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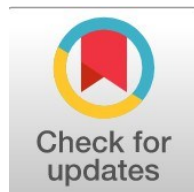
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Lean Six Sigma Reduces Defects and Improves Animal Feed Handling Efficiency

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Abstract

General Background: Warehouse material handling is critical for maintaining product quality, distribution continuity, and operational performance in the animal feed industry. **Specific Background:** PT XYZ experienced defects in animal feed material handling, including torn sacks, loose stitches, and contamination, which reduced process performance and caused operational losses. **Knowledge Gap:** Previous studies rarely focus on defect reduction in animal feed material handling, especially sack-based packaging, and the integration of Lean Six Sigma with Fuzzy FMEA in this context remains limited. **Aims:** This study aimed to identify waste levels, analyze defect causes, and propose priority improvements using Lean Six Sigma with the DMAIC approach, Process Cycle Efficiency, Pareto analysis, fishbone diagrams, and Fuzzy FMEA. **Results:** Defect waste ranked first with a weight of 3.25, followed by transportation, motion, overproduction, inventory, overprocessing, and waiting. The average defect rate was 0.58%, with DPMO of 1,943 and a sigma level of 4.4. Improvements reduced activities from 43 to 36 and lead time from 418 to 314 minutes, while PCE increased from 26.65% to 35.35%, producing a 24.88% efficiency improvement. **Novelty:** The study integrates waste identification and Fuzzy FMEA-based priority setting in animal feed material handling. **Implications:** The proposed actions support pallet standardization, stack height adjustment, forklift SOPs, operator training, 5S implementation, FIFO control, and defect reduction.

Highlights:

- Defect waste ranked first with a 3.25 score.
- Process steps decreased from 43 to 36.
- PCE rose from 26.65% to 35.35%.

Keywords: DMAIC, F-FMEA, Lean Six Sigma

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Introduction

The feed industry is a strategic sector that plays an important role in supporting the country's economic development, particularly in the livestock sector [1]. The availability of high-quality and affordable feed is crucial for the sustainability of livestock businesses, whether small, medium, or large scale [2]. In supporting the smooth distribution of these feed products, logistics and storage systems play a crucial role. The warehouse storage process includes various aspects that contribute to the efficiency and safety of the storage process [3]. Therefore, companies must maintain products in the warehouse area from receipt, storage, to delivery of goods to customers so that they have guaranteed quality [4]. PT XYZ is a leading entity involved in the largest and most integrated agri-food industry in Indonesia. This company is engaged in the production of animal feed (poultry, ruminants, and birds), pet food, and fish feed. One of its products is animal feed with sack packaging. In the animal feed storage area at PT XYZ, waste is still found which impacts the quality and efficiency of the process.

Based on field observations, there are several types of waste in the material handling process, where the dominant waste is defects with a defect rate of 0.58% which includes torn sacks, loose stitches, and contamination. In addition, motion waste was found due to repeated operator and forklift movements and transportation in the form of delays during the picking process. Other waste includes waiting due to the rework process, inventory due to stock buildup, overproduction due to production planning errors, and overprocessing that occurs due to the re-repair of defective products. Disability rate is in the range of 0.39% to 0.97%. The highest value occurred in February 2026, where increase in production volume followed by an increase amount product defects. This indicates that the handling capacity in the warehouse is not optimal in keeping up with the increasing workload, especially in the material handling process. This condition shows that the increase in production volume has not been balanced by the effectiveness of quality control in the warehouse area. Therefore, continuous improvement is needed to achieve zero defects through the implementation of Lean Six Sigma with a DMAIC to identify waste and reduce the defect [5].

One method widely applied in this effort is Lean Six Sigma, a data-driven management approach focused on reducing waste and process variation using five main stages: Define, Measure, Analyze, Improve, and Control [6]. This method has been proven to increase operational efficiency, reduce defect rates, and improve material handling in the warehouse area [7]. Several previous studies have shown the success of Lean Six Sigma in increasing productivity in the production and distribution processes [5]. However, its application to material handling activities in the animal feed industry still faces obstacles in material flow patterns and standardization of work procedures. Lean Six Sigma has been proven effective in reducing waste and dead stock in the warehouse through the DMAIC approach [8]. However, previous studies generally emphasize production processes or overall warehouse performance, while discussions on defect reduction in material handling activities within the animal feed industry, particularly in sack-based packaging, are still limited. Furthermore, the application of Lean Six Sigma combined with Fuzzy FMEA in this specific context has not been widely explored. This condition highlights a research gap in analyzing and prioritizing defect-related waste in material handling processes. Therefore, this study aims to identify defect-related waste, analyze its root causes using the DMAIC approach, and develop improvement recommendations based on Fuzzy FMEA to enhance operational efficiency and reduce defect rates. This study applies Lean Six Sigma through the DMAIC stages combined with Value Stream Mapping (VSM) to map material flow and identify non-value-added activities in the storage process [6]. [9]. In addition, Process Activity Mapping (PAM) is used to classify value-added and non-value-added activities according to the characteristics of the storage process [10]. Risk priority determination is carried out using the Fuzzy FMEA approach as a development of conventional FMEA so that the results of the severity, occurrence, and detection assessments are more objective. This approach is used to ensure that the proposed solution focuses on the main causes of the problem. The integration of Lean Six Sigma and Fuzzy FMEA is expected to be able to reduce packaging defects and increase the effectiveness of the storage process in the finished goods warehouse of PT XYZ.

Method

The data collection technique to identify waste due to product defects in the material handling process of PT XYZ uses a quantitative approach, the data used consists of primary and secondary data. Primary data collection was carried out through direct observation, interviews, and distribution of Likert scale questionnaires to respondents who understand the process. Secondary data obtained include production data, defect data, types of waste, and material handling process flow. The method used is Lean Six Sigma with the DMAIC approach and Process Cycle Efficiency (PCE) measurement to determine the comparison of value-added and non-value-added activities. In addition, problem cause analysis was carried out using fishbone and supported by Fuzzy FMEA as a basis for preparing improvement proposals. The steps that need to be taken to solve the problems in this study can be seen in the following explanation:

1. Initial Big Picture Mapping Depiction

This stage aims to observe and determine the company's condition. This involves creating a production process map that includes an information flow map and a physical flow map using *Big Picture Mapping tools*, so that *Process Cycle Efficiency* (PCE) is obtained. This PCE will later become the basis for identifying waste in the process [11].

$$PCE = \frac{\text{Value Added}}{\text{Total Lead Time}} \times 100\% \quad (1)$$

2. Determination of Critical Waste

Identifying the most dominant types of waste and prioritizing them for improvement. The analysis was conducted by processing observation and questionnaire data, which had been classified into seven types of *waste*.

