer) is a process improvisation tool that provides a key summary of inputs and outputs from one or in a continuous format.

The SIPOC diagram is a tool used by Six Sigma teams to identify all relevant elements in a process improvement before the process is carried out. This diagram helps in explaining a project that is complex and unclear in scope. In the DMAIC phase, this SIPOC diagram is found in the Measure phase. The explanation of the parts of the SIPOC diagram according to (Soemohadiwidjojo, 2017) is as follows:

1. Supplier - a person or group that provides information, raw materials, or other resources, to the process.
2. Input - something that feeds into the process
3. Process - a set of steps that process the input and add value to the input.
4. Output - the result of the process (product) or the final process.
5. Customer - the person group or process that receives the output.

2.5 DPMO (Defect Per Million Opportunity)

In the six sigma method, mismatches or offgrades are errors and mistakes made by customers. Output quality is measured in DPMO or the rate of offgrade per million opportunities. DPMO is a measure of failure in a Six Sigma quality improvement program that indicates failures per million opportunities. The target of Six Sigma quality control. Motorola is 3.4 DPMO, but is interpreted as follows: in a single product unit, there is an average chance of failure of a CTQ (chance of not meeting customer desires) is only 3.4 failures out of one million parts of the product (Gaspersz, 2002). DPMO calculation according to (Breyfogle, 2003) :

$$DPU = \frac{D}{U} \quad (1)$$

$$DPO = \frac{D}{O} = \frac{D}{U \times O} \quad (2)$$

$$DPMO = DPO \times 1.000.000 \quad (3)$$

Description:
DPU = Number of Defects per Unit
DPMO = Number of Defects per Opportunity
DPMO = Number of Defects per Million Opportunities
U = Number of Units
O = Number of Opportunities that will Result in Defects (Opportunity)
D = Number of Defects

Table 2 is a sigma level that can be used as a measure of performance targets in an industrial system. According to (Gasperz, 2002) the higher the sigma target achieved, the better the performance of the industrial system. So that 6-sigma is better than 4-sigma and 3-sigma. Sigma levels can be seen in Table 1.

Table 2. Sigma Performance Table

Sigma Level	Defects Per Million Opportunities
1	690,000
2	308,537
3	66,807
4	6,210
5	233
6	3,4

Source: P*and*e, P & Larry (2002:10) in (Ulinnuha, 2019)

2.6 FMEA (Failure Mode and Effect Analysis)

According to Hanif (in Hariani, 2017), FMEA is an engineering technique used to determine, identify, and eliminate known failures, problems, errors, and the like from a system, design, process, and/or service before it reaches consumers. From the definition of FMEA above, which refers more to quality, it can be concluded that FMEA is a method used to identify and analyze a failure and its consequences to avoid the failure. FMEA is an engineering technique used to define, identify, and eliminate known failures, problems, errors, and the like from a system, design, process, and/or service before it reaches the consumer (Stamatis, 1995).

By analyzing what is done we can find the effects or impacts that are likely to make mistakes in a product or the production process. With this FMEA method, it is possible to analyze problems that arise in a product that will be made or a process that will be carried out. Then, because the problem that has the potential to arise has been formulated, it can later be determined how to prevent it.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106 *e*-ISSN 2622-2035

According to Nurkertamanda and Wulandari (in Hariani, 2017) explained that RPN is an indicator of criticality to determine the corrective action by the failure mode. The RPN calculation is obtained with the following equation:

RPN = Severity x Occurrence x Detection (4)

RPN is used by many FMEA procedures to assess risk using the following three criteria:

a. Severity (S) - is the first step to analyzing risk, namely calculating how the impact or intensity of the event affects the output of the process. Severity grouping according to its rank level can be seen in Table 3.

Table 3. Severity

Rank	Class	Criteria
1	Negligible severity	We don't have to think about how this will impact the performance of the product. The end user will probably not notice this defect.
2	Mild Severity	The consequences are only mild. End users will not notice any change in performance. Repairs can be done during regular maintenance.
3		
4	Moderate severity	End-users will experience performance degradation, but it is still within tolerance limits. Repairs are inexpensive and can be completed in a short period.
5		
6		
7	High severity	End users will experience unacceptable adverse consequences that are beyond tolerance. Repairs are very expensive.
8		
9	Potential safety problems	The consequences are extremely dangerous and affect the safety of the user. Contrary to the law.
10		

Source: Hariani, 2017

b. Occurrence O - Is the likelihood that the cause will occur and result in some form of failure during use. Shows the value of the frequency of a problem that occurs. Grouping occurrence according to the level of ranking can be seen in Table 4.

Table 4. Occurrence

Rank	Class	Criteria
1	Remote	1 dari 100000
2	*Low*	10 dari 100000
3		50 dari 100000
4	*Moderate*	100 dari 100000
5		200 dari 100000
6		500 dari 100000
7	*High*	1000 dari 100000
8		2000 dari 100000
9	*Very High*	5000 dari 100000
10		10000 dari 100000

Source: Hariani, 2017

c. Detection D - This is a control tool used to detect potential causes. Identify methods that are applied to prevent or detect modes of failure. Grouping detection according to its rank level can be seen as in Table 5.

Table 5. Detection

Rank	Class	Criteria
1	Preventive methods are very effective. There is no chance that the cause may arise.	Almost definitely
2	The possibility of the cause occurring is very low.	Very high
3		
4	The possibility of causes occurring is moderate. Prevention methods are not yet effective. Causes are still recurring	Moderate-high
5		Moderate
6		Weak
7	The probability of causes occurring is still high. Prevention methods are still not effective. Causes are still recurring	Very weak
8		A few
9	The probability of the cause occurring is very high. Prevention methods are not effective. Causes always recur.	Very few
10		Almost impossible

Furthermore, the RPN results obtained from several respondents were calculated on average. The average result will show indicators to measure the risk of failure mode. The average value becomes the final value written in the RPN table. Then the calculation of the critical value of RPN is carried out. RPNs that are more than the critical value of RPN determine the priority scale level of repairs that must be made first. The calculation is done with the following equation:

DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106
p-ISSN 2622-2027
e-ISSN 2622-2035

$$A \quad v \quad = \frac{T \quad \ell v}{N \quad o \quad r} \qquad (5)$$

$$R \quad C \quad v \quad = \frac{T \quad v \quad R}{N \quad o \quad R} \qquad (6)$$

2.7 Bending

Bending is one of the forming processes commonly used to make everyday items such as car components, aircraft, and household appliances. The bending process is done by bending the workpiece until it changes shape which causes stretching of the metal around the straight line area (in this case the neutral axis). As we know a sheet plate with a wave shape has a higher stiffness than a flat sheet plate (Schmid, 2008).

III. RESULT AND DISCUSSION

3.1 *Define*

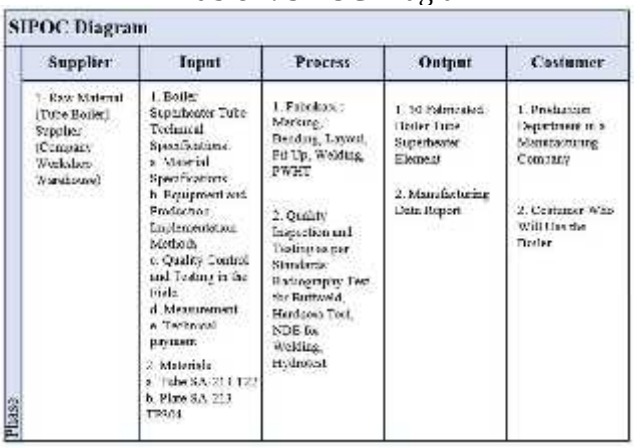
According to Montgomery (2009:52), defining is the first step taken to improve the Six Sigma method. The purpose of the define step is to determine the problem, research objectives, and scope of the process. After that, it will be determined what is Critical To Quality (CTQ) for the customer or what is considered problematic by the customer. The identification of potential CTQ is formulated in Table 6.

Table 6. CTQ on superheater tube boiler fabrication

No.	CTQ (Critical to Quality)
1	Dimensions and Tolerances
2	Material Characteristics a. Consideration for using other material specifications b. Material condition checking
3	Bending Method a. Careful planning b. Bending speed c. Bentonite sand filling method d. Use of mandrell ball e. Training of bending operators f. Consideration of new machine purchase
4	Inspection and Testing

The next stage is the creation of a SIPOC diagram which is used to illustrate the flow of the production process in the manufacture of boiler element tube superheater products. This diagram serves to find out the flow that occurs in the production process starting from suppliers, inputs, processes, outputs, and customers. The SIPOC diagram can be seen in Table 7.

Table 7. SIPOC Diagram



3.2 *Measure*

According to Harahap (Masdalifah, 2019) three main things must be done, namely:

1. Select or determine CTQ quality characteristics,
2. Develop a data collection plan,
3. Performance baseline measurement at the sigma output level. Calculation of DPMO (Defect per Million Opportunity) level and achievement of sigma capability level.

This measurement is carried out by observation during the production process on 30 *elements of the boiler tube superheater* (all products in this fabrication project). The results of the calculation of proportions, p, UCL, and LCL are in Table 8.

Table 8. Calculation Results of Proportion, $\bar{p}$, UCL, and LCL

NO	NG	Total Check	Proportion	$\bar{p}$	UCL	LCL
1	19	37	0,513514	0,403604	0,645576	0,161632
2	17	37	0,459459	0,403604	0,645576	0,161632
3	13	37	0,351351	0,403604	0,645576	0,161632
4	20	37	0,540541	0,403604	0,645576	0,161632
5	14	37	0,378378	0,403604	0,645576	0,161632
6	15	37	0,405405	0,403604	0,645576	0,161632
7	18	37	0,486486	0,403604	0,645576	0,161632
8	16	37	0,432432	0,403604	0,645576	0,161632
9	16	37	0,432432	0,403604	0,645576	0,161632
10	14	37	0,378378	0,403604	0,645576	0,161632
11	12	37	0,324324	0,403604	0,645576	0,161632
12	15	37	0,405405	0,403604	0,645576	0,161632
13	14	37	0,378378	0,403604	0,645576	0,161632
14	13	37	0,351351	0,403604	0,645576	0,161632
15	11	37	0,297297	0,403604	0,645576	0,161632

DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106
p-ISSN 2622-2027
e-ISSN 2622-2035

16	14	37	0,378378	0,403604	0,645576	0,161632
17	19	37	0,513514	0,403604	0,645576	0,161632
18	11	37	0,297297	0,403604	0,645576	0,161632
19	17	37	0,459459	0,403604	0,645576	0,161632
20	13	37	0,351351	0,403604	0,645576	0,161632
21	15	37	0,405405	0,403604	0,645576	0,161632
22	16	37	0,432432	0,403604	0,645576	0,161632
23	18	37	0,486486	0,403604	0,645576	0,161632
24	13	37	0,351351	0,403604	0,645576	0,161632
25	16	37	0,432432	0,403604	0,645576	0,161632
26	14	37	0,378378	0,403604	0,645576	0,161632
27	13	37	0,351351	0,403604	0,645576	0,161632
28	15	37	0,405405	0,403604	0,645576	0,161632
29	13	37	0,351351	0,403604	0,645576	0,161632
30	14	37	0,378378	0,403604	0,645576	0,161632
Total	448	1110				
Average	15	37				

Based on Table 8, a P control map graph is created to make it easier to find data that is outside the control limit. Making P control maps is assisted using Minitab *software*. Control map graph P fabrication *tube boiler superheater* can be seen in Figure 1.

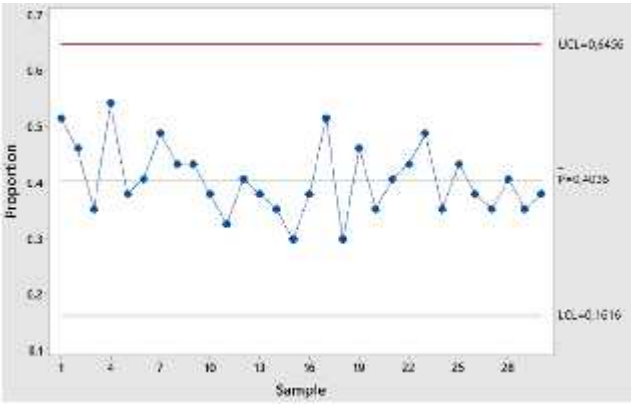


Figure 1. P-Control Map Graph

Figure 1 indicates that the average number of deviations in one element is 0.4036 with the same control limit. This is because the number of *samples* in each *element* inspected has the same value. There is no plot that is out of control, it shows that the P value in the production of *boiler tube superheaters* is still statistically controlled.

Furthermore, DPMO calculations are carried out to measure the sigma level using the DPMO conversion table of the Six Sigma assessment. Data calculation in Table 9.

Table 9. Data Calculation and Sigma Value Conversion

Value Data Calculation	Value
Amount of Boiler Tube Superheater Elements	30
D (Number of defective products that occur)	448
U (Number of product units)	1110
DPU Ovality	0,403604
DPO Ovality	0,004036
DPMO Ovality	40.360,36
Sigma Value	3,25

The calculation of the DPMO Ovality value gets a result of 40,360, then converted to a sigma table obtained a value of 3.25, which means that the production ability has a capability of 3.25 out of 6 sigma. The higher the sigma target achieved, the better the performance of the industrial system.

3.3 *Analysis*

The analysis was performed with Failure Mode and Effect Analysis (FMEA). FMEA is a method for identifying potential failures for good process planning to predict, reduce, or avoid error rates and predict damage or adverse effects caused by the production process. Based on the FTA diagram made earlier, it is known the cause of bending deviations that occur during the boiler tube superheater fabrication process. The weighting in the FMEA table contains Severity, Occurrence, and Detection values which are used to obtain RPN values to provide a risk rating for each cause of failure.

Table 10. Data Calculation and Sigma Value Conversion

Failure Mode	Causes of failure	S	O	D	RPN
Ovality deviation > 9%	*The bending speed* is too high	7	7	6	294
	No bentonite sand-filling method is carried out	8	6	5	240
	Not using mandrell ball	6	6	5	180
	OD *Dies* bending is not by the OD *tube* to be bending	8	8	5	320
	The distance between the *clamp* die and *the pressure die* is too far	8	8	5	320
	The pressure die is not level	6	6	5	180

Based on Table 10 determination of severity, occurrence, and detection values is carried out by the Quality Control Staff, Quality Control Supervisor,

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106 *e*-ISSN 2622-2035

Production Supervisor, and Production Manager by distributing FMEA questionnaires. From each respondent's answer, it is accumulated and calculated on average using Equation 4. It can be known that the highest RPN value obtained is 320 for ovality deviation, with the cause of failure OD Dies bending does not match the OD tube to be bent and the distance between the clamp die and pressure dies is too far.

The RPN Ovality assessment for severity OD Dies bending does not match the OD tube to be bent to get a severity value of 8, interpreted as very high. If such causes occur, then the influence on ovality deviations in bending products is very high. While the assessment of occurrence gets a value of 8 is interpreted as high. If such causes occur frequently, then the probability of deviations caused by such failure modes is about 1 in 50 events. While the assessment of detection gets a value of 5 is interpreted as medium. The ability of the control device to carry out deviation detection is classified as moderate.

After performing the FMEA analysis stage and calculating RPN, the next step is to calculate the critical value of RPN above the critical value. The calculation of the critical value for ovality deviation in equation 5 is as follows:

$$R \quad C \quad V \quad = \frac{R \quad T \quad V}{N \quad o \quad R}$$

$$R \quad C \quad V \quad = \frac{294 + 240 + 180 + 320 + 320 + 180}{6}$$

$$R \quad C \quad V \quad = 255{,}67$$

From the calculation above, a critical value of 255.67 is obtained using Equation 5. 3 factors cause failure that have a more critical RPN value of 294, two RPNs with a value of 320. Failure factors that have an RPN value greater than the critical value will be prioritized for further corrective action.

3.4 *Improve*

Improve is the stage of providing improvement proposals, the results of repair proposals obtained the quality of superheater tube boiler element products.

The proposed improvements are sorted from the causes of failure that have an RPN value above the critical RPN value. Proposed improvements to reduce the causes of ovality and wall thickness deviations in tube boiler superheater products can be seen in Table 11.

Table 11. Proposed Improvements to Bending Tube

Causes of Failure	RPN	Proposed Improvement Action	Things to Expect
Bending speed too high	294	Decreasing the machine speed during the pipe-bending process	Diameter dimensions maintained by standards and customer specifications
No bentonite sand-filling method performed	240	Filling the tube with sand before the bending process to engineer the product to be rigid	Solid objects will make it easier for operators to maintain tube dimensions
Not using mandrell ball	180	Considering the use of a mandrel ball if no bentonite sand filling is done	Improve dimensional accuracy to be more consistent and by specified specifications
The OD of the bending die does not match the OD of the tube to be bent.	320	Design planning and manufacturing of bending dies that match the OD of the tube	A well-designed mold can help improve tube shape and ensure good structural integrity.
The distance between the clamp die and the pressure die is too far	320	Spacing of clamp die and pressure die that is not too far apart	Allows for even stress distribution during bending
Pressure die not level	180	Equivalent pressure die adjustment	Reduces the possibility of defects in the bent tube

3.5 *Control*

The *Control* stage is the final stage of identification in the *Six Sigma* method. Repair trials were carried out using several improvement suggestions to test tube quality improvements. Trials are carried out in consideration of suggestions for improvement obtained from the company. The bending experiment in this study uses several variations of the planned method so that the data obtained can be processed with the specified method. The optimal combination obtained will then be experimented to validate the combination. The validation test can be found in Table 12.

Table 12. Bending Tube Improvement Method

Label	A	B	C	D	E	F
Trial 1	✓	-	-	-	-	✓
Trial 2	✓	✓	-	-	-	✓
Trial 3	✓	✓	✓	✓	-	✓

Description:

A. Decreasing the engine speed during the pipe bending process.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9355.98-106 *e*-ISSN 2622-2035

B. Filling the tube with sand before the bending process to engineer the product to be solid
C. Pellets will be spaced not too far from the clamp die and pressure die
D. Equal adjustment of pressure die
E. Consideration of hot bend execution in the bending process
F. Evaluation of the bending method such as modification of the bending tool (change of dies with a very tight radius). Inspection of material conditions and consultation with experts.

In the first bending trial, bending results with very high ovality deviations are shown in Table 13.

Table 13. Trial Improvement Bending Tube 1

		1		
	Process	COLD	COLD	COLD
Bending	Radius	R 50	R 50	R 50
	Degree	180	180	180
	Max	38,9	38,9	38,5
Roundness/	Min	32,4	31,2	32,0
Ovality	*Ovality*	17,11%	20,26%	17,11%
	Max. Req (%)	9,00%	9,00%	9,00%

In the first bending trial, *bending* was obtained with ovality deviations but not as high as in experiment 1, namely in Table 14.

