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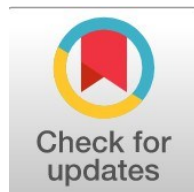
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HDPE Bag Production Waste Fell After Integrated Lean Analysis

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Abstract

General Background: Production efficiency is essential for manufacturing competitiveness, yet many systems remain dominated by non value added activities and seven waste categories. **Specific Background:** In HDPE plastic bag production, a defect rate of 7.02% exceeds the 3% standard and is accompanied by waiting, motion, and process inefficiencies. **Knowledge Gap:** Limited studies integrate Lean Manufacturing with Failure Mode and Effect Analysis in HDPE bag production contexts. **Aims:** This study aims to identify dominant waste and formulate improvement strategies using an integrated Lean approach. **Results:** Seven waste types were identified, with defects (RPN 441) and waiting (RPN 336) as priorities; improvements reduced activities from 39 to 31, decreased lead time from 214.94 to 151.14 minutes, and increased process cycle efficiency from 45.42% to 64.59%. **Novelty:** This study integrates Value Stream Mapping, Process Activity Mapping, fishbone diagram, and FMEA within a single framework tailored to HDPE bag production. **Implications:** The findings demonstrate that systematic waste identification and elimination of non value added activities improve production flow, quality, and operational efficiency while supporting structured maintenance and pull-based systems.

Highlights:

- Defect and waiting categories ranked as highest priority based on risk evaluation.
- Process restructuring reduced total operational steps and shortened processing duration.
- Integrated mapping and risk assessment enabled systematic identification of root causes.

Keywords: Lean Manufacturing, FMEA, HDPE Plastic Bags, Waste, Production Process.

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Introduction

Along with the development of technology and the dynamics of the global market, competition in the manufacturing sector is becoming increasingly intense. Companies are required to continuously improve the quality and efficiency of their production processes in order to maintain competitiveness and meet customer expectations [1]. This condition encourages the optimization of resource management so that both product quality and quantity can be achieved while maintaining operational efficiency [2]. Therefore, understanding the structure and workflow in the production area becomes very important, as the production line is a series of interconnected work stages starting from raw material processing to finished products that meet customer specifications [3].

PT XYZ is a polymer manufacturing company producing plastic bags made from Polypropylene (PP), Polyethylene (PE), and High-Density Polyethylene (HDPE), with HDPE 15 × 30 cm plastic bags as its main product. This polymer type and size is chosen as the focus because it is the most widely produced and distributed, especially for traditional markets, the retail sector, and simple packaging needs. The production process includes several stages, starting from raw material receiving, mixing, melting and extrusion, hot air blowing, rolling and cutting according to size, bottom sealing, bag forming, packaging, and finished goods storage.

Based on production data from January to December 2025, PT XYZ produced 1,600.27 tons of good products out of a total of 1,721 tons of High-Density Polyethylene (HDPE) plastic bags sized 15 × 30 cm. The total defect reached 120.73 tons or 7.02%, with an average monthly defect rate of 7.05%, which is significantly higher than the company's quality standard of 3%. The high defect rate results in more material waste, inefficient labor use, and rework activities, indicating that process control and defect prevention still needs improvement. The main defects include folding, incorrect cutting, asymmetry, and unformed handle holes, which reflect instability in critical production stages.

In addition to defects, the production process also shows significant non value added (NVA) activities. Waiting is the most dominant type of waste, with a total time of 59.39 minutes, mainly caused due to delays in work instructions and the buildup of work-in-process (WIP). This reflects an imbalance in the process and poor information flow, which contributes to longer production lead times [4]. Other inefficiencies include unnecessary motion of 7.49 minutes due to inefficient workstation layout and material handling, overprocessing of 7.12 minutes caused by repeated inspections and rehandling, and unnecessary transportation of 2.66 minutes that does not contribute to product value. The accumulation of inventory in the WIP area further reflects inefficiencies and is closely related to waiting, while also indicating overproduction driven by target-based scheduling. These conditions are worsened by the absence of integrated mapping of value added (VA), necessary non value added (NNVA), and non value added (NVA) activities, resulting in ineffective material flow and inconsistent process standards [5].