3. VALSAT Analysis

Determining the most appropriate analysis *tools for identifying critical waste*. The analysis is carried out by mapping *waste types* into the VALSAT matrix, then assigning weights to each *tool* based on their level of relevance [12]. *The tool* with the highest value is selected as the primary analysis tool.

Waste Weight X Correlation Value (H, L, M) (2)

Information:

Waste weight = Based on the *waste weight value* in the questionnaire summary calculation

Correlation Value = H: multiplier factor (9)

M = multiplier (3)

L = multiplier factor (1)

4. Define

In the *Define stage*, data analysis focuses on identifying initial problems in the form of types of packaging defects that appear during *the material handling process* [13]. Defect data is collected based on a certain period.

5. Measure

This stage measures and processes the data that *has been* obtained, focusing on calculating *defects per million opportunities* (DPMO), sigma values [14].

1. Calculate the proportion of damage using the formula:

$$p = \frac{np}{n} \quad (3)$$

2. DPMO

$$DPMO = \frac{\text{Total Defect}}{\text{Output Produksi} \times CTQ} \times 10^6 \quad (4)$$

3. Sigma Level

$$\text{Level Sigma} = \text{Normsinv} \frac{1.000.000 - DPMO}{1.000.000} + 1,5 \quad (5)$$

6. Analyze

This stage involves analyzing and identifying *waste* and determining the potential causes of the problem using Pareto diagrams and cause and effect diagrams (*fishbone*) to design improvement solutions [15] [16].

7. Improve

The improvement method used is *Fuzzy FMEA*. The creation of *Value Stream Mapping* (VSM) for future conditions (*future state*) will be carried out at this stage as a follow-up to the results of the improvement proposals that have been implemented. The *Fuzzy RPN* calculation method is as follows [17]:

$$FRPN = (R_1^S) \frac{w^S}{w^S + w^O + w^D} \times (R_1^O) \frac{w^O}{w^S + w^O + w^D} \times (R_1^D) \frac{w^D}{w^S + w^O + w^D} \quad (6)$$

Second, the case approach (*case The approach*) was conducted through an in-depth analysis of Supreme Court Decision

Results and Discussion

A. Data collection

The types and number of defects that occurred during the material handling process of animal feed products at PT XYZ can be seen in Table 1 :

Table 1. Types and Number of Defects in Animal Feed Products

Month	Production Quantity (Unit)	Torn Sack (Unit)	Loose Stitches (Unit)	Contaminated (Unit)	Number of Defects (Units)
Mar 2025	1,074,834	3,802	2,409	448	6,659
Apr 2025	875,793	2,352	1,557	264	4,173
Mei 2025	915,808	2,171	1,405	509	4,085
Jun 2025	971,342	2,099	1,333	385	3,817
Jul 2025	964,186	2,621	1,657	505	4,783
Agt 2025	913,713	2,708	1,799	547	5,054
Sep 2025	1,012,025	2,930	1,790	506	5,226
Oct 2025	1,086,359	3,147	2,035	800	5,982
Nov 2025	930,625	2,911	1,842	821	5,574
Dec 2025	1,007,392	3,700	2,106	912	6,718
Jan 2026	1,106,491	4,447	2,365	1,002	7,814
Feb 2026	1,030,387	5,610	2,950	1,435	9,995
Total	11,888,955	38,498	23,248	8,134	69,880

B. Data processing

1. Initial Big Picture Mapping Depiction

Big Picture Mapping is a tool used to visualize an entire system and its value streams within a company [18]. The value stream mapping of the material handling process at its initial state can be seen in Figure 1.

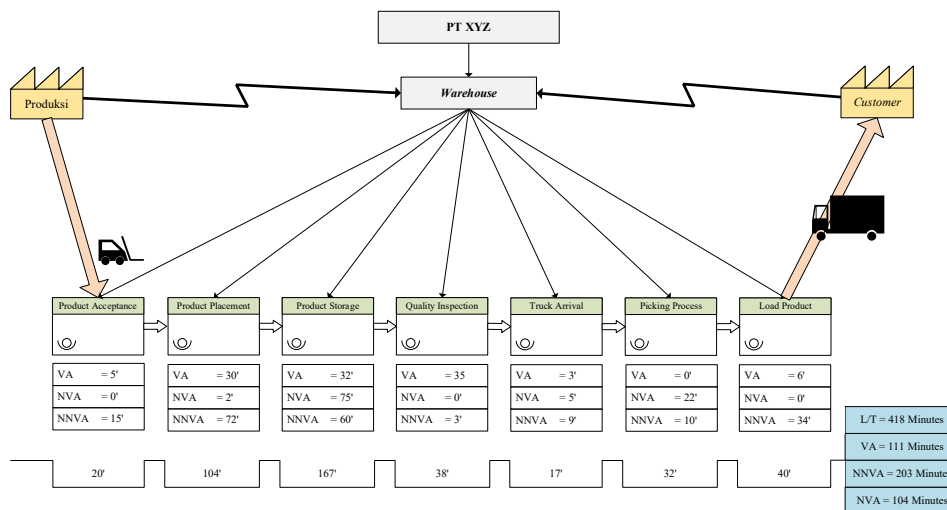


Figure 1. Big Picture Mapping of the Initial Material Handling Process for Animal Feed Products

Based on *big picture mapping*, the total lead time is obtained. The total lead time for animal feed material handling was 418 minutes with a total value-added time of 111 minutes, a total non-value-added time of 104 minutes, and a total necessary non-value-added time of 203 minutes. Therefore, the problem that occurred in the animal feed material handling process can be determined, namely the total lead time is too long at 418 minutes, equivalent to 6.96 hours or 6 hours 58 minutes, so the Process Cycle Efficiency (PCE) value is calculated as follows:

$$PCE = \frac{\text{Value added}}{\text{Lead Time}} \times 100\% = \frac{111}{418} \times 100\% = 26,56\%$$

C. Determination of Critical Waste

Critical waste was determined based on the results of a distributed questionnaire to determine which waste occurs frequently and which are the main priorities for improvement, as shown in Table 2.