Table 14. Trial Improvement Bending Tube 2

		2		
	Process	COLD	COLD	COLD
Bending	Radius	R 50	R 50	R 50
	Degree	180	180	180
	Max	38,2	38,4	38,3
Roundness/	Min	34,3	33,2	33,3
Ovality	*Ovality*	10,26%	13,68%	13,16%
	Max. Req (%)	9,00%	9,00%	9,00%

Bending results with fairly good ovality deviations with 2 points not exceeding the tolerance limit are shown in Table 15.

Table 15. Trial Improvement Bending Tube 3

		2		
	Process	COLD	COLD	COLD
Bending	Radius	R 50	R 50	R 50
	Degree	180	180	180
	Max	38,40	38,15	38,25
Roundness/	Min	35,65	35,55	34,80
Ovality	*Ovality*	7,24%	6,84%	9,08%
	Max. Req (%)	9,00%	9,00%	9,00%

From the results of the experiment, it can be identified if the third experiment is the best combination compared to other experiments. Of the three bending points, both points have two good ovalities. It can be concluded that the decrease in machine speed, the sand filling method, without the implementation of hot bends, the laying of the distance between the clamp die and pressure die is not too far, and the equivalent adjustment of the pressure die can affect the ovality of the bending tube results for the better.

IV. CONCLUSION

Based on the results of the analysis that has been carried out and discussed, the following conclusions are obtained:

1. From the analysis obtained using the FMEA method, the recommended corrective action plan according to the results of the analysis of the RPN value that exceeds the critical value with values of 294 and 320 for ovality inequality is:
   a. Speed drop during operation of the bending machine
   b. Planning the design and manufacture of bending die molds by OD tube
   c. Laying the distance between the clamp die and pressure die is not too far
2. The combination of variable process temperature, engine speed, and pressure as a preventive measure to reduce ovality and wall thickness deviations in bending tubes is:
   a. Temperature 600°C with a heating torch and consideration of hot bend method. After that cold bend with a C-Frame machine can also be further customized according to material specifications and customer application needs.
   b. Machine speed with a relatively small tube diameter (38mm) and a large bending radius (50mm), the recommended machine speed is 1 degree per second.
   c. The pressure applied during bending must be stable, which can be achieved by: Planning the design and manufacture of bending dies whose OD matches the OD of the tube, placing the clamp die and pressure die not too far apart, and adjusting the pressure die equivalent to the clamp die.

IV. ACKNOWLEDGMENT

The author would like to thank all those who have contributed and helped make this paper. Hopefully, this research can provide benefits and positives for many people.

V. REFERENCES

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p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9360.107-111 *e*-ISSN 2622-2035

Designing Improvement of Service effectiveness Using M/M/1 and M/M/S Queue Models (Case Study: Customer Arrivals at Jatim Park Tourist Destination During Holidays and Peak Hours)

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Abstract - Queueing is a collection of people lined up to wait to be served, after which they leave the queue. Queuing activities often arise due to ineffective or suboptimal service times, resulting in longer wait times. To maximize and schedule service time optimally, queueing models such as M/M/1 and M/M/S systems are utilized. This study applies these models to analyze the queuing system at the Jatim Park tourist destination. This research aims to determine the effectiveness of service at the ticketing counters of Jatim Park during holidays. Data on visitor arrival times and average service times were collected to initiate the study. The data analysis aims to optimize service effectiveness at the Kampung Coklat tourist area by implementing the FCFS (First Come, First Served) queueing method and the M/M/S system. The findings suggest that the optimal number of teller servers needed to serve visitors effectively is 2. The analysis also identifies that the longest queue occurs between 10:00 AM and 11:00 AM, with 3 visitors waiting at its peak. The average number of visitors in the queue during this period is approximately 1.3 or 1 visitor. Based on these results, the study concludes that the service effectiveness at the Kampung Coklat tourist area is sufficiently optimized.

Keywords : Queue Models, Jatim Park Tourist Destination, Designing Improvement of Service.

I. INTRODUCTION

Jatim Park is a tourist destination with high-quality service facilities. Established in 2004, this attraction offers educational experiences through various rides with diverse facilities and techniques. Additionally, Jatim Park provides a range of food options, local agricultural products, livestock, and more. This makes Jatim Park a popular destination for individuals and families to spend their holidays. Visitors come not only from the surrounding areas but also from outside Malang and Batu, even from outside the East Java province.

The long queues during holidays and peak hours at Jatim Park affect service efficiency. The long waiting times, lengthy service processes, and the number of arrival counters are concerns for the public regarding Jatim Park. Service during holidays and peak hours is not as crowded compared to regular days. Queue models M/M/1 and M/M/S are alternatives to determine the effectiveness of service at Jatim Park by analyzing arrival patterns and service times.

Therefore, a comparative analysis of the queue system during holidays is needed to address these issues and ensure the system runs smoothly without compromising the service effectiveness at Jatim Park. This research aims to determine the effectiveness of the service and apply a queuing model using comparative methods to find solutions for improving the queuing system.
the service is complete, customers leave the system.

II. LITERATURE REVIEW

Definition of Queue

A queue is a collection of people (or entities) standing in a specific line to be served (Jaman, 2014; Mahessya, 2017). Several basic components in a queuing system are involved, with the entities being referred to as customers (Nengsih & Yustanti, 2017). These customers are served according to queue discipline rules (Alrosyid et al., 2019; Alfita et al., 2023). Once

1.1. Queue System Analysis

The time between service completion follows an exponential distribution.

** M/M/1 Queue System**

Using queue notation, the following results are obtained (Hidayat et al., 2020):

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9360.107-111 *e*-ISSN 2622-2035

1. **Service Intensity Factor**
\[
\rho = \frac{\lambda}{\mu}
\]

2. **Average Waiting Time**
\[
W = \frac{1}{\mu - \lambda}
\]

3. **Average Number of Visitors**
\[
L = \frac{\lambda}{\mu - \lambda}
\]

Where:
- \(\lambda \) = Arrival rate
- \(\mu \) = Service rate

4. **Idle Time Percentage**
\[
P_0 = 1 - \frac{\lambda}{\mu}
\]

5. **Number of Visitors in the System**
\[
P_n = \frac{\lambda^n}{n!} \cdot \frac{1}{\mu^{n} \cdot (\mu - \lambda)}
\]

6. **Total Cost**
\[
\text{Total Cost} = \text{Waiting Cost} + \text{Service Cost}
\]

1.2. Queue Models

Several queue models are used, including single-server systems (M/M/1) and multi-server systems (M/M/S) (Suban et al., 2022).

a. M/M/1 System

The M/M/1 system is characterized by (Hermanto et al., 2019; Purwanto, 2021):
- A single queue with an unlimited or unbounded number of customers
- Poisson-distributed arrivals
- Unlimited source of arrivals
- Queue discipline is typically FCFS (First Come, First Served)

b. M/M/S System

The M/M/S queue model involves multiple servers (KA, 2020; Murnawan, 2023).

M/M/S Queue System

Queue formulas for the M/M/S model include:

1. **Probability of 0 People in the System (P0)**
\[
P_0 = \frac{1}{\sum_{n=0}^{M-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^M}{M! \cdot (1 - \lambda/(M \cdot \mu))}}
\]

2. **Average Number of Visitors in the System (Ls)**
\[
L_s = \frac{\lambda}{\mu - \lambda} \cdot \frac{1}{M!} \left[\frac{M \cdot \lambda}{\mu - \lambda} + \sum_{n=0}^{M-1} \frac{(\lambda/\mu)^n}{n!} \right]
\]

3. **Average Waiting Time in the Queue (Ws)**
\[
W_s = \frac{L_s}{\lambda}
\]

4. **Average Number of Visitors in the Queue (Lq)**
\[
L_q = L_s - \lambda
\]

5. **Average Waiting Time in the Queue (Wq)**
\[
W_q = \frac{L_q}{\lambda}
\]

DATA PROCESSING

Data collected from Jatim Park is processed and calculated to determine the average waiting time and queue length for customers. Microsoft Excel is used for data analysis.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9360.107-111 *e*-ISSN 2622-2035

III. RESEARCH METHODS

Data Collection

Data collection was done by directly observing the ticket counters at Jatim Park, focusing on arrival patterns and service times. Observations included the time customers entered the queue, waited, and received service.

Table 1. Average Visitor Arrival per Hour on Holidays

TIME INTERVAL	AVERAGE ARRIVAL
08:00 – 09:00	350
09:00 – 10:00	480
10:00 – 11:00	520
11:00 – 12:00	450
12:00 – 13:00	430
13:00 – 14:00	325
14:00 – 15:00	280
15:00 – 16:00	140

From Table 1, the peak arrival time is 10:00 – 11:00 with 520 visitors, while the lowest is from 15:00 – 16:00 with 140 visitors. The total average visitor service rate (μ) is calculated as:

$$\mu = \frac{\text{Total Average Arrival}}{\text{Total Hours}} = \frac{350 + 480 + 520 + 450 + 430 + 325 + 280 + 140}{8} = 371 \text{ visitors/hour}$$

M/M/1 Analysis

1. **Service Utilization Rate (ρ)**
$$\rho = \frac{\lambda}{\mu} = \frac{350}{371} = 0.94$$

2. **Average Number of Visitors in the System (L)**
$$L = \frac{\lambda}{\mu - \lambda} = \frac{350}{371 - 350} = 17$$

3. **Average Number of Visitors in the Queue (Lq)**
$$L_q = \frac{\lambda^2}{\mu (\mu - \lambda)} = \frac{350^2}{371 (371 - 350)} \approx 16$$

4. **Average Waiting Time in the System (W)**
$$W = \frac{1}{\mu - \lambda} = \frac{1}{371 - 350} \approx 0.0476 \text{ hours (2.8 minutes)}$$

5. **Average Waiting Time in the Queue (Wq)**
$$W_q = \frac{L_q}{\lambda} = \frac{16}{350} \approx 0.046 \text{ hours (2.6 minutes)}$$

M/M/S Analysis

1. **Probability of 0 People in the System (P0)**
$$P_0 = \frac{1}{\sum_{n=0}^{M-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^M}{M! \cdot (1 - \lambda/(M \cdot \mu))}}$$

2. **Average Number of Visitors in the System (Ls)**
$$L_s = \frac{\lambda}{\mu - \lambda} \cdot \frac{1}{M!} \left[\frac{M \cdot \lambda}{\mu - \lambda} + \sum_{n=0}^{M-1} \frac{(\lambda/\mu)^n}{n!} \right]$$

3. **Average Waiting Time in the Queue (Ws)**
$$W_s = \frac{L_s}{\lambda}$$

4. **Average Number of Visitors in the Queue (Lq)**
$$L_q = L_s - \lambda$$

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9360.107-111 *e*-ISSN 2622-2035

5. **Average Waiting Time in the Queue (Wq)**
\[
W_q = \frac{L_q}{\lambda}
\]

IV. CONCLUSION

Based on the analysis using M/M/1 and M/M/S methods:

1. Optimal Service Facilities: Two service counters (servers) are optimal for Jatim Park. The current setup with two service counters is appropriate.
2. Service Efficiency.

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Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9085.112-116 *e*-ISSN 2622-2035

The Effect of Using Crankcase Emission Control System Technology on the Performance of a 160 cc Single Cylinder Four Stroke Engine

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***Abstract*—**The research was carried out on a single-cylinder four-stroke petrol engine with a rotation variation of 1000 rpm - 9000 rpm, using crankcase emission control system (CECS) technology. The air that will enter the carburetor is mixed with hot gas that flows and comes from the CECS, causing the air to become warm and then mixed with the fuel in the carburetor, and then the mixture passes through the manifold into the combustion chamber. Investigation in the first stage under standard conditions and in the second stage using CECS technology. The use of CECS technology results in increased machine performance. After testing with and without using CECS technology, optimum performance in the form of power, torque and specific fuel consumption occurred at engine speeds of 8000 rpm, 6000 rpm, and 7000 rpm respectively producing power, torque and specific fuel consumption of 13.11; 1.504 kg.m and 0.152 kg/hp.an hour without CECS, and with the use of CECS technology of 13.20 hp; 1.56 kg.m and 0.151 kg/hp.hour.

Keywords: performance; blowby; crankcase emission control system; power; torque; specific fuel consumption.

I. INTRODUCTION

An internal combustion motor is an engine that utilizes a working fluid/hot gas resulting from combustion, where the medium that utilizes the working fluid (gas) and the working fluid are not separated by a dividing wall [14].

A piston combustion engine is a machine that converts heat energy into mechanical work. In a piston combustion engine, heat energy is released through the combustion of a mixture of fuel and air in the combustion chamber. A homogeneous mixture of fuel and air is needed for the combustion process to be complete [5].

In this research, an experiment was carried out using crankcase emission control system (CECS) technology. The air that will enter the carburetor is warmed first then mixed with the fuel in the carburetor and then the mixture passes through the manifold into the combustion chamber. And how does CECS technology affect machine performance [2].

The automotive world (especially motorbikes) is developing very rapidly. There are more and more technological devices on petrol motorbikes so that petrol motorbikes are more sophisticated and faster in the working process. Modifications that have been made by automotive manufacturers include the emergence of Crankcase Emission Control System (CECS) technology to increase engine performance.

The problem studied is how the Crankcase Emission Control System affects torque, power, and specific fuel consumption. The gas leak referred to here is a gas leak or gust from the combustion chamber due to a leak in the piston and piston ring against the wall leading to the crankcase. This is a leak that occurs in the piston and piston rings and piston rings from the cylinder wall to the crank chamber. The exhaust from this leak contains hydrocarbons (HC) around 20% of the total HC content of the engine and will increase by around 20% if the piston ring is damaged (worn). In this blowing gas, around 85% of the mixture from the carburetor is in the form of raw HC, of which the remaining 15% is burnt gas.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9085.112-116 *e*-ISSN 2622-2035

II.EXPERIMENTS

The research object here is intended to clarify the machines used in the research. The engine used is a single-cylinder four-stroke petrol motorbike/Honda. The testing tools and machines used are petrol motorbikes, 4 stroke/Honda - single cylinder, SOHC type, dynamometer, tachometer, fuel cylinder, and CECS.

In this study, the engine was started with the gas throttle fully open, then a braking load was applied to get the engine speed to vary as desired.

Meanwhile, the steps taken by researchers to collect test data are:

1. Start the engine by adjusting the gas throttle several degrees as needed, so that the engine is stationary.

2. Preheat 5 minutes at idle, to ensure engine working condition and reach engine working temperature.

3. To start data collection, first open the gas throttle slowly until it is fully open, then the load is applied until it reaches the desired engine speed.

4. Turn off the machine when the test is complete.

III. RESULTS AND DISCUSSION

The crankcase emission control system model used is standard from the Honda Megapro 160 cc manufacturer as shown in figure 2.

CECS technology utilizes warm air from the engine's respiratory tract by channeling it back into the combustion chamber so that combustion is easier and can improve engine performance. Apart from that, this technology can also reduce exhaust gas emissions in the crank chamber due to leaks in the piston and piston rings against the cylinder walls, mainly in the form of HC which ranges between 20 ÷ 35 % of the total.

The way this technology works is that when the engine is operating, the piston moves up and down in the cylinder and carries out a work cycle, especially when it moves to the top dead center (TDC) which carries out the compression and combustion process/steps, where when If both valves are in the closed position, then the gas in the cylinder will be pushed and compressed by the piston, so that the pressure will increase and the gas will move in all directions, especially against the push of the piston's movement, so that a small portion of the gas will leak/come out. to the crank chamber (crankcase) due to leaks in the piston and piston rings against the cylinder wall (blowby), where the gas will then be utilized and circulated to the combustion chamber which will previously pass through the air filter and then mix with oxygen (from the outside air) to become air. which is warm and then enters the combustion chamber because there is suction from the piston which previously passed through the carburetor and will be mixed with fuel (gasoline), so that the two gases become gas which is already in the form of mist, then enters the combustion chamber and carries out the further combustion process.

The picture below shows the parts of the CECS, namely 1. air filter, 2. carburetor, and 3. breathing duct from the crankcase.

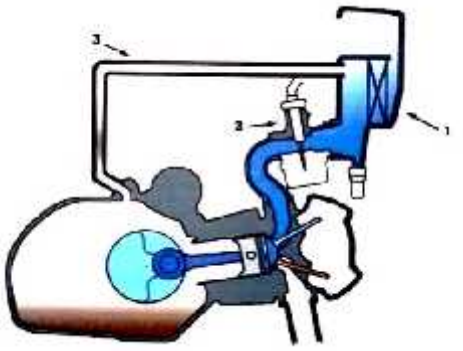

Figure 1. Crankcase emission control system

Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana
DOI : https://doi.org/10.36456/tibuana.7.2.9085.112-116
p-ISSN 2622-2027
e-ISSN 2622-2035

Table 1. Engine rotation, power, torque, and specific fuel consumption

Engine rotation	Remarks					
	Without CECS (standard)			With CECS		
	Power	Torque	Sfc	Power	Torque	Sfc
[rpm]	[hp]	[kg.m]	[kg/hp.h]	[hp]	[kg.m]	[kg/hp.h]
1000	0,158	0,11	2,01	0,137	0,026	2,259
2000	0,981	0,29	0,468	1,125	0,371	0,43
3000	3,23	1,049	0,205	3,316	1,327	0,197
4000	5,117	1,292	0,184	5,379	1,395	0,174
5000	7,45	1,429	0,154	7,467	1,481	0,152
6000	10,03	1,504	0,152	10,06	1,56	0,151
7000	12,14	1,34	0,156	12,21	1,42	0,151
8000	13,11	1,19	0,153	13,2	1,191	0,152
9000	12,24	0,99	0,188	12,65	1,052	0,178

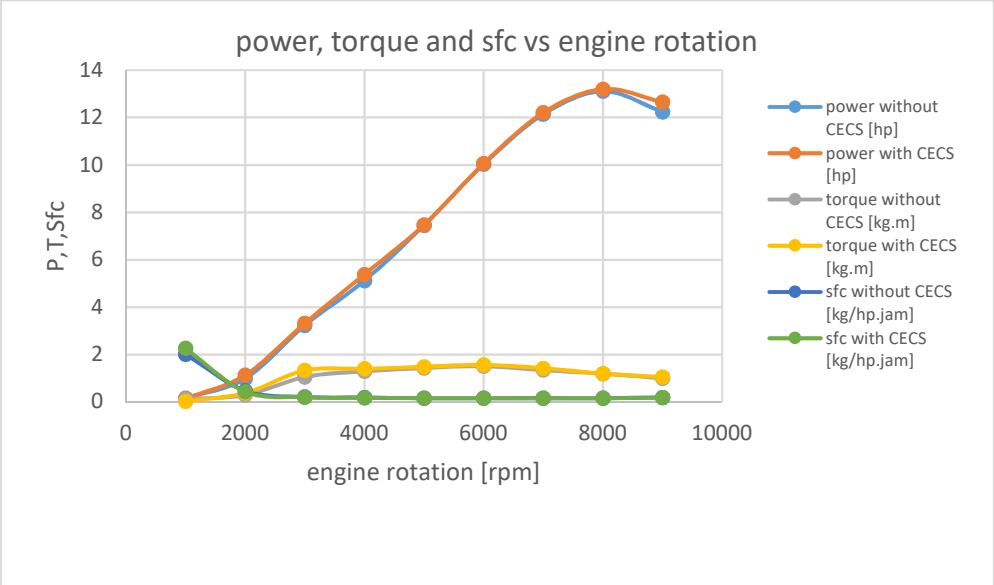

Figure 2. Relationship of power, torque, and specific fuel consumption to engine speed

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9085.112-116 *e*-ISSN 2622-2035

Figure 2 shows the relationship between power, torque, and specific fuel consumption with the engine speed of a single-cylinder four-stroke vehicle with a range of engine speed variations at 1000 to 9000 rpm with 1000 rpm intervals. This experiment was carried out under conditions without using CECS (standard) and was carried out using CECS so that a mixture occurred between the air entering the air filter and hot gas coming from the crankcase due to leaks in the piston and piston rings against the cylinder wall (blowby).