Lean Manufacturing is a suitable approach as it systematically eliminates waste and supports continuous improvement involving all employees [6]. Waste reduction plays a key role in improving product quality, where waste is defined as any activity that does not add value to the product [7]. In this study, Value Stream Mapping (VSM) is used to analyze process flow and identify bottlenecks, while Failure Mode and Effects Analysis (FMEA) is applied to identify potential failures, assess risks, and determine improvement priorities based on Risk Priority Number (RPN). Previous studies by [8] have demonstrated that the integration of VSM and FMEA can reduce waiting time and lead time while improving production efficiency, particularly in the automotive industry.

However, studies applying integrated lean manufacturing tools in plastic manufacturing, especially in HDPE plastic bag production, remain limited due to differences in process characteristics and defect types. Most existing studies focus on partial analysis and do not comprehensively integrate multiple tools to evaluate process flow, waste and failure risks that support more systematic improvements. Furthermore, no prior study at PT XYZ has combined Lean approach, VSM, VALSAT, Process Activity Mapping (PAM), Fishbone Diagram, and FMEA in a single framework. Therefore, this study aims to identify dominant waste, analyze root causes and failure risks and propose improvement strategies to enhance overall production efficiency performance.

Methods

This study applies the Lean Manufacturing approach, which is defined as a systematic method to design and improve manufacturing systems capable of producing products using only the necessary time required, while eliminating waste (non value added activities) and enhancing process efficiency without compromising product quality. Lean Manufacturing aims to increase customer value by maximizing value added (VA) activities and minimizing waste throughout the production process [9].

The research is conducted through several structured stages, begins with literature review study and field study. The literature review provides theoretical foundations, while field observations at PT XYZ are carried out to understand actual production conditions. This stage is followed by problem formulation and objective setting, focusing on identifying and reducing waste in the production process flow. There are seven types of waste identified and analyzed in this study, which are defect, waiting, unnecessary motion, overprocessing, unnecessary transportation, unnecessary inventory, and overproduction.

Data collection consists of primary and secondary data, with mixed method design. Primary data are obtained through direct observation, interviews and questionnaires. Observations are conducted across all stages of the HDPE plastic bag

production process (15 × 30 cm), from raw material receiving to finished goods, with relevant activities process time documented with data sufficiency test. Interviews are conducted with key personnel involved in the production process to gather information on operational issues, defect causes, and process constraints. The questionnaires uses a Likert scale (1-5) and distributed using purposive sampling to head of production, head of quality control, head of human resources, field supervisors, and production operators. Secondary data are collected from company documents, including production flow and waste data for the period January to December 2025, to support the analysis and provide a comprehensive understanding of production performance.

The analysis begins with Value Stream Mapping (VSM), also known as Big Picture Mapping, which visualizes and analyzes the flow of materials and information from raw materials to finished products to identify inefficiencies [10]. Process Cycle Efficiency (PCE) is used as an indicator to evaluate efficiency by comparing value-added time to total production time [11].

$$PCE = \frac{VA}{\Sigma LT} \times 100\% \quad (1)$$

Equation description:

PCE = Process Cycle Efficiency

VA= Value Added

ΣLT= Lead Time

Furthermore, seven common types of waste are considered, namely waiting, unnecessary motion, overprocessing, transportation, overproduction, unnecessary inventory, and defects [12]. Value Stream Analysis Tools (VALSAT) is applied to determine appropriate analytical tools, followed by Process Activity Mapping (PAM), which classifies activities into operation, transportation, inspection, delay, and storage, and further categorizes them into Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA) to improve process efficiency [13]

The root causes of waste are analyzed using a Fishbone Diagram (6M), covering factors related to man, machine, method, material, measurement, and mother nature (environment). Integration with Failure Mode and Effects Analysis (FMEA) is used to assess risks based on severity, occurrence, and detection, resulting in a Risk Priority Number (RPN) for prioritizing improvements [14].

$$RPN = (s) \times (o) \times (d) \quad (2)$$

Equation description:

(s)= Severity Level

(o) = Occurrence Potential Level

(d)= Detection Difficulty Level

Finally, improvement proposals are developed and evaluated through Future Value Stream Mapping (VSM) and simplified PAM to measure their impact on reducing waste and improving overall process efficiency.