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Table 2. Summary of Waste Questionnaire Results According to Ranking

No	Waste	Respondents				Weight	Ranking
		1	2	3	4		
1	Transportation	2	2	4	4	3	2
2	Inventory	3	3	2	1	2,25	5
3	Motion	2	3	4	2	2,75	3
4	Waiting	2	2	2	1	1,75	7
5	Overproduction	3	3	3	1	2,5	4
6	Overprocessing	3	2	1	2	2	6
7	Defect	2	2	4	5	3,25	1

Based on the table, the weighting results are obtained with the order of Ranking 1 to 7. Waste with Ranking 1 is defect with a weight of 3.25; Ranking 2 is transportation with a weight of 3; Ranking 3 is motion with a weight of 2.75; Ranking 4 is overproduction with a weight of 2.5; Ranking 5 is inventory with a weight of 2.25; Ranking 6 is overprocessing with a weight of 2; and Ranking 7 is waiting with a weight of 1.75.

D. VALSAT Analysis

The VALSAT analysis was carried out based on the results of the weight calculations obtained from interviews in determining critical waste in Table 2. The results of the Value Stream Analysis Tools (VALSAT) analysis can be seen in Table 3.

Table 3. Calculation of VALSAT Score

Waste/ Structure	Weight	VALSAT						
		PAM	SCRM	PVF	QFM	DAM	DPA	PS
Transportation	3	27	-	-	-	-	-	3
Inventory	2.25	6.75	6.75	6.75	-	6.75	6.75	2.25
Motion	2,75	24,75	2,75	-	-	-	-	-
Waiting	1,75	15,75	5,25	1,75	-	5,25	5,25	-
Overproduction	2,5	2,5	7,5	-	2,5	7,5	7,5	-
Overprocessing	2	18	-	6	2	-	2	-
Defect	3.25	3.25	-	-	29.25	-	-	-

Based on the data in Table 3, the tool with the highest ranking is Process Activity Mapping (PAM), so PAM was chosen as the tool to be used in the calculation process. Process Activity Mapping is used to identify activities that do not provide added value in the material handling process, as can be seen in Table 4.

Table 4 . Initial Process Activity Mapping

No	Process Description	Activity Type					Processing Time (Minutes)	Activity Type
		O	T	I	S	D		
Product Acceptance								
1	Product retrieval from the production <i>packing area</i>		P				5	NNVA
2	Checking the condition of the sack before moving it			P			5	VA
3	<i>forklift</i> operator records the <i>bagging</i> results report for entry into the warehouse to be submitted to the warehouse.			P			10	NNVA
Total Time							20	
Product Placement								
4	Placement of animal feed products based on empty plots				P		4	NNVA
5	Arrange the position of the sacks according to the capacity of the plot				P		6	NNVA
6	The report on the results of <i>bagging</i> into the warehouse is given to the warehouse officer.		P				2	NNVA
7	Checking the conformity of the physical stock of animal feed products received from production			P			10	NNVA
8	Recording of plot data and number of feed products in the production report book			P			50	NNVA
9	Warehouse officer submits production report book to WMS admin		P				2	NVA
10	Input physical stock from production report book to WMS system	P					30	VA

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No	Process Description	Activity Type					Processing Time (Minutes)	Activity Type	
		O	T	I	S	D			
Total Time								104	
Product Storage									
11	Warehouse officers check the physical stock of animal feed			P			40	NNVA	
12	Manual recording of stock information	P					40	NVA	
13	Stack stability check			P			25	NVA	
14	Marking of defective sacks and <i>repacking</i> of animal feed products	P					20	NNVA	
15	Minor rearrangements if needed	P					10	NVA	
16	Cleaning the storage area from dust and leftover feed	P					12	VA	
17	Temperature & humidity monitoring			P			5	VA	
18	Warehouse fumigation to prevent pest attacks	P					15	VA	
Total Time								167	
Quality Inspection									
19	QC determines <i>batch status</i> via WMS			P			5	VA	
20	Warehouse operator checks <i>batch status</i> (UU) via WMS as a requirement before Prep DO			P			3	NNVA	
21	QC performs MBE (<i>Material Body Examination</i>) to check physical stock			P			30	VA	
Total Time								38	
Truck Arrival									
22	The truck enters post 6 and the post officer verifies the identity of the driver and vehicle.			P			3	NNVA	
23	The officer handed over the KIM (Entry Permit Card) to the truck <i>driver</i> .		P				1	NNVA	
24	The driver takes <i>the Delivery Order</i> (DO) at the Sales department.		P				3	NNVA	
25	Sales provide RFID tap cards to drivers for scale/ <i>loading access</i>	P					1	VA	
26	The driver is directed to the weighing area by the officer.		P				5	NVA	
27	Trucks queue to go to Weighing Room 1 (empty weighing)					P	2	NNVA	
28	Empty weighing process (Weigh 1) using RFID card	P					2	VA	
Total Time								17	
Picking Process									
29	Receive <i>Delivery Order</i> (DO) from sales			P			1	NNVA	
30	<i>Batch</i> verification according to DO in WMS system			P			2	NNVA	
31	Operator searches for <i>batch location</i> according to plot in WMS			P			3	NNVA	
32	Waiting for <i>the forklift</i> to be used for other activities					P	10	NVA	
33	Repeated transfer of sacks due to DO <i>batches</i> not being in easily accessible positions		P				12	NVA	
34	Pick up of goods according to DO	P					3	NNVA	
35	Placement of goods in <i>loading dock</i> before the <i>loading process</i> onto the truck.				P		1	NNVA	
Total Time								32	
Load Product									
36	Truck heading to <i>loading</i> animal feed warehouse <i>dock</i>	P					2	NNVA	
37	Queue <i>loading dock</i> for feed loading process					P	10	NNVA	
38	The process of loading sacks onto a truck	P					15	NNVA	
39	Truck heading to Weigh 2 (weigh contents)		P				3	NNVA	
40	Weighing process (using RFID card)	P					2	VA	
41	Admin creates travel documents based on weighing results	P					4	VA	
42	Driver takes validated waybill & DO		P				2	NNVA	
43	Trucks do <i>Gate Out</i> leaving the company area		P				2	NNVA	
Total Time								40	
Total		13	10	14	3	3	418		

E. Define

Based on the control of animal feed products obtained from Table 1. The percentage of results for each product defect can be seen in the Table 5. and the Pareto diagram can be seen in Figure 2:

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Table 5. Percentage of Defects in Animal Feed Products