From the test results, the optimum power, torque, and specific fuel consumption values are 13.2 hp; 1.56 kg.m, and 0.150 kg/hp. hour respectively were produced at 8000 rpm, 6000 rpm, and 7000 rpm compared to other conditions. Optimum results were obtained in testing using CECS technology.

IV. CONCLUSION

From the test results, it can be seen that using CECS technology on the carburetor of a four-stroke, single-cylinder motorbike engine can improve performance compared to without using CECS technology (standard conditions). This is proven by the increase in power value at 8000 rpm engine speed, although less than 1%, the torque value at 6000 rpm engine speed reaches 3.72% and can minimize the specific fuel consumption value at 7000 rpm engine speed up to 3.22%.

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p-ISSN 2622-2027
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Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

Quality Matrix-Based Product Innovation in Birkinpet Pet Harness Apparel

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***Abstract* —** This study employs the Quality Function Deployment (QFD) method to develop BirkinPet pet harness apparel, focusing on customer needs and competitive advantages. A House of Quality (HoQ) matrix was constructed using responses from 96 participants, evaluating the relationship between Customer Importance and Technical Importance to identify key technical priorities for immediate implementation in BirkinPet's production process. The primary HoQ matrix results indicate that lightweight, comfort, and safety (481.5), design for various activities (416.1), and ergonomic and comfortable design (389.9) are the most important attributes to customers. The main technical priorities include ensuring the product is safe and strong (4.99) and providing a variety of sizes and options (4.86). The novelty lies in the comprehensive and structured application of QFD, emphasizing innovation in designing products that align with current market trends and customer preferences. By integrating comfort, safety, and flexible design, BirkinPet successfully creates a high-quality product that meets customer needs, enhancing customer satisfaction and loyalty while strengthening its competitive position in the pet accessories market.

Keywords : Pet Harness Apparel, Product Innovation, Quality Function Deployment

I. INTRODUCTION

Product innovation is a key determinant of a company's success in maintaining market competitiveness in a dynamically evolving environment. Effective product innovation can increase market share and contribute to long-term success [1]. Innovations based on customer needs and desires can enhance customer satisfaction and strengthen the company's competitive position in the market. Customer involvement in non-technical innovation processes can enhance customer satisfaction and loyalty, as well as improve company performance.

One effective method for identifying and implementing customer needs into product technical specifications is QFD [2]. QFD is a structured approach to defining customer needs and translating them into specific plans for producing a product. QFD integrates consumer requirements with product technical characteristics and ensures that these technical characteristics are prioritized in the product design [3]; [4]. [5]added that the multi-step innovative method often starts with HoQ to capture the voice of the customer and prioritize inputs in design refinement. Management teams apply QFD through a series of matrices, including HoQ [6]. QFD is critical in product design that contributes to increasing customer satisfaction and reducing design and development time [7].

Pet harness apparel has gained popularity as pet owners become more aware of the importance of comfort and safety for their pets. High-quality harnesses not only provide better control during walks but also minimize injury risks compared to traditional collars. BirkinPet sees this opportunity as a challenge to innovate harness products that not only meet basic pet needs but also emphasize design and quality aspects.

[8] highlighted the importance of choosing the right harness that does not cause stress or discomfort to pets. [9] that pet harness apparel plays a role not only in safety but also in providing comfort and enhancing the pet's appearance. [10] support the significant role of harnesses in improving pet mobility and comfort. [11] emphasized the importance of

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

regulatory oversight and improving product standards to ensure harnesses meet animal welfare criteria.

BirkinPet emerged as a product innovation designed to meet the growing demand for pet harness apparel. To enhance product quality and customer satisfaction, BirkinPet adopts the QFD method as part of its product innovation process. Using QFD as a strategic tool integrates BirkinPet customer needs with technical specifications and competitive advantages, while the HoQ framework helps identify and prioritize the most important product attributes for BirkinPet customers and compares them with close competitors.

QFD has been widely applied across various industries to improve product quality and meet customer expectations. In this study, QFD is used to develop pet harness apparel that is lightweight, comfortable, and safe, designed for various activities, and ergonomically comfortable. The implementation of QFD includes several stages: identifying customer needs, translating these needs into technical specifications, and setting key technical priorities. This method has proven effective in various studies and applications, including electronic product design and medical equipment [12]; [13]. Meanwhile, [14] applied QFD in construction to ensure key customer needs are considered from the project's outset, leading to successful outcomes such as timely delivery and high customer satisfaction.

In developing BirkinPet products, strict quality control, stylish design in various colors and patterns, and reflective safety features are top priorities. This study involves customer surveys and market analysis to gather relevant data, which is then analyzed using the HoQ matrix. The QFD analysis results indicate that the highest-ranking attributes are ergonomic and comfortable design, strong and durable materials, and easy-to-use design [15]; [16]; [17].

This study also shows that QFD can address various challenges in product development. For instance, [18] an integrated approach to prioritize technical characteristics, demonstrating that QFD can handle complexities in product development. [19] proposed a new framework for QFD using linguistic numbers to enhance accuracy in capturing customer needs. [20] introduced a new method for QFD based on rough cloud model theory, addressing shortcomings in traditional QFD by improving the accuracy of customer characteristic weight determination. Additionally, [21] stated that QFD can be applied in the healthcare sector to improve service and customer satisfaction.

Research by [22] confirms that applying QFD in mobile phone selection using a fuzzy approach can enhance efficiency in capturing customer needs. [23] highlighted the importance of using QFD for product development analysis to improve product quality according to customer needs. QFD effectively identifies customer needs and translates them into technical specifications applicable to the product design process. [24] stated that QFD is effective in customer-oriented product development, helping organizations plan and implement various technical support tools effectively. Subsequently, [25] applied multi-criteria decision-making in QFD for renewable energy, considering various important factors in renewable energy product development.

The use of QFD in BirkinPet's product innovation development helps identify key customer needs in pet harness apparel, translate these needs into specific technical attributes, and determine product development priorities based on the relationship between customer needs and technical attributes. With QFD, BirkinPet can develop implementation strategies to ensure that the product meets or exceeds customer expectations, competes successfully in the global market, and improves customer satisfaction.

II. RESEARCH METHODOLOGY

This study employs the QFD approach with a focus on HoQ to integrate customer needs with measurable product specifications and identify areas for improvement and innovation. A mixed-method approach was used to gain a comprehensive understanding of customer requirements and product performance. The quantitative approach involved collecting numerical data through surveys and performance metrics, while the qualitative approach included in-depth interviews and focus groups to explore customer perceptions and experiences.

Data were collected through surveys targeting users of pet harness apparel. The survey was designed to measure user

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

satisfaction with various aspects of the product. It was developed and distributed to pet product customers to gather data on product satisfaction, preferences, and customer needs. The survey included both closed-ended and open-ended questions to collect quantitative and qualitative data.

Interviews with stakeholders, including product managers, marketing personnel, and customers, as well as focus groups with product users, were conducted to gain deep insights into user experiences and expectations. Data were also collected for competitive analysis to understand the perception of competing products, identifying business benchmarks and areas for improvement. Competitive product data were gathered through market research and analysis of public documentation to assess BirkinPet's product positioning against competitors.

Analysis within HoQ was implemented using analytical software that enabled quantitative comparisons of various product aspects and visualized relationships between involved variables. The study was conducted from December 2023 to May 2024 in Surabaya to obtain primary data directly from end consumers. Consumer surveys were conducted on BirkinPet harness apparel products.

The research was carried out in several stages: a preliminary survey involving direct observation of BirkinPet operations, data collection through observation, and interviews to obtain a direct understanding of BirkinPet products and production activities. BirkinPet provided an overview of the existing problems. Problem identification and formulation were performed to determine clear and structured research objectives. A literature review was conducted by searching books, research journals, magazines, and other sources related to QFD and its application in companies. The research was limited to the Product Planning stage in the QFD method through the compilation of the House of Quality (HoQ).

This study involved academics, business experts, and customers. Academic respondents included lecturers in management and product design. Business experts were practitioners in the pet apparel industry. Customer respondents were end consumers in Surabaya. Information was obtained through interviews and questionnaires. Purposive sampling was used to select 80 frequent BirkinPet customers, while accidental sampling was used to randomly distribute questionnaires to consumers encountered incidentally.

Primary data for the research were obtained from various respondents through observations, interviews, and focus group discussions to understand customer desires and expectations for BirkinPet products. A questionnaire with closed-ended questions and a Likert scale was also used. Secondary data were obtained from the company and literature related to QFD, aiming to support the primary data. Validity and reliability tests were conducted through statistical analysis using SPSS 26.0 software.

III. RESULTS AND DISCUSSION

The analysis using the QFD method on BirkinPet's pet harness apparel can be seen in detail in Figure 1, which presents the complete House of Quality (HoQ) diagram.

What Matrix - Customer Requirements Matrix

The Customer Requirements Matrix highlights the key needs and expectations of consumers when selecting pet harness apparel. BirkinPet’s pet harness apparel is designed to provide comfort and safety for pets. Based on survey results, the main consumer concerns when choosing pet harness apparel are as follows:

Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

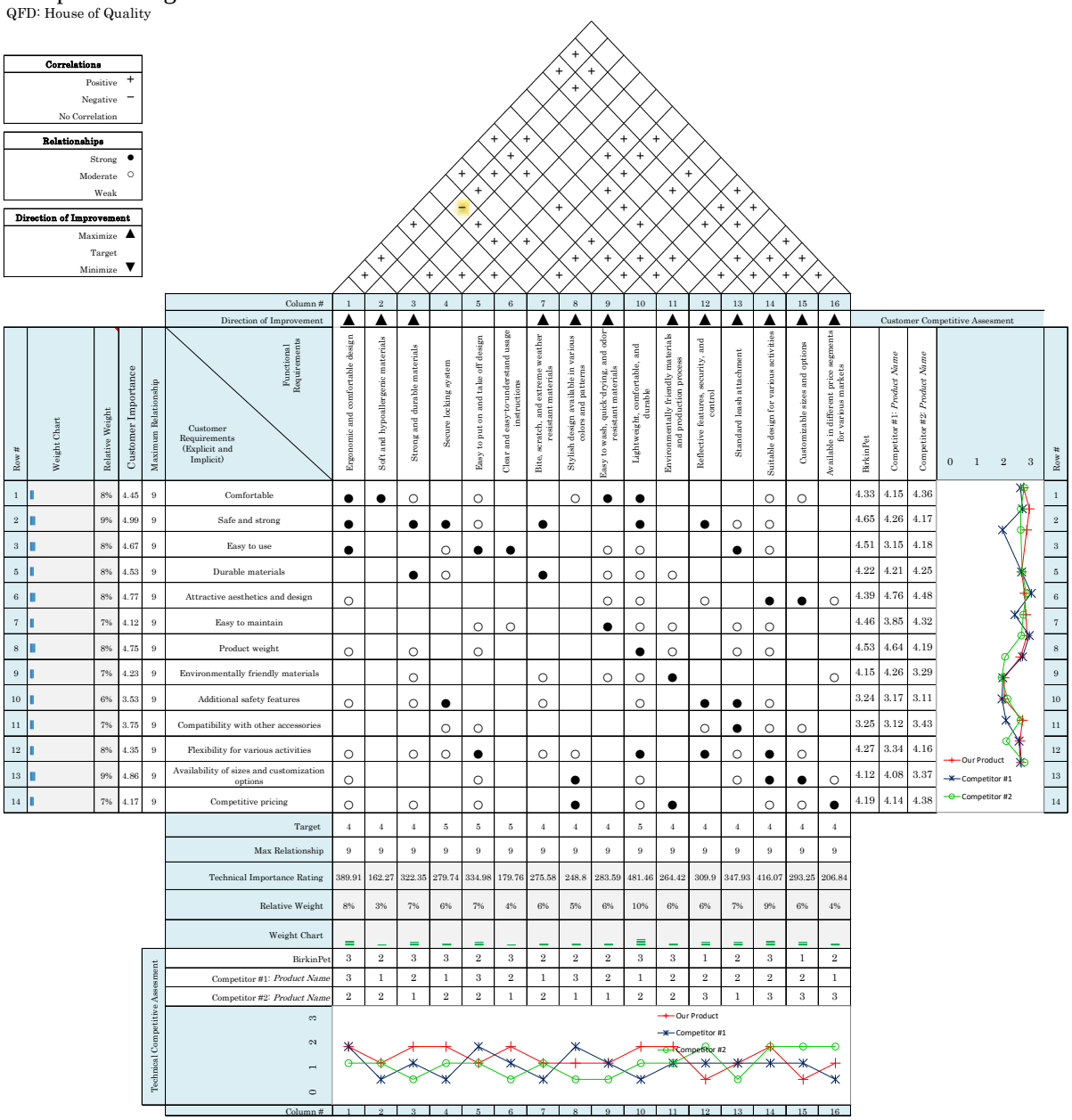

Figure 1. House of Quality (HoQ)

1. Comfort: Consumers want a harness that is comfortable for their pets, and does not cause irritation, or discomfort. Comfort is the top priority for users.
2. Safety and Strength: Product safety and strength are crucial factors. The harness must securely keep pets safe, with no risk of detachment or breakage.
3. Ease of Use: Ease of putting on and taking off the harness is a highly desired feature. The product should have an intuitive design and features that facilitate its use.
4. Durability of Materials: Consumers expect high-quality, durable, and environmentally friendly materials to be used in the harness.
5. Aesthetic and Attractive Design: An attractive and aesthetically pleasing appearance that aligns with pet fashion trends adds significant value for consumers.
6. Ease of Maintenance: Harnesses that are easy to wash, quick to dry, and do not absorb odors are highly appreciated, as they simplify daily maintenance.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

7. Product Weight: The harness should be lightweight yet strong to provide additional comfort without compromising durability.
8. Environmentally Friendly Materials: Consumers are increasingly concerned about the environment and appreciate the use of eco-friendly materials.
9. Additional Safety Features: Extra features, such as small pockets or attachments for pet identification, are highly valued by consumers.
10. Compatibility with Other Accessories: The ability to be used with other accessories enhances the product's flexibility and adds value for consumers.
11. Versatility for Various Activities: The product should be versatile and suitable for various activities, from leisurely walks to more intense outdoor activities.
12. Availability of Sizes and Options: Consumers expect the product to be available in various sizes and customizable options to meet the needs of pets of different sizes and preferences.
13. Competitive Pricing: Pricing that matches the quality offered is a critical factor in influencing consumer purchase decisions.

By understanding the needs and expectations of consumers, BirkinPet can develop products that meet or exceed customer expectations and maintain a competitive position in the market. Identifying Customer Needs is the primary focus in the development of BirkinPet's pet harness apparel. By focusing on key aspects such as comfort, safety, and durability, and ensuring an attractive design with innovative additional features, BirkinPet aims to strengthen its market position and enhance customer satisfaction.

How's Matrix – Functional Requirements

This matrix outlines the technical attributes that the company needs to implement. These attributes are derived from translating customer desires and expectations (the "What's") into specific product development characteristics that the company must achieve to meet consumer expectations. Based on interviews and observations, the following attributes were identified:

1. Ergonomic and Comfortable Design
   Objective: Ensure maximum comfort for pets.
   Implementation: Design that conforms to pet anatomy, preventing irritation or discomfort.
2. Soft and Hypoallergenic Materials
   Objective: Avoid skin irritation and allergies in pets.
   Implementation: Use hypoallergenic and breathable materials.
3. Strong and Durable Materials
   Objective: Ensure product safety and durability.
   Implementation: Use materials resistant to bites, scratches, and extreme weather.
4. Bite, Scratch, and Weather-Resistant Materials
   Objective: Enhance product durability under various conditions.
   Implementation: Use strong and long-lasting materials.
5. Stylish Design in Various Colors and Patterns
   Objective: Attract customers with appealing aesthetics.
   Implementation: Provide a variety of colors and patterns that follow trends.
6. Easy to Wash, Quick-Drying, and Odor-Resistant
   Objective: Facilitate maintenance and cleanliness of the product.
   Implementation: Use materials that are easy to wash and quick-drying.
7. Environmentally Friendly Materials and Production Processes
   Objective: Appeal to environmentally conscious customers.
   Implementation: Use recycled materials and implement eco-friendly production processes.
8. Reflective, Safety, and Control Features
   Objective: Enhance visibility and safety for pets.
   Implementation: Add reflective elements for better visibility.
9. Standard Leash Attachments
   Objective: Provide good security and control.
   Implementation: Use strong and durable leash attachments.
10. Design for Various Activities
    Objective: Flexibility for different activities.
    Implementation: Design suitable for a variety of outdoor and indoor activities.
11. Customization of Sizes and Others
    Objective: Meet the needs of pets of different sizes.
    Implementation: Provide various sizes and customization options.
12. Pricing Variants for Different Market Segments
    Objective: Reach various market segments.
    Implementation: Competitive pricing strategy with different price variants.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

By translating customer needs into technical specifications, BirkinPet can ensure better product development that aligns with customer expectations and strengthens BirkinPet's competitive position in the market.