The following flowchart illustrates the research methodology, as shown in Figure 1.

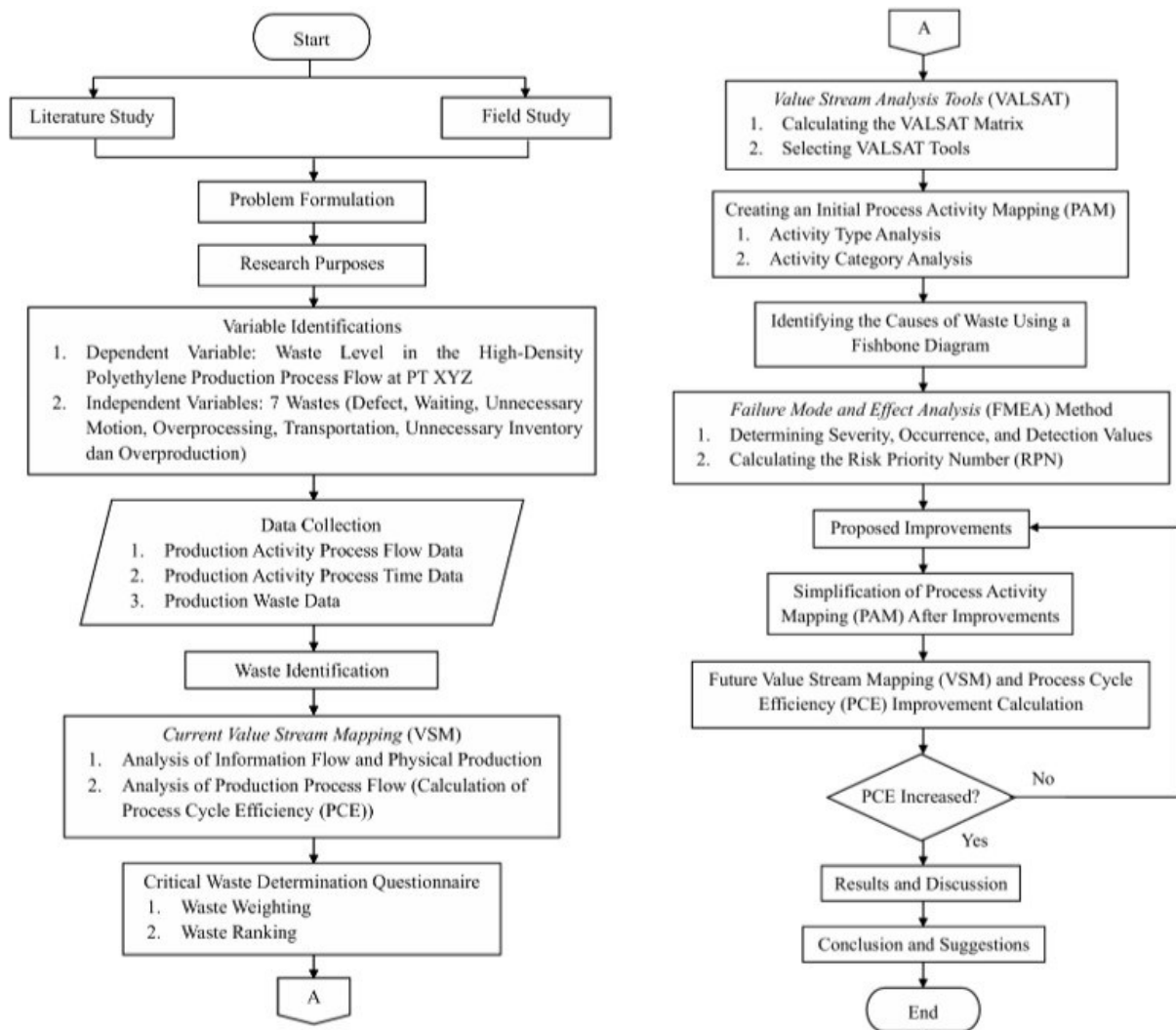


Figure 1. Flowchart

Result and Discussion

A. Waste Identification

Waste identification is conducted to determine the attributes of waste occurring in the production process of HDPE plastic bags sized 15 × 30 cm at PT XYZ. The results of the waste identification are presented in Table 1.