No	Types of Disabilities	Number of Defects (Units)	Production Quantity (Units)	Product Defect Percentage (%)
1	Torn Sack	38,498	11,888,955	0.3238%
2	Loose Stitches	23,248	11,888,955	0.1955%
3	Contaminated	8,134	11,888,955	0.0684%

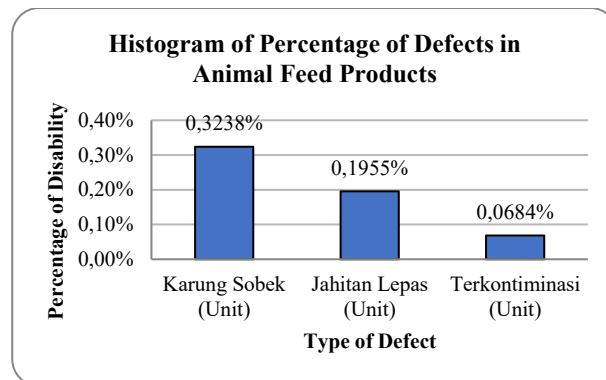


Figure 2. Histogram of Defect Types March 2025 - February 2026

Based on Figure 2. the histogram above, it can be seen that the highest number of defects is torn sacks amounting to 38,498 units with a percentage of 0.3238%, then followed by loose stitching defects amounting to 23,248 units with a percentage of 0.1955%, and contaminated amounting to 8,134 units with a percentage of 0.0684%. Therefore, reducing the percentage of defects to approach *zero defects* for animal feed products must be done and suggestions for improvement will be given.

F. Measure

In the measurement stage, the sigma value of animal feed product quality at PT XYZ is calculated to identify the defect level, while the calculation of DPO, DPMO, and sigma level in each period is carried out to analyze the probability of defects occurring in one million opportunities [14], which can be seen in Table 6 and refers to formulas (3), (4), and (5), as well as to evaluate process capability in accordance with Lean Six Sigma principles and identify opportunities for improvement.

Table 6. DPO, DPMO, and Sigma Level Values of Animal Feed Products March 2025 - February 2026

Month	Production Quantity	Defect	CTQ	DPO	DPMO	Sigma Level
March 2025	1,074,834	6,659	3	0.002065	2,065	4.37
April 2025	875,793	4.173	3	0.001588	1.588	4.45
May 2025	915,808	4.085	3	0.001487	1.487	4.47
June 2025	971,342	3.817	3	0.001310	1.310	4.51
July 2025	964,186	4.783	3	0.001654	1.654	4.44
August 2025	913,713	5.054	3	0,001844	1.844	4,40
September 2025	1.012.025	5.226	3	0,001721	1.721	4,43
Oktober 2025	1.086.359	5.982	3	0,001835	1.835	4,41
November 2025	930.625	5.574	3	0,001997	1.997	4,38
Desember 2025	1.007.392	6.718	3	0,002223	2.223	4.34
January 2026	1.106.491	7.814	3	0.002354	2.354	4.33
February 2026	1.030.387	9.995	3	0.003233	3.233	4.22
Total	11,888,955	69.880	36	0.023311	23.311	52.74
Rata-Rata	990.746	5.823	3	0.001943	1.943	4.4

The results above indicate that PT XYZ is at a sigma level of 4.4, or 4 sigma, with an average DPMO of 1,943 per 1,000,000 units. While this score is quite good compared to the Indonesian industry average, it still falls short of the US industry average. In this context, further evaluation is needed to understand the differences and potential improvements to achieve higher standards.

G. Analyze

1. Pareto diagram

The CTQ that has been determined in the data in Table 1., then a defect analysis is carried out to determine the cause of the highest defects which can be seen in Table 7.

Table 7. Defect Analysis Results

No	Types of Disabilities	Number of Defects (Units)	Cumulative	Total Percentage	Cumulative Percentage
1	Torn Sack (Unit)	38,498	38,498	55.09%	55.09%
2	Loose Stitches (Unit)	23,248	61,746	33.27%	88.36%
3	Contaminated (Unit)	8,134	69,880	11.64%	100.00%
Total		69,880		100.00%	

Based on the calculation results in Table 7 that have been carried out, a Pareto diagram of livestock feed product defects is depicted in Figure 3.

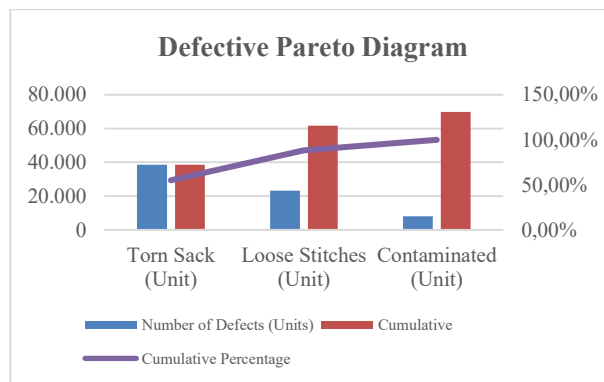


Figure 3. Pareto diagram

From the Pareto diagram, it can be seen that the highest order of defect types is torn sacks at 55.09%, loose stitching at 33.27%, and contamination at 11.64%.

2. Fishbone

An analysis was carried out using a fishbone diagram to analyze the cause and effect of the type of torn sack defect which can be seen in Figure 4.

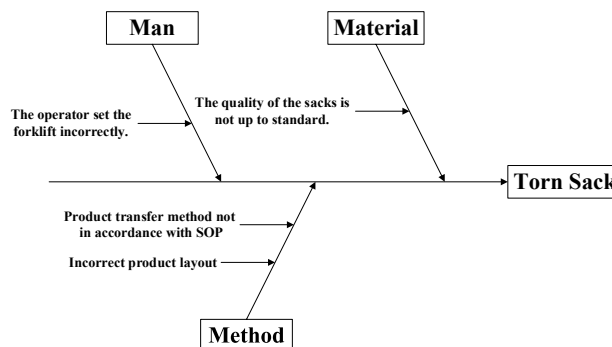


Figure 4. Fishbone Torn Sack

The causes of torn sacks in animal feed products are influenced by several factors, namely human, material, and method. From the human aspect, operators are less careful when operating forklifts due to rushing and improper fork height adjustment. From the

material aspect, substandard sack quality makes the packaging more susceptible to tearing when subjected to friction or impact. Meanwhile, from the method aspect, the transfer process does not comply with standard operating procedures (SOPs) and improper product arrangement, such as contact with damaged pallets or those with sharp edges, also increase the risk of packaging damage.