Technical Importance Planning Matrix

This matrix prioritizes the most crucial technical characteristics to achieve BirkinPet's product goals, enabling the design of products that better meet customer expectations and market demands. The stages include:

1. Target Sub-Matrix

Establish realistic and measurable targets for designing BirkinPet products according to their technical characteristics. The Target Sub-Matrix in this study includes:

a. Ergonomic and Comfortable Design: Achieve a minimum comfort score of 4.5 in customer product testing.
   Implementation: Develop a design that follows the pet's anatomy and ensure the use of hypoallergenic and breathable materials.
   Measurement Method: Conduct comfort testing through user surveys and product trials on various types of pets.

b. Soft and Hypoallergenic Materials: Use 100% hypoallergenic and breathable materials.
   Implementation: Use high-quality, durable, hypoallergenic materials resistant to bites and scratches.
   Measurement Method: Perform raw material quality audits and periodic product durability tests.

c. Strong and Durable Materials: Achieve a minimum durability score of 4.5 in product strength tests.
   Implementation: Use durable, high-quality materials, such as those resistant to bites, scratches, and extreme weather.
   Measurement Method: Conduct laboratory testing for material strength and durability periodically.

d. Secure Locking System: Maintain a detachment rate (harness coming loose) below 0.5%.
   Implementation: Use strong, rust-resistant locking systems to ensure pet safety.
   Measurement Method: Test the strength and durability of locks under normal and extreme usage conditions.

e. Easy to Put On and Take Off Design: Achieve a minimum ease-of-use score of 4.5 in customer product testing.
   Implementation: Develop intuitive locking mechanisms, prototype testing, and provide guides and video tutorials.
   Measurement Method: Use customer satisfaction surveys with a Likert scale and user testing to measure the time and difficulty of putting on/removing the harness.

f. Clear and Easy-to-Understand Instructions: Achieve instruction comprehension by 95% of users on the first try.
   Implementation: Provide comprehensive and simple usage guides, along with accessible video tutorials for all customers.
   Measurement Method: Use customer satisfaction surveys to measure instruction comprehension and conduct user testing to evaluate how well instructions are followed without additional assistance.

g. Bite, Scratch, and Weather-Resistant Materials: Achieve a minimum durability score of 4.5 in bite, scratch, and weather resistance tests.
   Implementation: Use high-quality materials resistant to bites, scratches, and extreme weather and conduct material durability tests.
   Measurement Method: Use customer satisfaction surveys with a Likert scale and perform durability tests against bites, scratches, and various weather conditions to ensure product longevity.

h. Stylish Design in Various Colors and Patterns: Provide at least 10 attractive color and pattern options.
   Implementation: Add appealing color and pattern variations following current pet fashion trends.
   Measurement Method: Use customer satisfaction surveys with a Likert scale to assess aesthetics and design appeal, and conduct market trend analysis to ensure the design remains relevant and attractive.

i. Easy to Wash, Quick-Drying, and Odor-Resistant: Materials that are machine washable and dry within 3 hours.
   Implementation: Use materials that are easy to wash, quick-drying, and odor-resistant. Develop clear care instructions.
   Measurement Method: Use customer satisfaction surveys with a Likert scale to evaluate ease of care and conduct laboratory tests to ensure materials meet the criteria for

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

easy washing, quick drying, and odor resistance.

j. Lightweight, Comfortable, and Strong: Harness weight not exceeding 150 grams for medium size.
Implementation: Use lightweight yet strong materials and test across various pet sizes to ensure comfort and strength.
Measurement Method: Use customer satisfaction surveys with a Likert scale to assess comfort and strength, and conduct laboratory tests to measure the material's weight and strength.

k. Environmentally Friendly Materials and Production Processes: Use at least 50% recycled materials.
Implementation: Identify and adopt high-quality recycled material sources and optimize production processes to be more environmentally friendly.
Measurement Method: Perform raw material audits to ensure the proportion of recycled materials and monitor carbon footprint and energy efficiency in the production process.

l. Reflective, Safety, and Control Features: Achieve a minimum safety score of 4.5 in customer product testing.
Implementation: Add reflective elements to the design, enhance safety features, and improve control of the harness.
Measurement Method: Use customer satisfaction surveys with a Likert scale to assess reflective and safety features and conduct field tests to ensure effective visibility and control under various conditions.

m. Standard Leash Attachments: Achieve a minimum strength score of 4.5 in customer product testing.
Implementation: Use high-quality, strong, and durable leash attachments, and conduct thorough material strength tests.
Measurement Method: Use customer satisfaction surveys with a Likert scale to assess leash attachment strength and conduct laboratory tests to measure the durability and strength of leash attachments under load and stress.

n. Design for Various Activities: Achieve a minimum flexibility score of 4.5 in customer product testing.
Implementation: Develop a versatile design that can be used for various activities, such as walking, running, and playing. Conduct trials in various activity scenarios.
Measurement Method: Use customer satisfaction surveys with a Likert scale to assess design flexibility and conduct field tests to ensure the product can be used comfortably and effectively in different activities.

o. Customization of Sizes and Others: Provide at least 5 different sizes.
Implementation: Develop products in various sizes that cover the range of pet sizes from small to large. Conduct testing to ensure each size fits and is comfortable for different types of pets.
Measurement Method: Use customer satisfaction surveys to assess size fit and comfort, and monitor sales and feedback for each available size.

p. Pricing Variants for Different Market Segments: Set 10 different price variants.
Implementation: Develop products with various features and materials to create variants suitable for different market segments, from economical to premium.
Measurement Method: Monitor sales and customer feedback for each price variant, and conduct market analysis to ensure each segment is well-served.

By setting realistic and measurable targets for each technical attribute, BirkinPet can ensure that the developed products meet customer needs and expectations. Establishing targets helps in developing better, higher-quality, and more competitive products in the market.

2. Sub-Matrix of Maximum Relationship

This matrix shows the strength of the relationship between Customer Requirements and the Technical Requirements of the BirkinPet product to be developed. The maximum relationship scores between customer needs and technical attributes are derived from the Voice of the Engineers process.

Comfort:

- Ergonomic and Comfortable Design (●): Very strong relationship. Ergonomic design is crucial for comfort.
- Soft and Hypoallergenic Materials (●): Very strong relationship. Soft and hypoallergenic materials ensure comfort.

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- Strong and Durable Materials (○): Moderate relationship. Durable materials should also be comfortable.
- Secure Locking System (▽): Weak relationship. The locking system focuses more on safety than comfort.
- Easy to Put On and Take Off Design (○): Moderate relationship. Easy design enhances comfort.
- Clear and Easy-to-Understand Instructions (▽): Weak relationship. Instructions focus more on ease of use.
- Bite, Scratch, and Weather-Resistant Materials (▽): Weak relationship. Durable materials focus more on durability.
- Stylish Design in Various Colors and Patterns (○): Moderate relationship. Stylish design can enhance psychological comfort.
- Easy to Wash, Quick-Drying, and Odor-Resistant (●): Very strong relationship. Materials that are easy to wash and odor-resistant are very comfortable.
- Lightweight, Comfortable, and Strong (●): Very strong relationship. Lightweight materials are very comfortable.
- Environmentally Friendly Materials and Production Processes (▽): Weak relationship. The focus is on sustainability, not directly on comfort.
- Reflective, Safety, and Control Features (▽): Weak relationship. The focus is on safety.
- Standard Leash Attachments (▽): Weak relationship. The focus is on safety and control.
- Design for Various Activities (○): Moderate relationship. Flexible design can enhance comfort.
- Customization of Sizes and Others (○): Moderate relationship. Size customization can improve comfort.
- Pricing Variants for Different Market Segments (▽): Weak relationship. The focus is on pricing diversity.

Safety and Strength:

- Ergonomic and Comfortable Design (○): Moderate relationship. The ergonomic design also contributes to safety.
- Soft and Hypoallergenic Materials (▽): Weak relationship. Hypoallergenic materials focus more on comfort.
- Strong and Durable Materials (●): Very strong relationship. Strong materials are crucial for safety.
- Secure Locking System (●): Very strong relationship. A strong locking system is crucial for safety.
- Easy to Put On and Take Off Design (○): Moderate relationship. Easy-to-use design also contributes to safety.
- Clear and Easy-to-Understand Instructions (▽): Weak relationship. Instructions focus more on ease of use.
- Bite, Scratch, and Weather-Resistant Materials (●): Very strong relationship. Bite and weather-resistant materials are crucial for safety.
- Stylish Design in Various Colors and Patterns (▽): Weak relationship. Stylish design focuses more on aesthetics.
- Easy to Wash, Quick-Drying, and Odor-Resistant (▽): Weak relationship. Focus is on ease of care.
- Lightweight, Comfortable, and Strong (●): Very strong relationship. Lightweight and strong materials ensure safety and comfort.
- Environmentally Friendly Materials and Production Processes (▽): Weak relationship. The focus is on sustainability.
- Reflective, Safety, and Control Features (●): Very strong relationship. Reflective features improve visibility and safety.
- Standard Leash Attachments (●): Very strong relationship. Strong and standard leash attachments ensure safety.
- Design for Various Activities (○): Moderate relationship. Flexible design enhances safety in various activities.
- Customization of Sizes and Others (○): Moderate relationship. Size customization ensures better safety.
- Pricing Variants for Different Market Segments (▽): Weak relationship. The focus is on pricing diversity.

Ease of Use:

- Ergonomic and Comfortable Design (○): Moderate relationship. Ergonomic design enhances ease of use.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

- Soft and Hypoallergenic Materials (▽): Weak relationship. The focus is on comfort.
- Strong and Durable Materials (▽): Weak relationship. The focus is on durability.
- Secure Locking System (○): Moderate relationship. A secure locking system facilitates ease of use.
- Easy to Put On and Take Off Design (●): Very strong relationship. The easy-to-use design significantly facilitates ease of use.
- Clear and Easy-to-Understand Instructions (●): Very strong relationship. Clear instructions greatly facilitate ease of use.
- Bite, Scratch, and Weather-Resistant Materials (▽): Weak relationship. The focus is on durability.
- Stylish Design in Various Colors and Patterns (▽): Weak relationship. The focus is on aesthetics.
- Easy to Wash, Quick-Drying, and Odor-Resistant (○): Moderate relationship. Easy-to-wash materials facilitate ease of care.
- Lightweight, Comfortable, and Strong (○): Moderate relationship. Lightweight and strong materials facilitate ease of use.
- Environmentally Friendly Materials and Production Processes (▽): Weak relationship. The focus is on sustainability.
- Reflective, Safety, and Control Features (▽): Weak relationship. The focus is on safety.
- Standard Leash Attachments (▽): Weak relationship. The focus is on safety and control.
- Design for Various Activities (○): Moderate relationship. Flexible design enhances ease of use.
- Customization of Sizes and Others (○): Moderate relationship. Size customization enhances ease of use.
- Pricing Variants for Different Market Segments (▽): Weak relationship. The focus is on pricing diversity.

Material Durability:

- Ergonomic and Comfortable Design (▽): Weak relationship. The focus is on comfort.
- Soft and Hypoallergenic Materials (▽): Weak relationship. The focus is on comfort.
- Strong and Durable Materials (●): Very strong relationship. Strong materials are crucial for durability.
- Secure Locking System (○): Moderate relationship. A secure locking system enhances durability.
- Easy to Put On and Take Off Design (▽): Weak relationship. The focus is on ease of use.
- Clear and Easy-to-Understand Instructions (▽): Weak relationship. The focus is on ease of use.
- Bite, Scratch, and Weather-Resistant Materials (●): Very strong relationship. Bite, scratch, and weather-resistant materials are crucial for durability.
- Stylish Design in Various Colors and Patterns (▽): Weak relationship. The focus is on aesthetics.
- Easy to Wash, Quick-Drying, and Odor-Resistant (○): Moderate relationship. Easy-to-wash materials enhance product durability.
- Lightweight, Comfortable, and Strong (○): Moderate relationship. Strong materials enhance durability.
- Environmentally Friendly Materials and Production Processes (○): Moderate relationship. Environmentally friendly materials and sustainable production processes enhance durability.
- Reflective, Safety, and Control Features (▽): Weak relationship. The focus is on safety.
- Standard Leash Attachments (▽): Weak relationship. The focus is on safety and control.
- Design for Various Activities (▽): Weak relationship. The focus is on usage flexibility.
- Customization of Sizes and Others (▽): Weak relationship. The focus is on comfort.

3. Sub-Matrix of Technical Importance Rating

This matrix assesses the importance of enhancing or improving specific technical features or specifications in BirkinPet products. The ratings are derived from the Voice of the

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

Engineer analysis and the maximum relationship matrix, with each feature assigned a Technical Importance Rating of 9. The stages are as follows:

a. Ergonomic and Comfortable Design: Ergonomic design is crucial for ensuring the comfort and functionality of the product. It affects how the product is used and how it feels when worn by pets. Importance: Ensures comfort and proper function, crucial for user satisfaction.
b. Soft and Hypoallergenic Materials: Soft, hypoallergenic materials are essential for pet comfort and health, preventing skin irritation and allergies. Importance: Critical for preventing discomfort and health issues in pets.
c. Strong and Durable Materials: Strong and durable materials ensure the product's safety and longevity, which is vital for users. Importance: Essential for product safety and longevity, improving user confidence.
d. Secure Locking System: A secure locking system ensures that pets cannot escape from the harness, enhancing product safety. Importance: Key for maintaining pet safety and security.
e. Easy to Put On and Take Off Design: The ease of putting on and taking off the harness is important for user convenience, making everyday use simpler. Importance: Increases user convenience and daily usability.
f. Clear and Easy-to-Understand Instructions: Clear and easy-to-understand instructions help users to use the product correctly and effectively. Importance: Assists in correct and efficient product use, reducing user frustration.
g. Bite, Scratch, and Weather-Resistant Materials: Materials that resist bites, scratches, and extreme weather ensure the product remains durable and functional in various conditions. Importance: Vital for maintaining product integrity under different conditions.
h. Stylish Design in Various Colors and Patterns: An attractive design available in various colors and patterns enhances the product's market appeal. Importance: Increases market appeal and attracts customers.
i. Easy to Wash, Quick-Drying, and Odor-Resistant: Ease of maintenance is a significant added value for users, ensuring the product remains clean and hygienic. Importance: Simplifies product maintenance, keeping it clean and hygienic.
j. Lightweight, Comfortable, and Strong: A product that is lightweight yet strong provides additional comfort without sacrificing durability. Importance: Enhances comfort while ensuring durability.
k. Environmentally Friendly Materials and Production Processes: Using environmentally friendly materials and production processes is important for attracting environmentally conscious consumers. Importance: Appeals to eco-conscious customers, adding value to the product.
l. Reflective, Safety, and Control Features: Adding reflective features increases pet visibility and safety, especially when used at night. Importance: Improves pet visibility and safety, particularly in low-light conditions.
m. Standard Leash Attachments: Strong and durable leash attachments are a standard feature necessary to ensure good safety and control. Importance: Essential for maintaining safety and control.
n. Design for Various Activities: A flexible design for various activities enhances the product's usefulness and value in the eyes of consumers. Importance: Increases product versatility and consumer value.
o. Customization of Sizes and Others: Providing various sizes and customization options ensures the product meets the needs of different types of pets. Importance: Allows the product to accommodate various pet sizes and preferences.
p. Pricing Variants for Different Market Segments: Offering different pricing variants helps reach various market segments and enhances the product's appeal. Importance: Expands market reach and attracts diverse customer segments.

By assigning a high technical importance rating to each attribute, BirkinPet can ensure that product development focuses on the most crucial aspects to meet customer needs and expectations. This will help BirkinPet design and produce high-quality, safe, comfortable, and attractive products for consumers.

4. Sub-Matrix of Relative Weight Technical Importance Rating

This sub-matrix determines the priority order of technical responses and assesses the comparative performance of the company's technical responses against competitors. Relative Weight is calculated based on the importance of each technical

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

attribute and how these attributes contribute to fulfilling customer needs. Although each technical attribute has the same Technical Importance Rating (9), the relative weight of each is calculated to show its proportionate importance in overall product development.

By assigning the same technical importance rating to each attribute and calculating the relative weight, BirkinPet can ensure that product development encompasses all critical aspects contributing to customer satisfaction. Focusing on technical attributes with strong relationships to customer needs and ensuring that each attribute receives appropriate attention in the product development process will help BirkinPet enhance its product quality and market competitiveness.

5. Sub-Matrix of Weight Chart Technical Importance Rating

This sub-matrix presents a bar chart or table with vertical pipe markers corresponding to the Technical Importance Rating values for BirkinPet's product. The weight chart or table illustrates the relative weight of each technical attribute based on the technical importance rating. This visualization aids in understanding the technical priorities that need to be addressed in BirkinPet's product development.

6. Technical Requirements and Relative Weight

This section visualizes the relative weight of each technical attribute in a table and chart, showing both the Technical Importance Rating and the Relative Weight of each technical attribute. With the relative weight assigned to each technical attribute, BirkinPet ensures that all critical aspects of the product are considered in the development process. The bar chart helps visualize that each technical attribute is prioritized for product development, highlighting the importance of balancing all customer needs and expectations.

Using the Weight Chart, BirkinPet can allocate resources and focus appropriately on each technical aspect, ensuring that the developed product is of high quality, safe, comfortable, and appealing to consumers.

Thus, BirkinPet can ensure that the resulting product meets or exceeds customer expectations, enhancing customer satisfaction and loyalty, and strengthening its competitive position in the market.

7. Sub-Matrix of Technical Competitive Assessment

This sub-matrix involves benchmarking product quality against competitors. Some technical response requirements in BirkinPet's production lag behind competitors, such as additional safety features and attractive design. However, BirkinPet excels in material quality and quality control. This sub-matrix evaluates the technical performance of BirkinPet's product compared to competitors' products. The assessment is conducted for each technical attribute based on consumer perceptions and technical testing.

BirkinPet excels in many technical aspects compared to competitors, particularly in comfort, material strength, ease of maintenance, and safety features. This indicates that BirkinPet effectively meets the primary needs of customers. BirkinPet has an advantage in hypoallergenic materials, secure locking systems, and material durability. Focusing on these attributes can further strengthen BirkinPet's position in the market.

IV. CONCLUSION

This study employed the Quality Function Deployment (QFD) method to evaluate and develop BirkinPet's pet harness apparel by prioritizing customer needs. By distributing questionnaires to 96 respondents and constructing a House of Quality (HoQ) matrix, the relationship between Customer Importance and Technical Importance was analyzed to determine the technical priorities to be implemented in BirkinPet's production process.

Based on the House of Quality matrix analysis, the attributes that stand out in BirkinPet's product are:

1. Lightweight, Comfortable, and Safe (481.46): This attribute indicates that customers highly value a product that is not only comfortable for pets but also safe.
2. Design for Various Activities (416.07): The flexibility of the design allowing for use in various activities is highly appreciated by customers.
3. Ergonomic and Comfortable Design (389.91): A design that follows the pet's anatomy for comfort is one of the attributes highly valued by customers.