Table 1. Waste Identification

Waste Types	Attributes
Defect	Defective products such as folded defects, incorrect cutting, asymmetry, and unformed handle holes.
	Defects require rework, increasing production time and cost.
Waiting	Waiting for work instructions (mixing composition and product specifications) before continuing the process.
	Waiting time of products in work-in-process (WIP) before the next stage.
Unnecessary Motion	Additional operator movements due to non-ergonomic workplace layout.
	Reaching for or adjusting materials and tools that are difficult to access.
Overprocessing	Repeated inspection or quality control before the next stage.
	Additional processes such as handling or transferring rework from defective products.
Unnecessary Transportation	Movement of materials between work areas that does not add value.
	Use of temporary storage areas that increase handling steps in the production flow.
Unnecessary Inventory	Accumulation of semi-finished or finished goods in the WIP area.
	Process imbalance causing inventory buildup before the next stage.
Overproduction	Production based on internal targets without considering actual demand.
	Indicated by WIP accumulation or temporary storage.

The following table presents defect data of HDPE plastic bags (15 × 30 cm) at PT XYZ for the period January–December 2025. These defects lead to rework or product rejection, resulting in increased processing time, reduced process efficiency,

and additional waste due to rework handling, as shown in Table 2.

Table 2. Defect Waste Data

No	Month (2025)	Total Production (ton)	Defect Product (ton)	Good Product (ton)	Percentage of Defect Product
1	January	150	9.59	140.41	6,39%
2	February	138	10.28	127.72	7,45%
3	March	150	10.65	139.35	7,10%
4	April	148	9.79	138.21	6,61%
5	May	125	10.95	114.05	8,76%
6	June	143	8.93	134.07	6,24%
7	July	128	9.82	118.18	7,67%
8	August	146	10.66	135.34	7,30%
9	September	150	9.91	140.09	6,61%
10	October	145	9.27	135.73	6,39%
11	November	148	10.34	137.66	6,99%
12	December	150	10.54	139.46	7,03%
Total		1721	120.73	1600.27	7.02%
Average		143.42	10.06	133.36	7.05%

Based on field observations, several types of defects were identified in the production process of HDPE plastic bags, including folded defects, incorrect cutting, asymmetry, and unformed handle holes. Folded defects occur when the plastic surface is uneven or overlaps during the flattening and rolling process. Incorrect cutting arises during the bag-forming stage when the cutting does not match the specified pattern. Asymmetry occurs during the sealing process due to misaligned sheets, resulting in uneven dimensions and disproportionate bag shapes. Meanwhile, unformed handle holes are caused by inaccurate hole-cutting processes that do not meet standards. These defects render the plastic bags unusable, as they fail to fulfill their primary function for customers.

B. Current Value Stream Mapping

Value Stream Mapping (VSM) is a Lean Manufacturing tool used to visualize and analyze material and information flow across the entire production process to identify waste and improve overall efficiency and customer value [15]. The current state value stream mapping of the HDPE production process flow is presented in Figure 2.