H. Improve

1. Fuzzy Failure Mode and Effect Analysis (F-FMEA)

This study used *Fuzzy Failure Mode and Effect Analysis* (F-FMEA) with the aid of Pareto diagrams and cause-and-effect diagrams to identify problem priorities. The analysis using *the Lean Six Sigma approach* showed that *defects were the most dominant source of waste* [17].

a. Severity, Occurrence, and Detection Identification

The first stage is to identify severity, occurrence, and detection in the material handling process, which can be seen in Table 8.

Table 8. Identification of *Severity* , *Occurrence*, and *Detection*

No	Modes of Failure	Effect of Failure	Cause of Failure	Detection Method
1	Torn Sack	Product spills occur which cause the product weight to decrease and disrupt the cleanliness of the warehouse area.	Forklift was not adjusted correctly by the operator (<i>fork height</i> , <i>mast tilt</i>).	Direct supervision during the <i>handling process</i> , <i>checklist</i> for checking <i>forklift settings</i> before operational and operator performance evaluation.
			The strength of the sack material is not up to standard.	Quality checks are carried out according to standards, as well as visual inspections of the physical condition of the sacks before use.
			Handling during the transfer of goods does not comply with Standard Operating Procedures.	Conduct <i>monitoring</i> during the process of transferring animal feed products.
			Product layout is not correct.	Conduct <i>monitoring</i> and evaluation of product arrangement with storage standards (SOP) in the warehouse area.

b. Determining the weight of importance

Determining the weight of expert importance in assessing the levels of Severity, Occurrence, and Detection, which are based on two main factors, namely experience and position held, can be seen in Table 9.

Table 9. Expert Importance Weight

Respondent Code	Information	Importance Weight(%)
R1	Load Coordinator	35%
R2	Field coordinator	30%
R3	WMS Admin	20%
R4	<i>Repacking Staff</i>	15%
Total		100%

c. Calculation of Aggregation of Assessment of Factors S, O, D

The calculation of the assessment aggregation is carried out by multiplying the importance weight of each respondent based on Table 9. with the Fuzzy Number Value (FN) with the importance weight (W). The aggregation of the Fuzzy Ranking assessment for the Severity, Occurrence, and Detection factors can be seen in Table 10, Table 11, and Table 12.

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Table 10. Aggregation of Fuzzy Rating Assessment Against Severity Factor

Type of Defect	Reason	R	S			WX FN			Total	ΣR^S	R_i^S		
			Rate	Fuzzy Number									
Torn Sack	Forklift is not adjusted properly (fork height, mast tilt)	R1	VL	3	4	5	1.05	1.4	1.75	4.2	11.55	2.89	
		R2	MR	2	3	4	0.6	0.9	1.2	2.7			
		R3	VL	3	4	5	0.6	0.8	1	2.4			
		R4	L	4	5	6	0.6	0.75	0.9	2.25			
	The strength of the sack material is not up to standard.	R1	VL	3	4	5	1.05	1.4	1.75	4.2	11.55	2.89	
		R2	MR	2	3	4	0.6	0.9	1.2	2.7			
		R3	VL	3	4	5	0.6	0.8	1	2.4			
	Handling during the transfer of goods does not comply with Standard Operating Procedures.	R1	VL	3	4	5	1.05	1.4	1.75	4.2	11.55	2.89	
		R2	MR	2	3	4	0.6	0.9	1.2	2.7			
		R3	VL	3	4	5	0.6	0.8	1	2.4			
	Product placement is incorrect.	R4	L	4	5	6	0.6	0.75	0.9	2.25	11.5	2.89	
		R1	VL	3	4	5	1.05	1.4	1.75	4.2			
		R2	MR	2	3	4	0.6	0.9	1.2	2.7			
		R3	VL	3	4	5	0.6	0.8	1	2.4			
			R4	L	4	5	6	0.6	0.75	0.9	2.25		

Table 11. Aggregation of Fuzzy Ranking Assessment Against Occurrence Factors

Type of Defect	Reason	R	S			WX FN			Total	ΣR^0	R_i^0		
			Rate	Fuzzy Number									
Torn Sack	Forklift is not adjusted properly (fork height, mast tilt)	R1	M	4	5	6	1.4	1.75	2.1	5.25	12.6	3.15	
		R2	L	2	3	4	0.6	0.9	1.2	2.7			
		R3	M	3	4	5	0.6	0.8	1	2.4			
		R4	M	4	5	6	0.6	0.75	0.9	2.25			
	The strength of the sack material is not up to standard.	R1	M	3	4	5	1.05	1.4	1.75	4.2	12.15	3.04	
		R2	M	3	4	5	0.9	1.2	1.5	3.6			
		R3	M	4	5	6	0.8	1	1.2	3			
	Handling during the transfer of goods does not comply with Standard Operating Procedures.	R4	L	2	3	4	0.3	0.45	0.6	1.35	12.6	3.15	
		R1	M	5	6	7	1.75	2.1	2.45	6.3			
		R2	M	3	4	5	0.9	1.2	1.5	3.6			
	Product layout is not correct.	R3	M	2	3	4	0.4	0.6	0.8	1.8	15.3	3.83	
		R4	L	1	2	3	0.15	0.3	0.45	0.9			
		R1	M	4	5	6	1.4	1.75	2.1	5.25			
		R2	M	5	6	7	1.5	1.8	2.1	5.4			
			R3	M	3	4	5	0.6	0.8	1	2.4		
			R4	M	4	5	6	0.6	0.75	0.9	2.25		

Table 12. Aggregation of Fuzzy Ranking Assessment Against Detection Factors

Type of Defect	Reason	R	S			WX FN			Total	ΣR^D	R_i^D	
			Rate	Fuzzy Number								
Torn Sack	Forklift is not adjusted properly (fork height, mast tilt)	R1	M	4	5	6	1.4	1.75	2.1	5.25	13.2	3.3
		R2	H	2	3	4	0.6	0.9	1.2	2.7		
		R3	M	4	5	6	0.8	1	1.2	3		
		R4	M	4	5	6	0.6	0.75	0.9	2.25		
	The strength of the	R1	VH	1	2	3	0.35	0.5	0.7	2.1	11.4	2.85

e. Determining the Fuzzy Risk Priority Number Value

The final stage of Fuzzy FMEA is determining the Fuzzy Risk Priority Number (FRPN) value which can be seen in Table 15.