The main technical priorities to achieve these important customer attributes are:

1. Safe and Strong (4.99): The safety and strength of the product are the primary technical priorities to ensure that the product meets high standards of safety and durability.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9294.117-129 *e*-ISSN 2622-2035

2. Availability of Sizes and Options (4.86): The variety in sizes and product options is an important technical aspect to be implemented to meet various customer needs.

In BirkinPet's product, ergonomic and comfortable design, flexibility for various activities, as well as comfort and safety, are the main characteristics that significantly impact customer satisfaction. To achieve and enhance customer satisfaction further, BirkinPet must focus on the technical implementation related to safety, strength, and product variety. By prioritizing and implementing the most important technical attributes, BirkinPet can continue to meet or even exceed customer expectations, increase customer satisfaction and loyalty, and strengthen its competitive position in the pet accessories market.

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Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9295.130-136 *e*-ISSN 2622-2035

The Overview Literature Review on Competence-Based Education in The Industrial Engineering Using PRISMA 2020

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Abstract— Structured methods for the methodical re-alignment of professional education programs are needed for the comprehensive integration of the human workforce in digital and sustainable manufacturing and logistics systems. It is believed that investing in engineering education is essential to the advancement of both industry and society. Future engineers, though, will need more than simply a solid foundation in technology. The focus on competence orientation is often neglected, particularly in the field of Industrial Engineering (IE), and empirically proven success criteria that support the holistic reorientation of engineering education are usually studied. The authors of this work perform a thorough literature review on engineering education, focusing on competence-based engineering education within the field of IE. Additionally, the writers offer beneficial implications for the competence-based for Industrial Engineering students and lectures writings.

Index Terms— BoK, Curriculum, Industrial Engineering, Overview

I. INTRODUCTION

Maintaining innovation and, by extension, the long-term competitiveness of the entire economy, is critical to Indonesian society's sustained prosperity. One of the key success elements for professionalization programs can be considered to be the comprehensive integration of individuals into the so-called "factory of the future" and the related retraining or further certifications of the workforce. Thus, it is believed that investing in engineering education is essential for the future.

Recent studies demonstrate a significant increase in the shortage of skilled workers in manufacturing enterprises over the next few years, highlighting a substantial demand for qualified engineers in smart and sustainable operations management as the primary area of application for industrial engineering and management professionals. Engineering education for IEs has evolved and expanded continuously since the middle of the 18th century, like these disciplinary advancements. The advancements of the Industrial Revolution are comparable to the ongoing professionalization initiatives. Thus, we can anticipate a paradigm change in the working world in the future, particularly for engineers.

The term "Engineering Education 5.0" refers to the implications that the technological advancements based on the further development of Industry 5.0 concepts and models will have for engineering education. These advancements will permanently alter work processes, replace traditional occupational fields, and generate new occupational fields. To do this, (future) IE specialists will require training beyond just a solid grounding in science and technology. The pandemic and the rapidly advancing implementation of Industry 4.0/Industry 5.0 concepts have sparked transformative educational processes that call for not only a redesign of teaching and learning methodologies but also a redesign of learning content and competencies taught, particularly in engineering education for tomorrow's IE professionals. The problem today facing educational institutions is to properly integrate the aforementioned trends and requirements into IE engineering education to ensure future generations' well-being, the workability of engineers, and the comprehension of their roles.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9295.130-136 *e*-ISSN 2622-2035

This paper, therefore, pursues the following central research questions

1. What challenges is the IE discipline currently facing and what are the implications
   for engineering education of IEs?
2. Which competencies are perceived as necessary concerning the engineering education of IEs?

To determine the current state of research on competencies and teaching strategies in engineering education in the context of the fifth industrial revolution, the paper will conduct a systematic literature review (SLR), there are 46 literature studies. Based on the findings, it will conclude the knowledge triangle, which consists of business, science, and education. The format of the paper is as follows: The research design and, thus, the methodology of this work. Result and discussion overview of the descriptive findings and the content analysis that led to the identification of two categories. Review of the findings and their significance for researchers and practitioners. The important claims in the paper's conclusion.

II. MATERIALS AND METHODS SYSTEMATIC LITERATURE REVIEW

Using the SLR method makes it possible to compile an extensive overview of the best literature available on a certain subject. The most acceptable systematic strategy for an open, understandable, and comprehensive analysis of the body of literature was to adopt the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) standard. The implementation of PRISMA 2020 has promise for numerous parties. Readers can evaluate the suitability of the procedures and, consequently, the reliability of the results, with the help of comprehensive reporting. The synthesis process facilitates the assessment of the findings' relevance for IE practitioners. Describe the degree of confidence in the body of evidence supporting an outcome and the implications of findings to assist managers, policymakers, and other decision-makers in developing suitable practice or policy recommendations.

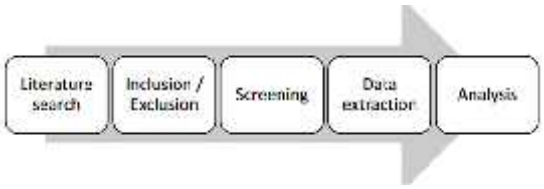

Figure 1. PRISMA Process (1)

III. RESEARCH METHODOLOGY

The PRISMA method follows a systematic approach. This is shown in Figure 2 and will be described in more detail below (1).

A. Literature search and inclusion and exclusion criteria

This study focuses on literature that has already been published by professors and students in the PGRI Adi Buana Surabaya Program Study Industrial Technology at the University PGRI Adi Buana Surabaya Program. The total amount of published works is 89, with 11 IE lectures contributing to the total throughout the 2019–2024 time frame. From these few literary works, humata.ai eventually quotes them and performs categorization. The results of this classification were then manually entered onto paper, which became a reset group or reset topic. This is important to understand because the curriculum's results are aligned with previously published analyses.

B. Literature search and inclusion and exclusion criteria

Following the inclusion and exclusion criteria, all relevant papers were downloaded as full texts from the respective online sources for the subsequent analysis. Before the content analysis, all 26 identified papers were analyzed descriptively to provide an overview of the current state of research. The content analysis was generated based on guidelines of qualitative social research using qualitative content analysis using inductive thematic categorization of the literature examined (2).

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9295.130-136 *e*-ISSN 2622-2035

IV. DISCUSSION AND IMPLICATIONS

Our study sought to openly provide a well-organized summary of the most recent research on "Engineering Education 5.0," with an emphasis on competence-based learning in the field of IE. The findings of this study suggest additional efforts to professionalize engineering education, which in turn helps to further characterize engineering education in the field of IE. The competency discourse's research trends can be determined by carefully carrying out the SLR. Additionally, two categories within didactical planning—the macro level and the meso level, respectively—as well as their theme clusters can be identified. Considering the first study question, which examines the clusters within the macro level category, it is possible to identify the following issues and suggest some improvements for IE engineering education. The papers together draw attention to the necessity of coordinating learning outcomes, professional requirements, and educational objectives. To overcome these obstacles, academic staff, and students can utilize a teaching and learning center and train-the-teacher approaches.

On the other hand, it is acknowledged that sustainability factors, soft skills, and transversal skills receive insufficient emphasis. The majority of the examined IE curricula lack courses and initiatives that help students build their transdisciplinary and interpersonal skills, instead emphasizing just technical knowledge. Other efforts include going above and beyond the traditional curriculum, creating a mentorship program that pairs grads with current students, and issuing badges through the university job center.

Figure 2. Themes mapping using humata.ai

Based on the analysis of several previously completed documents, several major topics have emerged, Summary of Key Aspects from the Documents in help with humata.ai.

1. Evaluation of Quality and Production Efficiency
2. Ambition and Production Strategy
3. Material and Technology Development
4. Ergonomics, Health, and Workplace Safety
5. Education and Training
6. Psychology and Adversity

Figure 3. Six BoK mostly used in research IE Adi Buana Surabaya

The last 10 years' effects of artificial intelligence, with an emphasis on supply chain management, robots, quality assurance, predictive maintenance, and operational optimization. Machine learning algorithms provide predictive maintenance, which reduces downtime and maximizes resource allocation. Operational optimization improves decision-making, resource usage, and overall efficiency. It is accomplished by AI's real-time data analysis. Artificial Intelligence (AI) in robotics improves production capacities and advances image recognition and machine learning in quality control processes to guarantee better quality. Artificial intelligence (AI) improves inventories, expedites routes, forecasts demand, and promotes resilience in supply chain management. The revolutionary

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9295.130-136 *e*-ISSN 2622-2035

synergy between human-machine collaboration is exemplified by collaborative robots and AI-driven workforce empowerment. The piece ends with a review of the last ten years' advancements, highlighting the continuous growth of AI in industrial engineering and promising more intelligent, flexible, powerful (3).

V. LIMITATION

The study conducted a review of the scientific literature from 2018 to 2023 for IE lectures at the University Adi Buana, the date of data extraction from the IE Department Adi Buana database. A limitation of this research is that during the period of the screening, selection, analysis, and development of the framework, further research on competence-based engineering education may have been performed and published. The current rapid development of research in this area is a limit to the results of this review.

In summary, these documents cover many important aspects of quality control, production efficiency, technological advancement, workplace safety and health, education, and psychological well-being. Work Design & Measurement, Operations Research & Analysis, Engineering Economic Analysis, Facilities Engineering & Energy Management, Quality & Reliability Engineering, Ergonomics & Human Factors, Operations Engineering & Management, Supply Chain Management, Engineering Management, Safety, Information Engineering, Design and Manufacturing Engineering, Product Design & Development, System Design & Engineering are the fourteen bodies of knowledge that are based on Industrial System Engineering (4). All of the BoK has already been completed at IE Universitas PGRI Adi Buana Surabaya; nevertheless, if the 14th BoK is examined more closely, the majority of the research that is done is six Bok.

Table 1. Literature reviews as part of IE Studies

VI. DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

VII. CONCLUSION

Particularly the industry and the related engineering education must completely realign due to the primary forces of digitalization and sustainability (Industry 4.0) as well as human centeredness (Industry 5.0), a greater commitment to sustainable business management, and ultimately crises, global disruption, internationalization, and pandemics. This makes it clear that engineering education is still in need of further growth before it becomes sufficiently professionalized. One major challenge that needs

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9295.130-136 *e*-ISSN 2622-2035

to be addressed is the alignment of educational objectives, learning outcomes, and professional obligations. Innovative teaching and learning techniques, industry collaboration, and real-world applications must all be incorporated into the curriculum to meet this challenge. Challenge-based learning, the use of tools, simulations, and specialized software, life-cycle engineering, flipped classrooms and laboratories, and closer industry engagement are a few examples of these teaching and learning strategies. The latter can be accomplished using strategic partnerships and collaborations with nearby sectors, involving alumni to cultivate relationships and tackle real-world issues and challenges to establish environments that are favorable for learning.

More research should focus on identifying the competencies required for both professional and private competence development to successfully navigate both the professional and personal spheres of daily life. To do this, future research should focus on developing better methods for measuring competencies or undertake more thorough studies using mixed-method approaches to investigate the competencies required of IE experts. Future studies to further engineering education should start with the findings of this paper. An immersive adaptation of the professional education and training of (future) engineers is necessary, as was already noted in the introduction. The dynamic junction of AI and industrial engineering has undergone a dramatic metamorphosis that has propelled the industry into the era of Industry 4.0. In addition to completely redefining conventional manufacturing processes, this revolutionary integration of AI technology has ushered in a period of previously unheard-of efficiency, predictive power, and data-driven decision-making. Predictive maintenance has emerged as a crucial application of artificial intelligence, which has caused a seismic upheaval in the industrial sector. Machine learning algorithms anticipate equipment breakdowns by carefully analyzing data from sensors and machinery, which enables preventative maintenance interventions.

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p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9304.137-143 *e*-ISSN 2622-2035

Autoregressive Integrated Moving Average (ARIMA) Simulation Methods In Product Inventory 9969B Printable Splicing Tape

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Abstract - Simulation is applied to the 9969B Printable Splicing Tape product. The ARIMA (Autoregressive Integrated Moving Average) method, which is a method that is based on the values of changes that have occurred in the past, is then used to determine historical data patterns. This research aims to simulate forecasting inventory control needs for Printable Splicing Tape stock. The temporary ARIMA model is p = 8 (PACF dying down plot), d = 2 (one differencing), and q = 1. So, the temporary ARIMA model obtained is (8, 2, 1). The sales forecast for all Printable Splicing Tape products type 9969B on average per month during June-December 2023 is estimated that the average forecast for the company's Inventory Control must stock 608 rolls with a tracking error of -1 (e < 4) so it is very permissible because it is less than quaternion.

Keywords: *Inventory, ARIMA, Moving Average*

I. INTRODUCTION

Control of products as inventory is carried out by the Inventory Control (IC) section. This section organizes procurement and inventory control to support sales activities. One of the activities of this section is providing product quantity data to the purchasing department to order from PT 3M Indonesia[1]. Product orders are based on the number of requests determined by the Inventory Control (IC) section and the marketing department by calculating the amount of inventory in the warehouse. All products purchased by PT. ACA from PT 3M Indonesia is an imported product imported by PT 3M Indonesia from its factories in the Americas, Europe, Asia, and Australia. The business world is currently faced with competitive conditions, so the need for forecasting for production handling must be good [2].

Ordering activities are divided into 2, namely regular orders and emergent orders. Regular orders are product orders that are made regularly every month with a lead time of 5 working days for products available in the PT 3M Indonesia warehouse and 3 months if there is no inventory at PT 3M Indonesia and must be imported from factories abroad. successful business, a fairly large amount of capital is required [3]. Delivery of products from PT 3M factories abroad to PT 3M Indonesia is carried out by sea transportation mode (ship) or by air transportation mode (air freight). Meanwhile, emergency orders are carried out as an action against an increase in demand from customers. The form is in the form of additional (additional) order quantities [4]. Additional order activities require additional product procurement costs. In emergency orders, product delivery with an accelerated delivery lead time uses air transportation mode (air freight) [5].

The ARIMA (Autoregressive Integrated Moving Average) method, which is a method that is based on the values of a variable that has occurred in the past, is then used to determine historical patterns of data and then to extrapolate these patterns into the future [6]. The concept of applying ARIMA is by plotting time series data (time series plot), ACF, and PACF [7]. Test data stationarity by looking at time series data plots, ACF plots, and Box-cox plots, and carrying out unit root tests using the ADF test [8].

Carrying out data transformation is done by using the Box-Cox transformation method if the data used is not stationary in variance. Perform differentiation on data if the data used is not stationary on average. Next, check the stationarity of the data that has been transformed or differentiated. This stage is carried out until the data is stationary [9].

Determine the temporary prediction model. Determine the model order by looking at the ACF and PACF plots of stationary data. Estimating the parameters and then testing the

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9304.137-143 *e*-ISSN 2622-2035

significance of the model parameters using the t-test or looking at the p-value [10].

Based on existing historical data, the most frequent shortages and overstocks are adhesive and double-sided tape. This condition occurs due to quite large fluctuations in changes in demand estimates, without any method that can anticipate changes that occur by paying attention to possible demand patterns that were formed in the previous period. This shortage and overstock situation occurs in imported materials with a long lead time (3 months), certainly not a good forecast for a very large company [11].

To overcome these fluctuations, proper inventory control is needed. Inventory shortages can cause PO cancellations and customers switching to using competitor products so that customers do not cancel POs and switch to using PT competitor products. ACA [12]. This research aims to simulate forecasting inventory control needs for Printable Splicing Tape stock.

II. METHODOLOGY

The ARIMA model itself is a combination of the AR (Autoregressive) model, which is a method for seeing the movement of a variable through the variable itself, and MA (Moving Average), which is a model for knowing the movement of a variable with its residuals in the past [13]. Seasonal ARIMA (SARIMA) is a development method of the ARIMA method for forecasting patterned data. These two methods were chosen because they have good forecasting accuracy for short-term forecasting. The ARIMA method is used for data with constant data patterns, while the SARIMA method is generally used for data with seasonal patterns.

The equipment used in this research is SPSS version 26.0 software which is used to create forecast models using the ACF and PACF methods, as well as model forecasts using the ARIMA method, and Microsoft Excel is used to calculate correlation and RMSE (Root Mean Square) values. Error) between the output results of the two methods. Sample data was obtained from requests from two companies, namely PT. TJ Mojokerto and PT. SP Sidoarjo, data taken in 2023 for product type 9969B.

III. RESULT AND DISCUSSION

PT ACA receives orders from consumers in the form of purchase orders (PO). Consumers issue a PO every month for one delivery or a PO forecast for delivery in the next 2-3 months, with a maximum lead time of 5 working days from the delivery date determined by the consumer, if this is not met there could be cancellation of the PO because the consumer does not use one brand for double tape.

Figure 1. 9969B *Printable Splicing Tape*

Based on this data, there is a difference between demand and stock provided by the company, where a stock reaches 7.450 rolls and demand reaches 6,470 rolls, resulting in a difference of 980 rolls or around 15.1%.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9304.137-143 *e*-ISSN 2622-2035

Table 1. Demand and Stock for Product Type 9969 B

No	Month	*Customer Quantity*		Qty Total	Amount Stock
		PT. TJ	PT. SP		
1	January	0	0	0	800
2	February	700	325	1025	800
3	March	0	400	400	1000
4	April	0	0	0	200
5	May	800	300	1100	200
6	June	200	100	300	600
7	July	900	370	1270	800
8	August	0	300	300	400
9	September	0	450	450	500
10	October	125	0	125	400
11	November	800	600	1400	1750
12	December	0	100	100	0
			Total	**6470**	**7450**
			Difference	**980**	
			%	**15.1%**	

Suorce : PT ACA, 2023

Bearing in mind that in 2023 the double tape product type 9969 B will experience a stock difference of 980 rolls or around 15.1%, so to reduce this, linear trend forecasting is used which is based on demand and stock for January - June 2023 to forecast demand and stock for July - December 2023

Table 2. Percentage Of Stock Difference For Double Tape Product Type 9969B

No	Month	Stock	Forecast (*MAV*)	Demand
1	January	800	800	0
2	February	800	800	1025
3	March	1000	1000	400
4	April	200	200	0
5	May	200	200	1100
6	June	600	600	300
7	July	800	604	1270
8	August	400	605	300
9	September	500	605	450
10	October	400	606	125
11	November	1750	607	1400
12	December	0	607	100
	Total	**7450**	**7234**	**6470**
	Difference	**980**	**764**	
	Difference (%)	**15.1**	**11.8**	

Based on this forecast, the number of rolls of double tape type 9969B during 2023 required 7234 rolls with a demand of 6470 rolls so the difference is smaller, namely 764 rolls or around 11.8% from the initial stock (original) of 15.1%, there is an estimated decrease in the stock of around 3.3%.

Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana
p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9304.137-143 *e*-ISSN 2622-2035

1. Average Stationarity

Stasioneritas rata-rata dilakukan untuk mengetahui apakah data penjualan selama berbulan-bulan pada kedua perusahaan yang membutuhkan produk perusahaan PT ACA, stasioner terhadap rata-rata. Stasioneritas rata-rata menggunakan plot ACF dan PACF untuk menunjukkan autokorelasi data pada ARIMA

Average stationarity was carried out to find out whether sales data for months at the two companies that needed PT ACA company products were stationary relative to the average. Average stationarity uses ACF and PACF plots to show data autocorrelation in ARIMA.

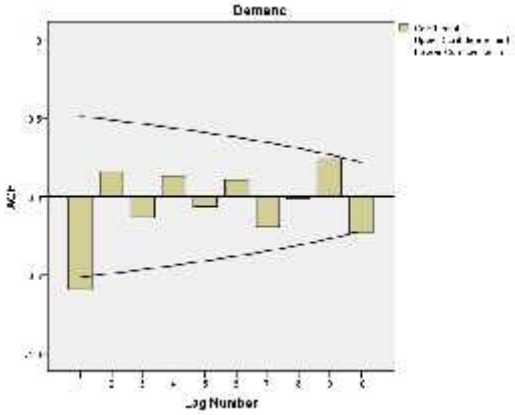

Figure 2. ACF (Autocorrelation Function)

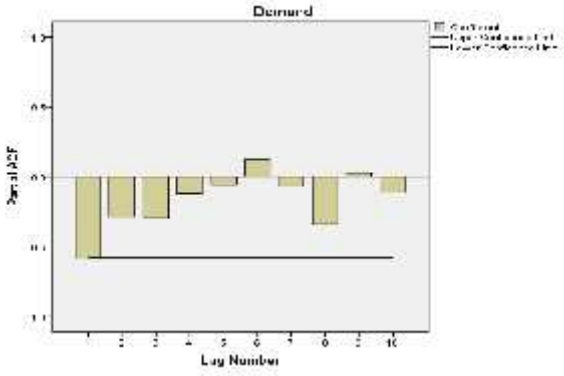

Figure 3. PACF (Partial Autocorrelation Function)

Figure 2 shows the ACF data plot after one differencing, as well as Figure 3 shows the PACF plot after one differencing. One differentiation carried out in ARIMA will determine the order d in the ARIMA model.

Based on Figure 3 and Figure 4, it can be seen that the PACF plot is more dying down than the ACF plot, so the data tends to be AR (Autoregressive). Because the data tends to be AR of order p in the ARIMA model

1. Identify the ARIMA Model

The ARIMA model has the notation (p, d, q). Where the order p is Autoregressive (AR), d is a difference, and q is Moving Average (MA). Based on Figure 2 and Figure 3, the temporary ARIMA model obtained is p = 8 (PACF dying down plot), d = 2 (one differencing), and q = 1. So, the temporary ARIMA model obtained is (8, 2, 1)

One way to evaluate forecasting techniques is to use a measure of the level of difference between forecast results and actual demand which is often used, namely MAD. This is the average absolute error over a certain period without paying attention to whether the forecast results are greater or smaller than reality. Mathematically, MAD is formulated as follows:

2. *Mean Absolute Deviation* = MAD

$$\text{the th MD} = \sum \left| \frac{\text{At} + \text{Ft}}{\text{n}} \right|$$

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Journal of applied Industrial Engineering-University of PGRI AdiBuana
p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9304.137-143 *e*-ISSN 2622-2035
Calculating of MAD

$$\text{Period I (0,1)} = \frac{-0.78 - 1.31 - 1.78 - 2.20 - 2.58 - 2.92}{6} = -11.56/6 = -1.93$$

$$\text{Period 2 (0,2)} = \frac{-0.76 - 1.21 - 1.57 - 1.86 - 2.08 - 2.27}{6} = -9.75/6 = -1.63$$

$$\text{Period 3 (0,5)} = \frac{-0.70 - 0.95 - 1.08 - 1.14 - 1.17 - 1.19}{6} = -6.22/6 = -1.04$$

3. *Mean Square Error* = MSE

MSE is an alternative method in a forecasting method. This approach is important because this technique produces moderate errors rather than a forecast that produces very large errors. MSE is calculated by adding the squares of all forecast errors in each period and dividing it by the number of forecasting periods, and the calculation results are as follows:

$$\text{MSE} = \sum \left[\frac{A + F}{n}\right]^2$$

Calculating of MSE

$$\text{Period I (0,1)} = \frac{-(0.78)^2 - (1.31)^2 - (1.78)^2 - (2.20)^2 - (2.58)^2 - (2.92)^2}{6} = 25.48/6 = 4.25$$

$$\text{Period 2 (0,2)} = \frac{-(0.76)^2 - (1.21)^2 - (1.57)^2 - (1.86)^2 - (2.08)^2 - (2.27)^2}{6} = 17.44/6 = 2.91$$

$$\text{Period 3 (0,5)} = \frac{-(0.70)^2 - (0.95)^2 - (1.08)^2 - (1.14)^2 - (1.17)^2 - (1.19)^2}{6} = -6.62/6 = 1.10$$

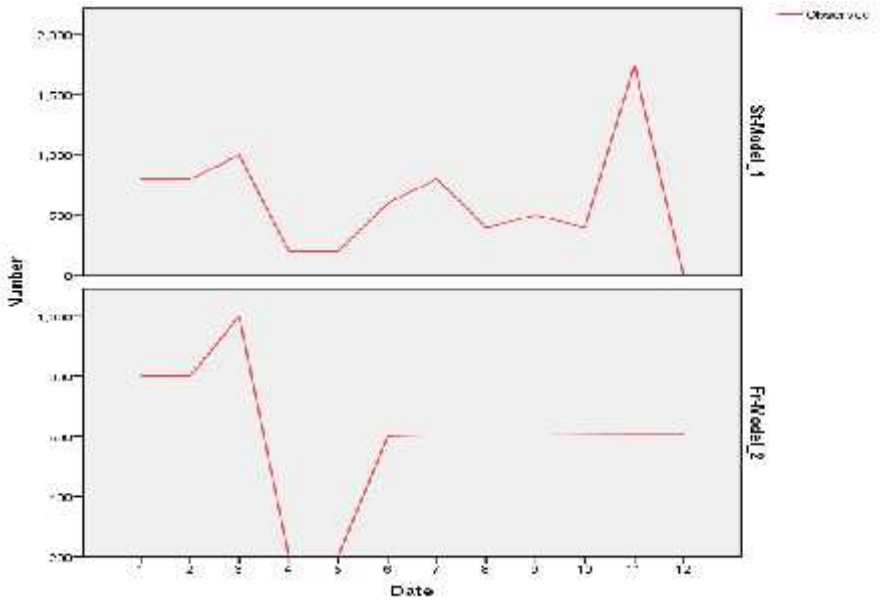

Figure 5. Demand Fluctuation Trends

In the first Stock Model image (ST-Model_1) there is an up and down trend indicating that the observed variables experienced fluctuations or changes in the period analyzed. An up-and-down trend can indicate a cyclical pattern or natural fluctuation in company data before forecasting is carried out in 2020. In contrast to the image of the Second Forecasting Model (Fr-Model_2), after the fifth month, there is a stable fluctuation until the twelfth month based on market demand for 9969B Printable products Splicing Tape.

The results for $\sigma = 0.5$ tracking signal for the value in the 7th month (2023 period) with an actual stock value of 608 with a forecasting stock result of 607, the result is a reduction of 0.70 and divided by MAD of -1.04, the tracking signal is -0.68, The following is the basis of the analysis:

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9304.137-143 *e*-ISSN 2622-2035

$$t_i = \frac{\sum a \quad - f}{M}$$

a. The forecasting results for stock in the 7th month (July 2023) were set at 607 rolls with a forecasting tracking error of -0.68 (this is said to be feasible because the tracking error value is below 4 or e < 4)
b. Forecasting results for stock in the 8th month (August 2023) were set at 607 rolls with a forecasting tracking error of -0.92 (this is said to be feasible because the tracking error value is below 4 or e < 4)
c. The forecasting results for stock in the 9th month (September 2023) were set at 608 rolls with a forecasting tracking error of -1.04 (this is said to be feasible because the tracking error value is below 4 or e < 4)

$$t_i = \frac{\sum 608 - 607}{-1.04}$$
$$= -0.68$$

d. The forecasting results for stock in the 10th month (October 2023) were set at 608 rolls with a forecasting tracking error of -1.10 (this is said to be feasible because the tracking error value is below 4 or e < 4)
e. Forecasting results for stock in the 11th month (November 2023) were set at 609 rolls with a forecasting tracking error of -1.13 (this is said to be feasible because the tracking error value is below 4 or e < 4)
f. The forecasting results for stock in the 12th month (December 2023) were set at 610 rolls with a tracking error forecast of -1.14 (this is said to be feasible because the tracking error value is below 4 or e < 4)

IV. CONCLUSION

1. Inventory estimates for product 9969B after forecasting, the number of rolls of double tape type 9969B during 2023 is needed at 7234 rolls with a demand of 6470 rolls so the difference is smaller, namely 764 rolls or around 11.8% of the initial (original) stock of 15.1%, there is an estimated decrease in stock around 3.3%.
2. Forecasting for Product 9969B on average per month during December 2023, it is estimated that the average forecast for the company's Inventory Control must stock 608 rolls with a tracking error or forecast error of -1 (e < 4) so it is very permissible.
3. The ARIMA model has the notation (p, d, q). Where the order p is Autoregressive (AR), d is a difference, and q is Moving Average (MA). Based on Figure 2 and Figure 3, the temporary ARIMA model obtained is p = 8 (PACF dying down plot), d = 2 (one differencing), and q = 1. So, the temporary ARIMA model obtained is (8, 2, 1)
4. In the first Stock Model image (ST-Model_1) there is an up and down trend indicating that the observed variables experienced fluctuations or changes in the period analyzed. An up-and-down trend can indicate a cyclical pattern or natural fluctuation in company data before forecasting is carried out in 2020. In contrast to the image of the Second Forecasting Model (Fr-Model_2), after the fifth month, there is a stable fluctuation until the twelfth month based on market demand for 9969B Printable products Splicing Tape.

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Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

Implementation of the Gravity Location Models Method in Determining Regional Warehouse Locations to Minimize Goods Transport Costs at PT X

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Abstract— A supply Chain is a network of companies that work together to create and deliver a product to the end user. PT X is a company engaged in manufacturing whose products are steel pipes. not only steel pipes are produced. Supply chain management at PT X is considered inefficient because it has to supply four warehouses or depots at once. this can cost a lot of shipping costs in the PT X Supply Chain process. Therefore. supply chain management needs to be carried out using the Gravity Location Model method which aims to minimize the costs of transporting goods at PT X. this research aims to determine the variables needed to determine the location point of PT X regional warehouse using the Gravity Location Model method and to determine the regional warehouse location and optimal shipping costs using the Gravity Location Model method at PT X. From the results of research that has been carried out. the variables used to determine the location points for PT X regional warehouse construction include X and Y. Xn and Yn. dn. Cn. Dn. and TC as well as calculating cost minimization through a comparison of 20 iterations. it was found that the minimum cost was in the 11th iteration. namely IDR 386.955.50. with coordinates X = -4.13 and Y = 115.18.

Index Terms: *Supply Chain*. *Gravity Location Model*

I. INTRODUCTION

In the Industry 4.0 era. many companies are competing or vying to market their products. from small companies to relatively large companies participating in marketing their products to increase the company's productivity and income. Production activities in a company cannot be separated from the term Supply Chain or can be called the company's Supply Chain. According to (Pujawan. 2017) in (Febryanto & Prihono. 2019) Supply Chain is a network of companies that work together to create and deliver a product to the end user. Supply chain management is a concept or mechanism for increasing a company's total productivity in the supply chain by optimizing time. location. and flow of material quantities (Pongoh. 2016). A company that can control its Supply Chain means that the company can reduce costs and can still compete in the business realm. According to (Retnowo & Fira Waluyo. 2022) Supply Chain Management provides major benefits for manufacturers allowing them to improve their response to market changes. Increase visibility into aggregate demand. production. and supply across the Company. and Optimize supply to meet demand profitably.

PT X. produces steel pipes with the largest production capacity in Indonesia and is experienced in producing various kinds of steel pipes or tubes and various other products. PT X To supply several depots in areas that are quite far from the company's location. additional vehicle or expedition costs must be required to supply these depots. Broadly speaking. distribution costs can be defined as costs related to all activities. starting from when goods are purchased/produced until the goods arrive at the customer's location and are marketing or sales costs. (Muhammad et al.. 2017) Transport costs are usually calculated from the transportation distance. Therefore. there is a need for a breakthrough by building a regional warehouse located in the middle of the regional depot. This is useful for minimizing transportation distances so that you can also minimize shipping transportation costs to any regional depot and then to consumers or customers. One method for determining the location point for regional warehouse construction is to use the Gravity Location Model method. Gravity Location Model is a model used to determine the location of a facility. Part of the Supply Chain network development strategy is providing the coordinates of the closest point and the shortest distance from an object. for example. warehouses and factories which are the link between supply sources and various market sources (Prasetyo et al.. 2018) This model was developed to help multinational

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

companies in developing transportation goods because it excels in analyzing distribution cost reduction. The Gravity Location Model is based on selecting a distribution center point that provides the shortest distance to all production zone centers that require service.

II. METHODOLOGY

This research uses the Gravity Location Model method in which there are several stages to find the coordinates through several iterations. Before using the gravity location method. the data used as input parameters need to be prepared. This data includes demand data from consumers. transportation costs per unit from the facility location to the consumer. and methods for calculating the distance from the candidate facility location to each consumer (Print et al.. 2021). The population in this research is the Supply Chain Management network of PT X (Afandy et al.. 2022) Then it is calculated using the formula

$$d = \sqrt{(X - X)^2 + (Y - Y)^2}$$

Information:

dn: Distance between the facility location and the nth source of supply or barn.

Cn: Shipping costs derived from transportation costs/weight/kilometer distance. (Mawadati et al.. 2020)

Dn: number or weight of goods under one truck.

Xn and Yn: Coordinates of each depot.

Repeatedly until the coordinate points in the iteration do not experience significant changes. then that coordinate point will be used as the location for building a regional warehouse at PT X. After the coordinate points have been found. according to (Susanto. 2022) then look for the total cost or total costs for the number of iterations that have been carried out using the formula

$$T = \sum_{n-1}^{k} d$$

Information:

TC: Total Cost

dn: Distance between the facility location and the nth source of supply or barn

Dn: number or weight of goods under one truck.

Cn: Shipping costs.

To find the minimum cost value in the calculated iterations. this is done because one of the objectives of this method is to minimize the costs that have been calculated in several iterations.

III. RESULTS AND DISCUSSION

From the data that has been obtained. the calculation results are applied to the iteration tabulation with the formula $d = \sqrt{(X - X)^2 + (Y - Y)^2}$ as follows:

Table 1. Iteration 1

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	5.19	24000	0.61	-19610.1	303502.9	2821.0	75946.7358
Jakarta	-6.17	106.69	6.18	24000	0.57	-13551.3	234496.8	2197.9	83965.77128
Samarinda	-0.54	117.15	8.08	24000	0.61	-974.7	212098.0	1810.5	118314.1371
Makassar	-5.10	119.46	7.06	24000	0.85	-14802.9	346551.1	2901.0	144487.024
		Total				-48939.1	1096648.7	9730.4	422713.6681
X						-5.03			
Y						112.70			

Table 2. Iteration 2

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	5.47	24000	0.61	-18615.8	288114.9	2678.0	80002.99193
Jakarta	-6.17	106.69	6.12	24000	0.57	-13688.9	236876.8	2220.2	83122.11138
Samarinda	-0.54	117.15	6.32	24000	0.61	-1246.8	271296.7	2315.8	92497.22504
Makassar	-5.10	119.46	6.76	24000	0.85	-15462.8	362000.9	3030.3	138320.4533
		Total				-49014.4	1158289.4	10244.4	393942.7817
X						-4.78			
Y						113.07			

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

Table 3. Iteration 3

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	5.89	24000	0.61	-17267.5	267246.3	2484.0	86250.22947
Jakarta	-6.17	106.69	6.52	24000	0.57	-12840.2	222190.1	2082.6	88616.44443
Samarinda	-0.54	117.15	5.89	24000	0.61	-1337.6	291045.4	2484.4	86220.89566
Makassar	-5.10	119.46	6.40	24000	0.85	-16321.6	382104.2	3198.6	131043.1224
		Total				-47766.7	1162586.1	10249.6	392130.692
X						-4.66			
Y						113.43			

Table 4. Iteration 4

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	6.27	24000	0.61	-16216.7	250983.8	2332.9	91838.81028
Jakarta	-6.17	106.69	6.90	24000	0.57	-12133.9	209968.7	1968.0	93774.47351
Samarinda	-0.54	117.15	5.55	24000	0.61	-1418.8	308721.7	2635.3	81284.19444
Makassar	-5.10	119.46	6.05	24000	0.85	-17274.7	404418.4	3385.4	123812.6993
		Total				-47044.1	1174092.6	10321.6	390710.1775
X						-4.56			
Y						113.75			

Table 5. Iteration 5

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	6.61	24000	0.61	-15385.5	238119.2	2213.3	96800.48441
Jakarta	-6.17	106.69	7.24	24000	0.57	-11566.7	200153.9	1876.0	98372.816
Samarinda	-0.54	117.15	5.26	24000	0.61	-1497.1	325751.0	2780.6	77034.89104
Makassar	-5.10	119.46	5.73	24000	0.85	-18221.2	426575.8	3570.9	117381.563
		Total				-46670.4	1190599.9	10440.9	389589.7544
X						-4.47			
Y						114.03			

Table 6. Iteration 6

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	6.91	24000	0.61	-14730.1	227975.3	2119.0	101107.6554
Jakarta	-6.17	106.69	7.54	24000	0.57	-11115.4	192343.7	1802.8	102367.2635
Samarinda	-0.54	117.15	5.02	24000	0.61	-1570.6	341746.4	2917.2	73429.28607
Makassar	-5.10	119.46	5.46	24000	0.85	-19124.1	447714.7	3747.9	111839.3747
		Total				-46540.1	1209780.2	10586.9	388743.5796
X						-4.40			
Y						114.27			

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

Table 7. Iteration 7

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.16	24000	0.61	-14216.2	220022.0	2045.1	104762.5073
Jakarta	-6.17	106.69	7.78	24000	0.57	-10759.0	186176.9	1745.0	105758.0471
Samarinda	-0.54	117.15	4.81	24000	0.61	-1637.3	356259.9	3041.1	70437.88961
Makassar	-5.10	119.46	5.23	24000	0.85	-19956.7	467207.8	3911.0	107173.155
		Total				-46569.2	1229666.5	10742.2	388131.5989
X						-4.34			
Y						114.47			