$$\begin{aligned}
 FRPN &= (R_i^S) \frac{\hat{w}_i^S}{\hat{w}_i^S + \hat{w}_i^O + \hat{w}_i^D} \times (R_i^O) \frac{\hat{w}_i^O}{\hat{w}_i^S + \hat{w}_i^O + \hat{w}_i^D} \times (R_i^D) \frac{\hat{w}_i^D}{\hat{w}_i^S + \hat{w}_i^O + \hat{w}_i^D} \\
 &= (2,89) \frac{0,41}{0,41+0,35+0,38} \times (3,15) \frac{0,35}{0,41+0,35+0,38} \times (3,3) \frac{0,38}{0,41+0,35+0,38} \\
 &= 5,44
 \end{aligned}$$

Table 15. Determination of Fuzzy Risk Priority Number Value

Modes of Failure	Cause of Failure	R_i^S	R_i^O	R_i^D	\hat{w}_i^S	\hat{w}_i^O	\hat{w}_i^D	FRPN	Rank
Torn Sack	Forklift was not adjusted correctly by the operator (fork height, mast tilt).	2.89	3.15	3.30	0.41	0.35	0.38	5.44	2
	The strength of the sack material is not up to standard.		3.04	2.85				4.53	4
	Handling during the transfer of goods does not comply with Standard Operating Procedures.		3.15	3.11				5.13	3
	Product layout is not correct.		3.83	2.78				5.56	1

After calculating the FRPN in Table 15, to determine repair priorities, repair recommendations are obtained for each damage, as shown in Table 16.

Table 16. Repair Recommendations Based on FRPN Sequence

Rank	Modes of Failure	Cause of Failure	FRPN	Recommendation
1	Torn Sack	Product layout is not correct.	5.56	Standardize product arrangement and pallet use by adding pallets made of good quality iron to minimize the risk of damage to sacks due to rough surfaces, and also carry out regular inspections of pallet conditions.
2	Torn Sack	Forklift not adjusted properly (fork height, mast tilt)	5.44	Perform forklift checks and settings before operation, as well as daily checklists for operators.
3	Torn Sack	Handling during the transfer of goods does not comply with Standard Operating Procedures.	5.13	Optimizing handling procedures by prohibiting the dragging of sacks, using appropriate tools, and monitoring activities based on operational checklists.
4	Torn Sack	The strength of the sack material is not up to standard.	4.53	Conducting regular inspections of incoming materials, as well as evaluating sack suppliers who are able to meet the established quality standards.

Recommendations for improvement from the Fuzzy FMEA analysis were used to identify the root causes of defects. These were then developed into comprehensive waste improvement proposals based on Lean principles, as shown in Table 17.

Table 17. Improvements to Causes of Waste

Rank Priority	Types of Waste	Recommendation
1	<i>Defect</i>	Improvements focused on preventing packaging damage, standardizing pallet use, and limiting the height of sack stacks to avoid friction. Inspections and environmental controls were also implemented to minimize contamination.
2	<i>Transportation</i>	Control of moving activities is required by setting SOPs for forklift speed limits, as well as providing operator training so that the risk of collisions and falling products can be minimized.
3	<i>Motion</i>	Implementing 5S to create a neater and more organized work area and using tools to reduce

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Rank Priority	Types of Waste	Recommendation
		excess manual activity and increase movement efficiency.
4	Overproduction	Production control is carried out by adjusting production quantities based on demand and monitoring stock to prevent stockpiling.
5	Inventory	Inventory management is carried out by consistently applying FIFO, labeling each product, and setting stock limits to prevent stockpiling of goods.
6	Overprocessing	Minimize additional processing due to damage through increased control over product handling and storage.
7	Waiting	Reducing waiting times is done through workforce optimization, creating <i>forklift usage schedules</i> and improving coordination between processes to ensure smoother workflow.

2. Future Big Picture Mapping

The future big picture mapping is developed in line with Lean principles that emphasize the elimination of non-value added (NVA) activities [19], by simplifying process activity mapping in the material handling process, as shown in Table 18.

Table 18. Future Process Activity Mapping

No	Process Description	Activity Type					Processing Time (Minutes)	Activity Type
		O	T	I	S	D		
Product Acceptance								
1	Product retrieval from the production <i>packing area</i>		P				5	NNVA
2	Checking the condition of the sack before moving it			P			5	VA
3	<i>forklift</i> operator records the <i>bagging</i> results report for entry into the warehouse to be submitted to the warehouse.			P			10	NNVA
Total Time							20	
Product Placement								
4	Placement of animal feed products based on empty plots				P		4	NNVA
5	Arrange the position of the sacks according to the capacity of the plot				P		6	NNVA
6	The report on the results of <i>bagging</i> into the warehouse is given to the warehouse officer.		P				2	NNVA
7	Checking the conformity of the physical stock of animal feed products received from production			P			10	NNVA
8	Recording of plot data and number of feed products in the production report book			P			50	NNVA
9	Input physical stock from production report book to WMS system	P					30	VA
Total Time							102	
Product Storage								
10	Warehouse officers check the physical stock of animal feed			P			40	NNVA
11	Marking of defective sacks and <i>repacking</i> of animal feed products	P					20	NNVA
12	Cleaning the storage area from dust and leftover feed	P					12	VA
13	Temperature & humidity monitoring			P			5	VA
14	Warehouse fumigation to prevent pest attacks	P					15	VA
Total Time							92	
Quality Inspection								
15	QC determines <i>batch status</i> via WMS			P			5	VA
16	Warehouse operator checks <i>batch status</i> (UU) via WMS as a requirement before Prep DO			P			3	NNVA
17	QC performs MBE (<i>Material Body Examination</i>) to check physical stock			P			30	VA
Total Time							38	
Truck Arrival								