Table 8. Iteration 8

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.36	24000	0.61	-13815.8	213825.2	1987.5	107798.5745
Jakarta	-6.17	106.69	7.99	24000	0.57	-10479.8	181345.1	1699.7	108575.8629
Samarinda	-0.54	117.15	4.65	24000	0.61	-1695.8	368988.0	3149.7	68008.15316
Makassar	-5.10	119.46	5.05	24000	0.85	-20700.1	484611.2	4056.7	103324.3345
		Total				-46691.5	1248769.6	10893.7	387706.9251
X						-4.29			
Y						114.63			

Table 9. Iteration 9

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.53	24000	0.61	-13505.8	209027.9	1942.9	110272.5971
Jakarta	-6.17	106.69	8.16	24000	0.57	-10262.6	177587.8	1664.5	110873.0362
Samarinda	-0.54	117.15	4.51	24000	0.61	-1745.5	379807.0	3242.1	66070.91565
Makassar	-5.10	119.46	4.89	24000	0.85	-21344.2	499688.4	4182.9	100206.7134
		Total				-46858.1	1266111.1	11032.4	387423.2623
X						-4.25			
Y						114.76			

Table 10. Iteration 10

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.67	24000	0.61	-13267.3	205336.8	1908.6	112254.8784
Jakarta	-6.17	106.69	8.30	24000	0.57	-10095.0	174686.5	1637.3	112714.4796
Samarinda	-0.54	117.15	4.41	24000	0.61	-1786.6	388754.5	3318.5	64550.23745
Makassar	-5.10	119.46	4.77	24000	0.85	-21887.2	512401.3	4289.4	97720.53183
		Total				-47036.1	1281179.1	11153.7	387240.1272
X						-4.22			
Y						114.87			

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

Table 11. Iteration 11

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.78	24000	0.61	-13084.8	202512.4	1882.3	113820.4334
Jakarta	-6.17	106.69	8.40	24000	0.57	-9966.3	172460.2	1616.5	114169.5045
Samarinda	-0.54	117.15	4.33	24000	0.61	-1819.8	395985.4	3380.2	63371.51457
Makassar	-5.10	119.46	4.68	24000	0.85	-22334.4	522870.8	4377.0	95763.86511
		Total				-47205.4	1293828.9	11256.0	387125.3175
X						-4.19			
Y						114.95			

Table 12. Iteration 12

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.86	24000	0.61	-12945.9	200361.8	1862.3	115042.1346
Jakarta	-6.17	106.69	8.49	24000	0.57	-9868.1	170761.2	1600.5	115305.4906
Samarinda	-0.54	117.15	4.27	24000	0.61	-1846.2	401720.3	3429.1	62466.82798
Makassar	-5.10	119.46	4.60	24000	0.85	-22695.4	531322.1	4447.8	94240.64205
		Total				-47355.6	1304165.4	11339.7	387055.0952
X						-4.18			
Y						115.01			

Table 13. Iteration 13

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.92	24000	0.61	-12840.5	198730.9	1847.2	115986.2585
Jakarta	-6.17	106.69	8.55	24000	0.57	-9793.5	169470.3	1588.4	116183.7674
Samarinda	-0.54	117.15	4.22	24000	0.61	-1866.8	406201.9	3467.4	61777.64982
Makassar	-5.10	119.46	4.55	24000	0.85	-22982.0	538032.1	4503.9	93065.32721
		Total				-47482.8	1312435.2	11406.9	387013.0029
X						-4.16			
Y						115.06			

Table 14. Iteration 14

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	7.97	24000	0.61	-12760.9	197498.1	1835.7	116710.2243
Jakarta	-6.17	106.69	8.60	24000	0.57	-9737.1	168493.2	1579.3	116857.5149
Samarinda	-0.54	117.15	4.19	24000	0.61	-1882.7	409664.1	3496.9	61255.53948
Makassar	-5.10	119.46	4.50	24000	0.85	-23206.5	543288.5	4547.9	92164.89863
		Total				-47587.2	1318944.0	11459.9	386988.1773
X						-4.15			
Y						115.09			

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

Table 15. Iteration 15

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	8.01	24000	0.61	-12700.8	196568.8	1827.1	117261.9953
Jakarta	-6.17	106.69	8.64	24000	0.57	-9694.4	167755.8	1572.4	117371.1952
Samarinda	-0.54	117.15	4.16	24000	0.61	-1894.9	412315.9	3519.6	60861.57456
Makassar	-5.10	119.46	4.47	24000	0.85	-23380.5	547362.3	4582.0	91478.95629
		Total				-47670.7	1324002.9	11501.0	386973.7214
X						-4.14			
Y						115.12			

Table 16. Iteration 16

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	8.04	24000	0.61	-12655.6	195869.7	1820.6	117680.5452
Jakarta	-6.17	106.69	8.67	24000	0.57	-9662.4	167200.6	1567.2	117760.9698
Samarinda	-0.54	117.15	4.14	24000	0.61	-1904.2	414333.9	3536.8	60565.14588
Makassar	-5.10	119.46	4.44	24000	0.85	-23514.3	550492.9	4608.2	90958.7262
		Total				-47736.4	1327897.1	11532.8	386965.387
X						-4.14			
Y						115.14			

Table 17. Iteration 17

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	8.06	24000	0.61	-12621.7	195344.6	1815.7	117996.8897
Jakarta	-6.17	106.69	8.69	24000	0.57	-9638.2	166783.2	1563.2	118055.64
Samarinda	-0.54	117.15	4.12	24000	0.61	-1911.2	415862.4	3549.8	60342.54977
Makassar	-5.10	119.46	4.42	24000	0.85	-23616.3	552882.8	4628.2	90565.53915
		Total				-47787.5	1330873.0	11557.0	386960.6186
X						-4.13			
Y						115.16			

Table 18. Iteration 18

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	8.08	24000	0.61	-12596.3	194950.6	1812.0	118235.3264
Jakarta	-6.17	106.69	8.71	24000	0.57	-9620.1	166470.0	1560.3	118277.786
Samarinda	-0.54	117.15	4.11	24000	0.61	-1916.5	417015.9	3559.7	60175.6286
Makassar	-5.10	119.46	4.41	24000	0.85	-23693.9	554698.1	4643.4	90269.16548
		Total				-47826.8	1333134.6	11575.5	386957.9065
X						-4.13			
Y						115.17			

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

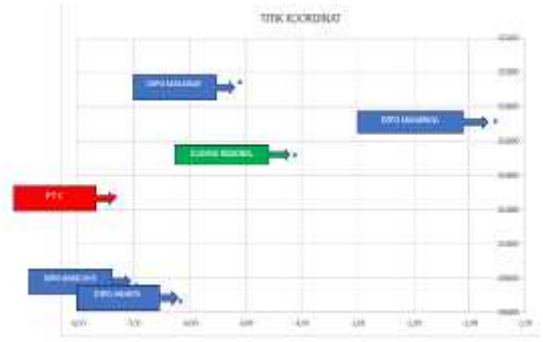
Table 19. Iteration 19

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	8.09	24000	0.61	-12577.2	194655.4	1809.3	118414.666
Jakarta	-6.17	106.69	8.72	24000	0.57	-9606.6	166235.1	1558.1	118444.9
Samarinda	-0.54	117.15	4.10	24000	0.61	-1920.5	417884.3	3567.1	60050.57819
Makassar	-5.10	119.46	4.40	24000	0.85	-23752.5	556071.4	4654.9	90046.22649
		Total				-47856.8	1334846.2	11589.4	386956.3707
X						-4.13			
Y						115.18			

Table 20. Iteration 20

Depo	Xn	Yn	dn	DN	Cn	DnCnXn/dn	DnCnYn/dn	DnCn/dn	TC
Bandung	-6.95	107.59	8.10	24000	0.61	-12562.9	194434.3	1807.2	118549.3427
Jakarta	-6.17	106.69	8.73	24000	0.57	-9596.4	166059.1	1556.5	118570.412
Samarinda	-0.54	117.15	4.10	24000	0.61	-1923.5	418536.8	3572.7	59956.95882
Makassar	-5.10	119.46	4.39	24000	0.85	-23796.8	557107.3	4663.6	89878.79042
		Total				-47879.6	1336137.5	11600.0	386955.504
X						-4.13			
Y						115.18			

From the tabulation results above. to supply the 4 shops or depots owned by PT X **X = -4.13** and **Y = 115.18** namely in the Djorong area. South Kalimantan. Development also follows the surrounding natural conditions.



Picture 1. Regional Warehouse Coordinates

Picture 2. Maps

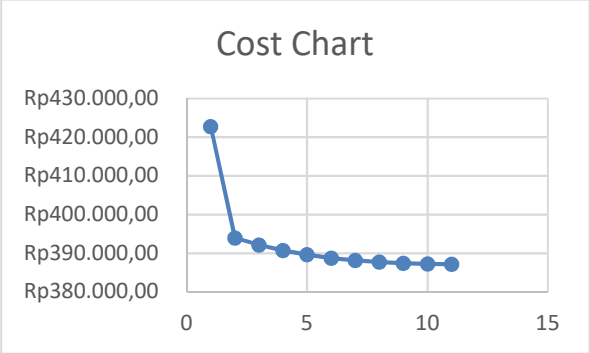
After obtaining the coordinates that are considered optimal. the next step is to calculate the total cost or TC. namely using the formula $T = \sum_{n-1}^{k} d$ as follows:

Table 21. Total Cost

	TC
Iteration 1	Rp 422.713.67
Iteration 2	Rp 393.942.78
Iteration 3	Rp 392.130.69
Iteration 4	Rp 390.710.18
Iteration 5	Rp 389.589.75
Iteration 6	Rp 388.743.58
Iteration 7	Rp 388.131.60
Iteration 8	Rp 387.706.93
Iteration 9	Rp 387.423.26
Iteration 10	Rp 387.240.13
Iteration 11	Rp 387.125.32
Iteration 12	Rp 387.055.10
Iteration 13	Rp 387.013.00
Iteration 14	Rp 386.988.18
Iteration 15	Rp 386.973.72
Iteration 16	Rp 386.965.39
Iteration 17	Rp 386.960.62
Iteration 18	Rp 386.957.91

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9299.144-151 *e*-ISSN 2622-2035

Iteration 19	Rp 386.956.37
Iteration 20	Rp 386.955.50



Picture 3. Cost Chart

IV. CONCLUSIONS AND SUGGESTIONS

From the results of calculations using the Gravity Location Models method. it can be concluded that regional warehouse coordinate points were determined through 11 iterations. resulting in coordinate location points and minimum costs from the distribution process. The results of cost minimization calculations through comparison of 11 iterations found the minimum costs in the third iteration. 20. which is IDR. 386.955.50. with coordinates X = -4.13 and Y = 115.18. The results of these coordinates. if seen from the Google Maps map. are in the Djorong area. South Kalimantan. Warehouse construction also follows the surrounding natural conditions.

The advice obtained in this research is that it is hoped that further research using the Gravity Location Models method can expand its coverage not only between cities or provinces but also between countries so that we can see how far the Gravity Location Models method can be developed.

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Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana
p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9340.152-160 *e*-ISSN 2622-2035

Analysis Of Defects In Laminated Doors Using Failure Mode And Effect Analysis (FMEA) And Fault Tree Analysis (FTA)

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Abstract— Quality control is a crucial part of the production process because product quality must meet established standards. Based on drawbacks that happen in the laminating door production process, prioritizing different failure types is essential to reduce the occurrence of defects in the same production process. To enhance product quality and minimize defects, consider implementing by using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA). The purpose of this study is to identify the types of factors causing product defects in the laminating door production process and provide recommended actions in the improvement phase to minimize the number of defects. This study analyzes six types of defects in laminating door products. The results show that operator errors are the dominant cause, influenced by environmental conditions and an unsupportive work system. Based on the Risk Priority Number (RPN) values, the defects with the highest values are glue not sticking (RPN 294) caused by machine factors, cracks (RPN 252) by method factors, groove size not meeting specifications (RPN 245) by man factors, peeling paint (RPN 180) by method factors, scratches on the laminate surface (RPN 175) by man factors, and imprecise joints (RPN 120) by man factors. Improvement suggestions include operator training, machine maintenance, replacement of inadequate equipment, selection of appropriate raw materials, and implementation of clear Standard Operating Procedures.

Keywords: FMEA; FTA; Quality; RPN Value.

1. INTRODUCTION

Quality control is the most important part of the production process to ensure that products and services meet specified standards. One of the stages of quality control is inspection through product testing. If the product meets the standards, the next stage can proceed further. However, if the standards are not met, it will result in a reduction in production quantity. A carefully executed manufacturing process that focuses on quality aspects can prevent production defects so that in operation, it does not cause damage to the product (Syahrullah & Izza, 2021). Therefore, quality control is more than just inspection activities or evaluating product quality to determine if it is feasible (Haryono & Sumiati, 2023). Quality involves all aspects of products and services, including marketing, engineering, production, and maintenance, aimed at ensuring that products and services will meet consumer expectations when used (Cahyono et al., 2023). Quality is not only the product produced but also viewed from the process. If a company neglects the quality of its products, market traction can decline (Andespa, 2020).

Companies have made efforts to control product quality to satisfy consumers. However, in the production process, there are still often discrepancies with specifications, resulting in defective products. The more defective products, the greater the impact on the productivity of the production process. Product defects are not only caused by machines but also by worker negligence due to lack of thoroughness or not following procedures properly. One suitable technique to stabilize product quality and reduce the number of failed products is using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA). Failure Mode and Effect Analysis (FMEA) is chosen as a method to analyze experiences using technology to find failures in the production process and plan to reduce defects (Ali M & Kusuma, 2019). FMEA prioritizes prevention and improves work safety, and customer satisfaction (Kartika et al., 2016). The assessment refers to the level of incidence (occurrence), severity, and detection to identify potential failures. Fault Tree Analysis (FTA) analyzes the correlation of origins and then presents it in the form of a fault tree. Fault Tree Analysis (FTA) is a method to

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9340.152-160 *e*-ISSN 2622-2035

find the root cause of failures. This analysis is carried out through a top-down approach, starting by assuming failure from the top event and then detailing the background of the top event to the root cause (Ariyanty, 2021).

2. RESEARCH METHODOLOGY

The following research adopts the FMEA and FTA methods. The selected data for analysis includes both primary and secondary data. Secondary data is collected from company defect information. Primary data refers to the results of interviews and field observations. The results of this field research will reveal the issues occurring in the laminated door production process. The next stage is to identify the causes of failure for each type of defect obtained using the FMEA method by calculating the values of Severity, Occurrence, and Detection, and then determining the RPN (Risk Priority Number) value. After obtaining the highest RPN value, the next step is the FTA analysis to analyze the root causes of the most at-risk product defect types, so that the improvement process to address these defects can be determined.

3. RESULTS AND DISCUSSIONS

3.1 DATA COLLECTION

Data Collection In the next process, the defect data of laminated door products for January 2024 was collected for analysis. This data was obtained from the Quality department. The defect data of laminated door products is included in the following Table 1:

Table 1. Laminated Door Product Defect Data for January 2024

Date	Production Amount (pcs)	Defects Standart	Jenis Cacat						Defects amount (pcs)	Defects Percentages (%)
			Unsticky Glue	Crack	Unprecision joint	Unsuitable groove size	Peeling Paint	Scratch		
3-Jan-24	505	2%	9	6	3	6	7	2	33	6.53
4-Jan-24	510	2%	8	3	5	6	5	7	34	6.67
5-Jan-24	508	2%	9	4	6	1	6	8	34	6.69
9-Jan-24	512	2%	6	7	5	4	5	5	32	6.25
10-Jan-24	508	2%	5	4	6	7	5	5	32	6.30
11-Jan-24	508	2%	9	6	4	4	6	5	34	6.69
12-Jan-24	515	2%	6	9	4	5	5	6	35	6.80
15-Jan-24	510	2%	7	4	2	5	7	8	33	6.47
16-Jan-24	505	2%	7	4	4	4	6	7	32	6.34
17-Jan-24	509	2%	7	4	4	3	7	7	32	6.29
18-Jan-24	507	2%	5	8	4	5	4	7	33	6.51
19-Jan-24	507	2%	9	4	6	3	5	4	31	6.11
22-Jan-24	505	2%	8	5	6	2	5	5	31	6.14
23-Jan-24	508	2%	7	7	4	4	4	6	32	6.30
24-Jan-24	505	2%	8	4	5	4	3	7	31	6.14
25-Jan-24	508	2%	8	8	2	6	8	2	34	6.69
26-Jan-24	511	2%	10	7	3	2	6	4	32	6.26
29-Jan-24	508	2%	3	7	5	7	5	5	32	6.30
30-Jan-24	506	2%	9	6	5	5	6	3	34	6.72
31-Jan-24	505	2%	8	5	4	3	5	7	32	6.34
Jumlah	10160	2%	148	112	87	86	110	110	653	128.54
Rata-rata	508	2%	7.40	5.60	4.35	4.30	5.50	5.50	32.65	6.43

Based on the data in Table 1, the number of defective laminated door products does not meet the company's standards and specifications. On average, the number of products experiencing defects is 33 pieces, with a percentage reaching 6.43%.

3.2 FMEA ANALYSIS

The first step is to calculate Severity, Occurrence, Detection, and the RPN value calculation. Below is the FMEA table for laminated doors

Tibuana
Journal of applied Industrial Engineering-University of PGRI AdiBuana

DOI : https://doi.org/10.36456/tibuana.7.2.9340.152-160

p-ISSN 2622-2027
e-ISSN 2622-2035

Table 2. Table for FMEA of Laminated Door Products

No	*Failure Mode*	*Effect of Failure Mode*	*Factor*	*Cause of Failure Mode*	S	O	D	RPN	*Recommended Action*
1	Unsticky Glue	The glue doesn't stick to the product properly	*Man*	Untrained Operator	4	3	6	72	Conduct intensive training for operators on operating the lamination machine.
			Machine	Stability of the glue application machine	7	7	6	294	Routine maintenance on the machine.
			Material	Poor quality of glue	4	5	4	80	Check the quality of the glue before use and ensure it is within the recommended usable period.
			Methode	Not following procedures properly	4	4	5	80	Ensure that the glue application procedure is followed correctly by operators and conduct regular inspections.
			Environment	High Humidity	4	6	3	72	Control air humidity in the production area with appropriate ventilation systems.
2	Crack	The product cannot be used in the subsequent process (rejected).	*Man*	Untrained Operator	6	4	3	72	Conduct intensive training for operators on operating the press machine.
			Machine	The machine was not maintained properly.	4	4	5	80	Routine maintenance on the machine
			Methode	Unproperly Pressing process	6	7	6	252	Ensure that procedures are followed correctly by the operator and conduct regular inspections.
3	Unprecision Joint	The joint tightness on the product is insufficient.	*Man*	Untrained operator	6	4	5	120	Conduct intensive training for operators in performing the joint process.
			Material	Poor quality raw material	3	2	2	12	Check the quality of the joint materials before use.
			Methode	The joint process does not comply with the SOP	4	2	3	24	Ensure that the joint procedures used are by standards and effective.
4	Ukuran *groove* tidak sesuai spesifikasi	Produk tidak bisa digunakan pada	*Man*	Untrained operator	7	5	7	245	Provide training to operators to enhance their skills in operating the CNC router.

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DOI : https://doi.org/10.36456/tibuana.7.2.9340.152-160 *e*-ISSN 2622-2035

		proses selanjutnya (*reject)*	*Machine*	The machine was not maintained properly	5	4	4	80	Routine maintenance on the machine
			Methode	The program is not suitable (the settings do not match the work loading being performed)	6	4	4	96	Ensure that procedures are correctly followed by operators according to product specifications, and conduct regular inspections.
			Man	Untrained operator	6	2	4	48	Conduct intensive training for operators on how to properly carry out the paint filler process.
			Material	Poor quality raw material	5	3	4	60	Check the quality of the paint before use and ensure that it is within the recommended shelf life.
5	Cat mengelupas	Mengurangi nilai kualitas produk							
			Methode	Wrong method of painting	5	6	6	180	Ensure that the paint application procedures are followed correctly and meet the standards.
			Environment	Unstable room temperature	4	1	3	12	Maintain the paint application environment to be stable by controlling temperature and humidity appropriately.
			Man	Untrained operator	5	7	5	175	Provide training to operators to improve their skills in the sanding process.
6	*Scratch* pada permukaan laminasi	Mengurangi nilai kualitas produk	*Material*	Poor quality raw material	4	2	5	40	Check the quality of the sanding material before use.
			Methode	Unproperly Pressing process	6	7	6	252	Ensure that procedures are followed correctly by the operator and conduct regular inspections.

From the data of the FMEA analysis, the highest RPN values were obtained based on the 4M+1E factors as follows: adhesive not sticking with a machine factor of 294, cracking with a method factor of 252, imprecise joint with a manpower factor of 120, incorrect groove size specifications with a manpower factor of 245, paint peeling with a method factor of 180, and scratches on the laminated surface with a manpower factor of 175. Based on the results of the RPN from the FMEA analysis, the highest value will be analyzed using the FTA method.

3.3 FTA Analysis

Based on the highest RPN values obtained from the FMEA method, the next step involves conducting an analysis using the Fault Tree Analysis (FTA) method to determine the root causes of the existing problems. Below is the analysis using the FTA method for the defects: adhesive not sticking, cracking, imprecise joint, incorrect groove size specifications, paint peeling, and scratches on the laminated surface, to identify the factors that contribute to these defects.

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Journal of applied Industrial Engineering-University of PGRI AdiBuana
p-ISSN 2622-2027
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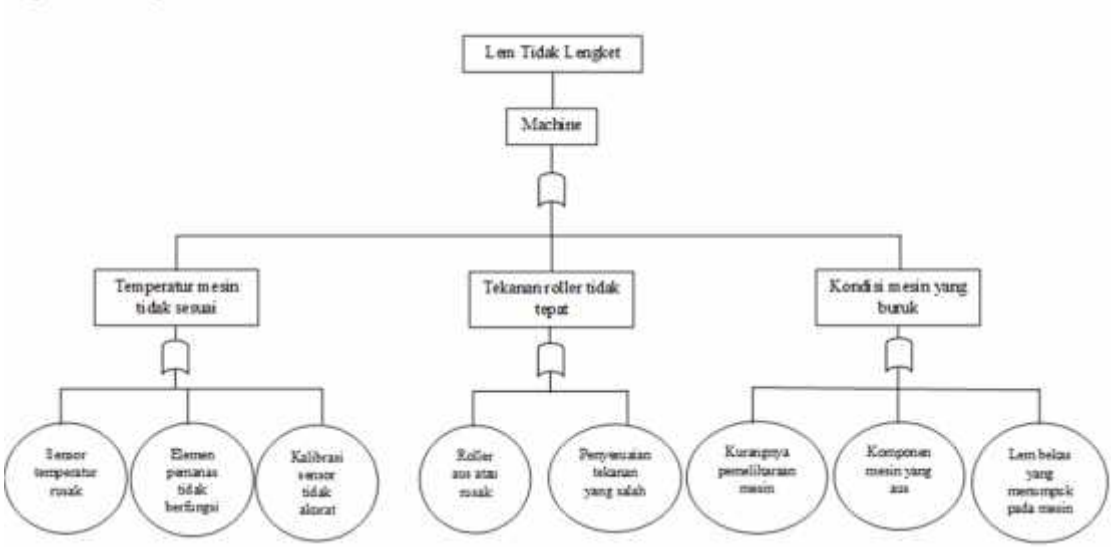

Figure 1. FTA Analysis Unsticky Glue Defect

In Figure 1, the defect of adhesive non-sticking is caused by three main factors: incorrect machine temperature due to damaged sensors or heating elements, improper roller pressure due to worn-out rollers or incorrect adjustments, and poor machine condition due to inadequate maintenance or worn-out components.

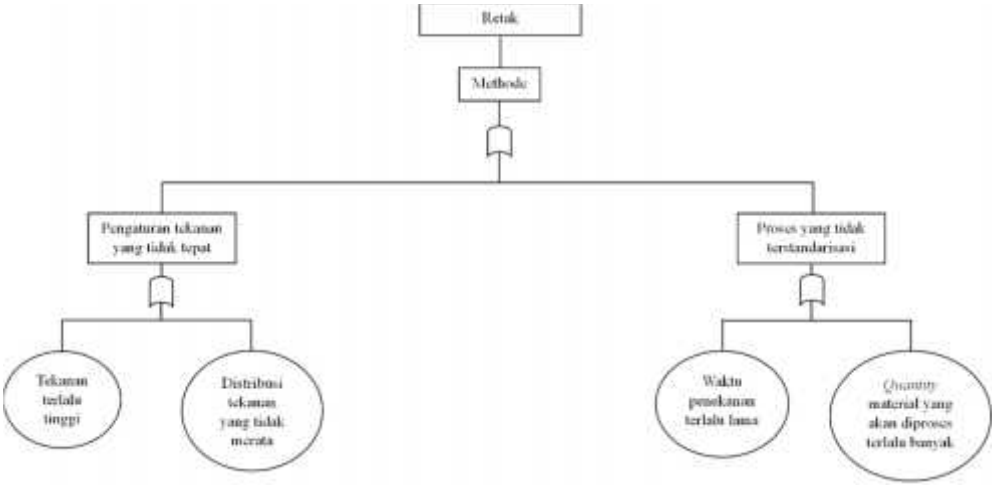

Figure 2. FTA Analysis Crack Defect

In Figure 2, the cracking defect can be caused by two factors. Firstly, improper pressure settings. Excessive pressure or uneven pressure distribution can cause excessive deformation and internal stress in the door material, leading to cracking. Secondly, non-standardized processes. Without clear standards, machine settings such as temperature, pressure, and pressing time may vary between batches. Different operators may use different methods, resulting in inconsistencies in the final product outcomes.

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Journal of applied Industrial Engineering-University of PGRI AdiBuana
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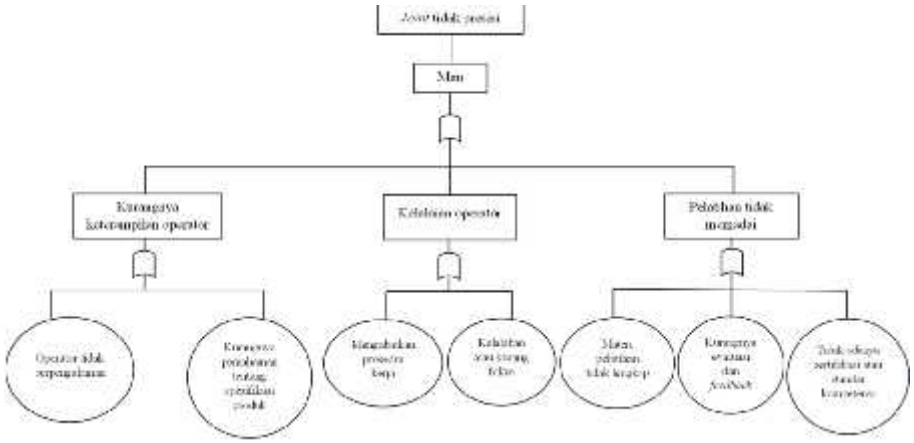

Figure 3. FTA Analysis Unprecision Joint Defect

In Figure 3, the imprecise joint defect can be caused by three factors. Firstly, lack of operator skills. Inexperienced operators may make errors in setting up and operating the equipment. Secondly, operator negligence. Lack of focus during the joint assembly process can lead to mistakes in assembling components. Thirdly, inadequate training. Without regular training, operators may not be aware of updates or procedural improvements, and without competency standards or certifications, operators may be insufficiently trained in equipment operation.

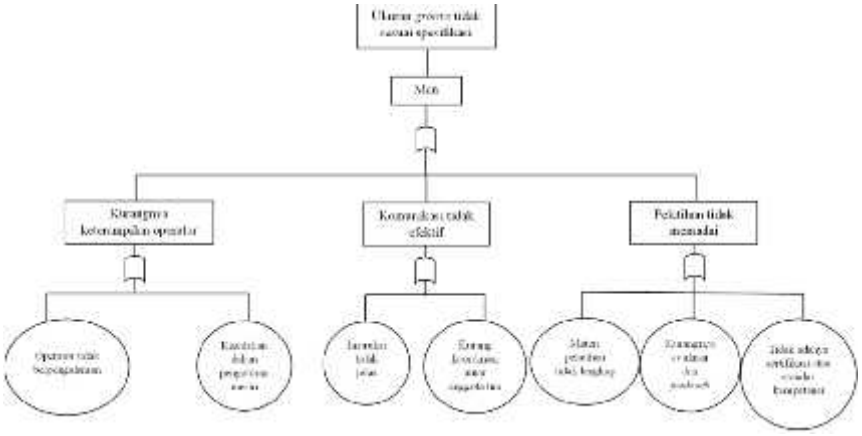

Figure 4. FTA Analysis Unsuitable Groove Size Defect

In Figure 4, the defect of incorrect groove size specifications can be caused by three factors. Firstly, lack of operator skills. Inexperienced operators may make errors in setting up and operating the CNC router machine. Secondly, ineffective communication. Unclear instructions or lack of team coordination can lead to operators not fully understanding their tasks. Thirdly, inadequate training. Incomplete training materials and the absence of competency standards or certifications can result in operators lacking the knowledge and qualifications to operate the equipment effectively.

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9340.152-160 *e*-ISSN 2622-2035

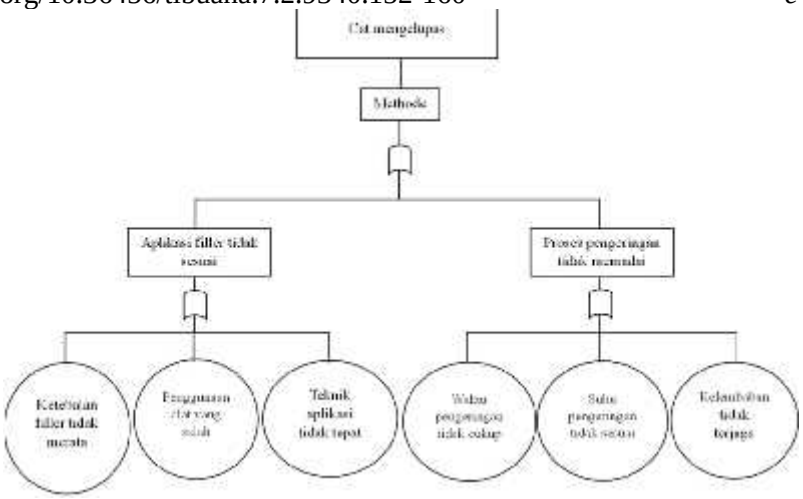

Figure 5. FTA Analysis Peeling Paint Defect

In Figure 5, the defect of paint peeling can be caused by two factors. Firstly, improper filler application can result in uneven paint application and a tendency to peel due to incorrect techniques. Secondly, an inadequate drying process, such as insufficient drying time or suboptimal temperature and humidity conditions, can also cause the paint to dry poorly and peel off.

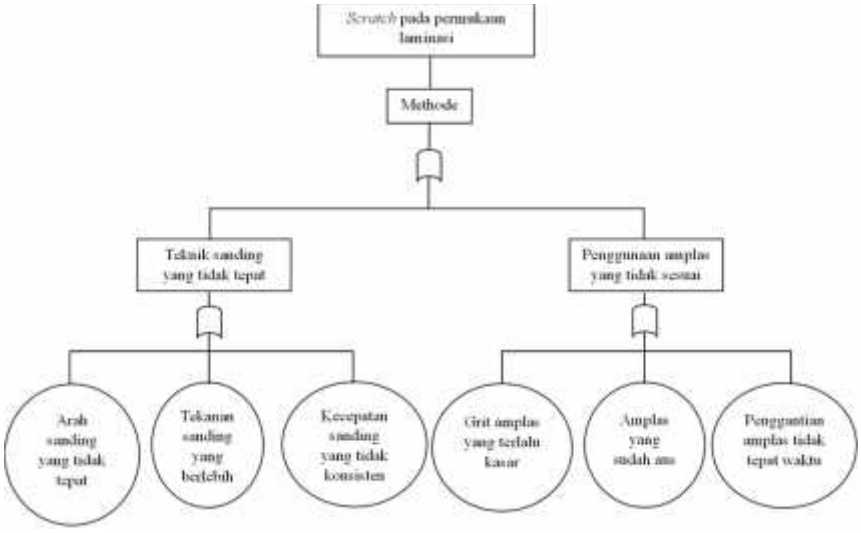

Figure 6. FTA Analysis Scratch on Lamination Surface Defect

In Figure 6, the defect of scratches on the laminated surface can be caused by two factors. Firstly, improper sanding techniques, such as incorrect sanding direction, can lead to scratches on the laminated surface. Additionally, excessive pressure and unstable speed during the sanding process can also result in imperfections on the laminated surface. Secondly, improper sandpaper usage, such as using grit that is too coarse, can cause scratches. Furthermore, not replacing the sandpaper at the right time can also lead to inconsistent results.

3.4 SUGGESTED IMPROVEMENTS

Based on the FMEA and FTA analyses, here are the suggested improvements for each product defect with the highest RPN values:

1. Adhesive Not Sticking (RPN 294) - Machine Factor
   a. Maintenance and Calibration of Machines: Conduct regular maintenance and calibration of the laminating machines to ensure optimal operation.
   b. Temperature and Pressure Monitoring: Implement an automatic monitoring

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9340.152-160 *e*-ISSN 2622-2035

system to ensure correct temperature and pressure during the laminating process.
c. Replacement of Machine Components: Periodically replace worn or damaged machine components to prevent malfunctions.
d. Operator Training: Provide training to operators on the proper operation and maintenance of laminating machines.
2. Cracking (RPN 252) - Method Factor
a. Standardization of Pressing Methods: Develop and implement standard procedures for the pressing process, including the correct pressure and time.
b. Pressing Technique Training: Conduct training sessions for operators on the correct pressing techniques and the importance of following standard procedures.
c. Quality Control During Process: Implement quality control measures during the pressing process to detect and correct errors immediately.
d. Research and Development: Research to better understand the optimal conditions that prevent cracking, such as material properties and temperature.
3. Imprecise Joint (RPN 120) - Man Factor
a. Training and Certification: Implement training and certification programs for operators to improve their skills and knowledge in joint assembly.
b. Supervision and Evaluation: Enhance supervision and evaluation of operator performance during the assembly process.
c. Use of Accurate Measuring Tools: Provide accurate measuring tools and calibrate them regularly.
d. Motivation and Incentives: Offer incentives to encourage operators to work with precision and adhere to standards.
4. Incorrect Groove Size Specifications (RPN 245) - Man Factor
a. Training in Measurement and Marking: Conduct intensive training for operators on proper measurement and marking techniques.
b. Calibration of Measuring Tools: Ensure measuring tools are regularly calibrated for accurate measurements.
c. Standard Operating Procedures (SOPs): Develop and implement clear SOPs for the measurement and marking process.
d. Supervision and Quality Control: Increase supervision and quality control during the CNC router process to ensure groove sizes meet specifications.
5. Paint Peeling (RPN 180) - Method Factor
a. Standardization of Paint Application Process: Develop and implement standard procedures for paint application, including ideal environmental conditions.
b. Paint Application Training: Conduct training sessions for operators on the correct paint application techniques.
c. Selection of Appropriate Paint Materials: Use paint materials that meet specifications and are suitable for the application environment.
d. Environmental Quality Control: Implement environmental controls such as humidity and temperature during the paint application process.
6. Scratches on Laminated Surface (RPN 175) - Man Factor
a. Sanding Process Training: Conduct training sessions for operators on the correct sanding techniques and proper use of sanding tools.
b. Use of Appropriate Sanding Tools: Ensure sanding tools are in good condition and suitable for the type of surface being worked on.
c. Supervision During Sanding Process: Increase supervision during the sanding process to detect and correct errors immediately.
d. Establishment of Cleanliness Standards: Ensure the work area is always clean to prevent scratches on the laminated surface.

IV. CONCLUSION AND SUGGESTION

CONCLUSION

The analysis conducted in this study using FMEA and FTA methods has been completed, revealing that out of the six types of defects in laminated door products, operator errors are the primary cause. However, the implemented work system and an unsupportive work environment also impact operator performance. The FMEA calculations indicate that each cause with the highest complexity levels should be analyzed further for more specific improvement suggestions. The highest RPN values based on the 4M+1E factors are as follows: adhesive not sticking with the machine factor at 294, cracks

p-ISSN 2622-2027
DOI : https://doi.org/10.36456/tibuana.7.2.9340.152-160 *e*-ISSN 2622-2035

with the method factor at 252, imprecise joints with the man factor at 120, groove size not meeting specifications with the man factor at 245, peeling paint with the method factor at 180, and scratches on the laminate surface with the man factor at 175. Recommendations for improvements include conducting training for operators, paying more attention to machine maintenance and replacing substandard equipment or components, selecting appropriate raw materials, and implementing clear Standard Operating Procedures.

SUGGESTION

After conducting a study using Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) on laminated door products, the next direction for research to further deepen the analysis and improve production quality and efficiency is the implementation of Lean Manufacturing. The expected outcomes are increased production efficiency, reduced cycle time, and lower production costs.

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