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No	Process Description	Activity Type					Processing Time (Minutes)	Activity Type				
		O	T	I	S	D						
18	The truck enters post 6 and the post officer verifies the identity of the driver and vehicle.			P			3	NNVA				
19	The officer handed over the KIM (Entry Permit Card) to the truck driver .		P				1	NNVA				
20	The driver takes the <i>Delivery Order</i> (DO) at the Sales department.		P				3	NNVA				
21	Sales provide RFID tap cards to drivers for scale/ <i>loading access</i>	P					1	VA				
22	Trucks queue to go to Weighing Room 1 (empty weighing)					P	2	NNVA				
23	Empty weighing process (Weigh 1) using RFID card	P					2	VA				
Total Time							12					
Picking Process												
24	Receive <i>Delivery Order</i> (DO) from sales			P			1	NNVA				
25	<i>Batch</i> verification according to DO in WMS system			P			2	NNVA				
26	Operator searches for <i>batch location</i> according to plot in WMS			P			3	NNVA				
27	Pick up of goods according to DO	P					3	NNVA				
28	Placement of goods in <i>loading dock</i> before the <i>loading process</i> onto the truck.				P		1	NNVA				
Total Time							8					
Load Product												
29	Truck heading to <i>loading animal feed warehouse dock</i>	P					2	NNVA				
30	Queue <i>loading dock</i> for feed loading process					P	10	NNVA				
31	The process of loading sacks onto a truck	P					15	NNVA				
32	Truck heading to Weigh 2 (weigh contents)		P				3	NNVA				
33	Weighing process (using RFID card)	P					2	VA				
34	Admin creates travel documents based on weighing results	P					4	VA				
35	Driver takes validated waybill & DO		P				2	NNVA				
36	Trucks do <i>Gate Out</i> leaving the company area		P				2	NNVA				
Total Time							40					
Total						11	7	13	3	2	314	

Based on the future process activity mapping shown in Table 17, the material handling process can then be described with the future big picture mapping in Figure 5, where this improvement is aligned with the concept of Process Cycle Efficiency (PCE) in Lean, which emphasizes increasing the proportion of value-added activities in a process [11].

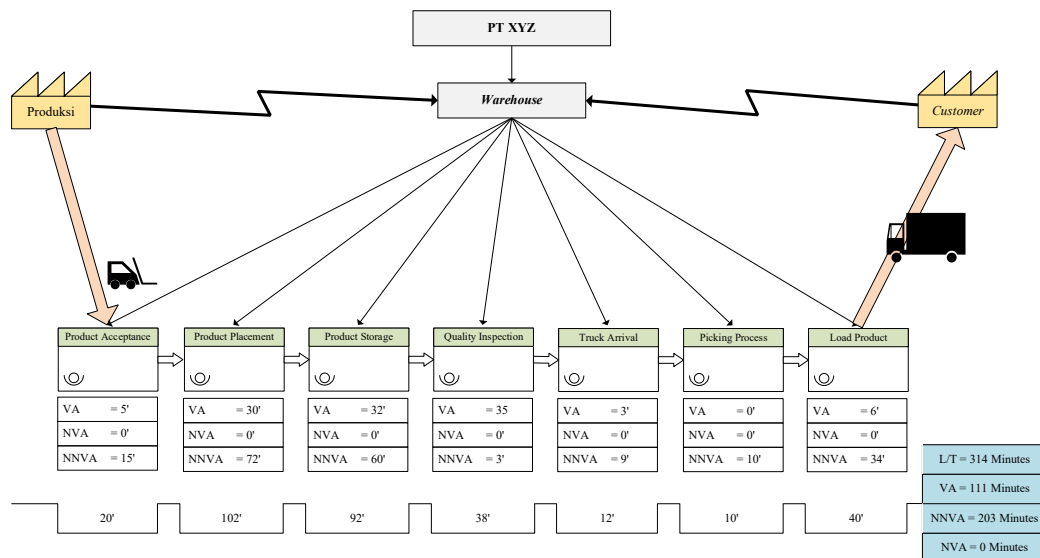


Figure 5. Big Picture Mapping Proposal Animal Feed Product Material Handling Process

Based on the time calculation after the improvement, namely by eliminating NVA from the *material handling process* of animal feed products, the lead time obtained was 314 minutes or equivalent to 5 hours 14 minutes with a total value-added time of 111 minutes, the necessary non-value-added time of 203 minutes. This indicates that there is a reduction in lead time so that the *material handling process* of animal feed can be more efficient. Therefore, the value for the percentage increase in efficiency in

the *material handling process* of animal feed can be described as follows:

$$\% \text{ Peningkatan Efisiensi} = \frac{\text{Lead time awal} - \text{Lead time usulan}}{\text{Lead time awal}} \times 100\%$$

$$\% \text{ Peningkatan Efisiensi} = \frac{418 - 314}{418} \times 100\% = 24,88\%$$

Process Cycle Efficiency (PCE) value can be determined using the following formula:

$$\text{PCE} = \frac{\text{Value Added}}{\text{Lead time}} \times 100\% = \frac{111}{314} \times 100\% = 35,35\%$$

From the calculation results of the proposed *Process Cycle Efficiency (PCE)* value, the result obtained was 35.35%, which means that the animal feed *material handling process* has improved.

I. Control

Control phase aims to monitor the sustainability of improvements to waste occurring in the *material handling process*, so that the proposed improvements can be implemented consistently over a longer period of time. However, in this study, the *control phase* could not be implemented directly because the decision regarding the implementation of the proposed improvements rests entirely with PT XYZ. Therefore, the process of controlling the results of the improvements could not be carried out in this study.

Conclusion

Based on the research objectives, this study successfully identified the dominant type of waste in the *material handling process*, namely defects with a weight of 3.25, followed by transportation, motion, overproduction, inventory, overprocessing, and waiting. The results show that the initial lead time of 418 minutes with a *Process Cycle Efficiency (PCE)* of 26.65% can be reduced to 314 minutes with a *PCE* of 35.35% through the elimination of non-value added (NVA) activities, resulting in an efficiency improvement of 24.88%. The proposed improvements include pallet standardization, stack height adjustment, environmental inspection, implementation of forklift speed SOPs, operator training, 5S implementation, production adjustment based on demand, FIFO application, and workforce optimization. This study contributes to the application of Lean Six Sigma in *material handling processes* by integrating waste identification with Fuzzy FMEA-based improvement prioritization, as well as providing practical implications for improving warehouse efficiency and reducing defect rates. Furthermore, future research is recommended to evaluate the implementation of the proposed improvements and their impact on efficiency, productivity, and waste reduction, while companies should focus on minimizing time-related waste and defect rates to achieve zero defects and increase the sigma level towards 6.

References

1. I. Purnama et al., "Study Literatur Manajemen Penyimpanan Bahan Pakan Jagung, Dedak dan Tepung Ikan untuk Ternak Unggas," *Jurnal Peternakan Borneo*, vol. 3, no. 2, pp. 35–42, 2024, doi: 10.34128/jpb.v3i2.33.
2. A. H. H. Slamet, B. H. Purnomo, D. W. Soedibyo, A. Asmunir, and R. Ningtias, "Analisis Pemilihan Pakan Ternak Unggas di PT XYZ Kabupaten Banyuwangi Menggunakan Metode Bayes," *Jurnal Agroteknologi Merdeka Pasuruan*, vol. 7, no. 1, p. 1, 2023, doi: 10.51213/jamp.v7i1.80.
3. M. Bahaul and N. Haryuni, "Feed Storage Management at PT Gombekk Boer Indonesia," *Bestindo Animal Science*, vol. 1, no. 1, pp. 70–76, 2024. [Online]. Available: <https://bestindolestari.id/index.php/bas/article/view/15>
4. D. M. Rahmawati and D. A. Anggraini, "Analisis Pengendalian Kualitas Produk Pada Gudang PT. DSV Solutions Indonesia (Semarang Site) Menggunakan Metode FMEA," *Surya Teknika*, vol. 12, no. 1, pp. 153–160, 2025, doi: 10.37859/jst.v12i1.8791.
5. R. Kusumawardani and A. Widyatmoko, "Enhancing Pharma Manufacturing Efficiency: Integrating Lean Six Sigma and Fuzzy FMEA for Waste Reduction," *Spektrum Industri*, vol. 22, no. 2, pp. 179–192, 2024, doi: 10.12928/si.v22i2.199.
6. N. Muvida, E. Yunitasari, and Kusmendar, "Pengendalian Kualitas Produk Menggunakan Lean Six Sigma dan Fuzzy FMEA Dalam Upaya Menekan Kecacatan Produk," *Jurnal Engine Energi, Manufaktur, dan Material*, vol. 7, no. 2, pp. 86–95, 2023, doi: 10.30588/jeemm.v7i2.1617.
7. A. F. Amelia and M. T. Safirin, "Penerapan Lean Six Sigma untuk Meningkatkan Efisiensi Proses Inbound dan Outbound di Gudang PT XYZ," *Jurnal Serambi Engineering*, vol. X, no. 1, 2025. [Online]. Available: <https://jse.serambimekkah.id/index.php/jse/article/view/673>
8. A. Putri and D. Isfianadewi, "Lean Six Sigma to Reduce Dead Stock at PT Globalindo Intimates," *Jurnal Indonesia Sosial Teknologi*, vol. 5, no. 4, pp. 1806–1813, 2024, doi: 10.59141/jist.v5i4.1031.
9. M. Rosyidah and R. Ismariyani, *Lean Manufacturing: Langkah Pengurangan Pemborosan dalam Produksi*. Yogyakarta, Indonesia: Deepublish Publisher, 2022.
10. M. Ilham, Nofirza, M. Umam, M. Yola, and Anwardi, "Evaluasi Aktivitas Non Value Added dengan Menggunakan Metode Value Stream Mapping dan Process Activity Mapping," *Jurnal Heuristic*, vol. 21, pp. 1–12, 2024, doi: 10.30996/heuristic.v21i1.10043.
11. A. N. Rasyid, I. A. Hendaryanto, W. Setiawan, and A. Winarno, "Analisis Re-layout Line Machining Oil Separator dengan Metode Value Stream Mapping dalam Meningkatkan Efisiensi Produktivitas di PT Astra Otoparts Divisi Nusametal," *Jurnal Engine Energi, Manufaktur, dan Material*, vol. 8, no. 2, pp. 96–105, 2024, doi: 10.30588/jeemm.v8i2.1848.
12. Marsella, W. Kosasih, and L. Salomon, "Analisis Pemborosan Produksi Kain Panel Melalui Pendekatan Lean Supply Chain," 2025, pp. 106–117, doi: 10.24912/jmti.v4i2.34956.
13. S. F. Utami, M. Almatsir, I. Mashabai, and N. Hudaningsih, "Analisis Kualitas Kopi Arabika di Matano Coffee Menggunakan Metode Six Sigma DMAIC," vol. 4, no. Nov., pp. 212–226, 2023, doi: 10.37373/jenius.v4i2.570.
14. A. Juwito and A. Z. Al-Faritsyi, "Analisis Pengendalian Kualitas untuk Mengurangi Cacat Produk dengan Metode Six

Academia Open

Vol. 11 No. 1 (2026): June

DOI: 10.21070/acopen.11.2026.14138

Sigma di UMKM Makmur Santosa,” *Jurnal Cakrawala Ilmiah*, vol. 1, no. 12, pp. 3295–3315, 2022. [Online]. Available: <http://bajangjournal.com/index.php/JCI>

15. R. I. Liperda, N. R. Fatahayu, E. V. Khairunnisa, M. A. Logika, M. Hibatullah, and R. Fridayanti, “Simulasi Sistem Penggunaan Ruang di Gedung Griya Legita Universitas Pertamina,” *JISI: Jurnal Integrasi Sistem Industri*, vol. 8, no. 2, pp. 65–75, 2021, doi: 10.24853/jisi.8.2.65-75.
16. Nurlaela, *Implementasi Value Stream Mapping pada Perumahan Sederhana di Indonesia*. Yogyakarta, Indonesia: Deepublish Publisher, 2023.
17. A. B. Rizkyllah and E. Aryanny, “Product Defect Level Analysis Bone Plate with The Six Sigma Method and Fuzzy Failure Mode and Effect Analysis (F-FMEA): Analisis Tingkat Kecacatan Produk Bone Plate dengan Metode Six Sigma dan Fuzzy Failure Mode and Effect Analysis (F-FMEA),” vol. 26, no. 4, pp. 1–15, 2025, doi: 10.21070/ijins.v26i4.1477.
18. M. Y. Muchsinin and W. Sulistiyowati, “Quality Control Analysis to Reduce Product Defects with the Lean Six Sigma Method and Fault Tree Analysis,” vol. 3, 2022, doi: 10.21070/pels.v3i0.1323.
19. M. F. Fadilah and R. Wibero, “Rancangan Lean Manufacturing untuk Mengurangi Pemborosan Pada Proses Pembuatan Sepatu dengan Pendekatan Metode Value Stream Mapping (VSM) dan Root Cause Analysis (RCA) di Home Industry Sepatu,” *Jurnal Greenation Ilmu Teknik*, vol. 2, no. 1, pp. 16–25, 2025, doi: 10.38035/jgit.v2i1.230.