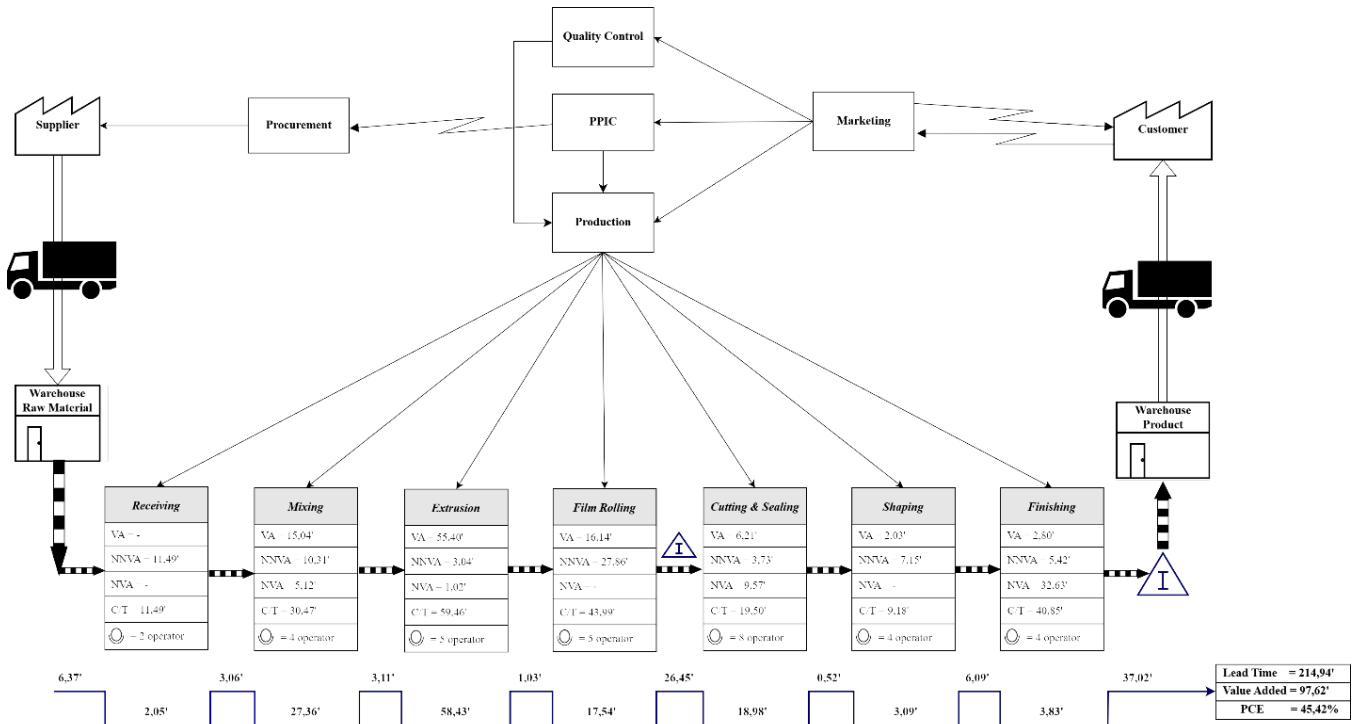


Figure 2. Current Value Stream Mapping

The information flow in the High-Density Polyethylene plastic bag production process represents the movement of data, instructions, and decisions that control and coordinate physical operations. Although production is primarily based on internally determined daily targets, the flow begins with customers providing general demand information and product requirements to the marketing department. This information, including product specifications and demand trends, is forwarded to Production Planning and Inventory Control (PPIC) as a reference for production planning. However, production

quantities are not directly based on actual demand. PPIC determines production targets by considering machine capacity, labor availability and previous sales performance, which are then translated into production schedules. These schedules are communicated to procurement for raw material supply planning and to the production department for execution.

During production, the Quality Control (QC) department monitors raw materials, processes, and finished products based on established quality standards. Inspection results are fed back to production and PPIC for corrective actions if necessary. Information regarding finished goods availability is then communicated to marketing for distribution planning. Overall, this system reflects a push production system, as production is driven by internal targets rather than real-time customer demand.

The total lead time of the process is 214.94 minutes (approximately 3.58 hours). Of this, value added (VA) activities account for 97.62 minutes, while the remaining time consists of non value added and necessary non value added activities, indicating significant opportunities for process improvement. The comparison between value added time and total lead time results in a Process Cycle Efficiency (PCE) of 45.42%.

C. Critical Waste Determination

The weighting of each waste attribute was determined by calculating the average scores from respondent’s responses. The ranking of each type of waste is presented in Table 3.

Table 3. Critical Waste Determination

No.	Waste Type	Average Score	Ranking
1	Defect	4.6	1
2	Waiting	4.4	2
3	Unnecessary Motion	3.7	3
4	Overprocessing	3.6	4
5	Unnecessary Transportation	3.1	5
6	Unnecessary Inventory	2.7	6
7	Overproduction	2.6	7

Based on the questionnaire data presented in Table 3, seven types of waste were identified and ranked according to their impact on production efficiency. Defect (4.6) is the most critical waste, significantly affecting production flow due to product quality issues that lead to rework and increased costs. This is followed by waiting (4.4), which contributes to longer lead time and reflects delays in the production process. Unnecessary motion (3.7) and overprocessing (3.6) also have a considerable impact by increasing process time without adding value. Meanwhile, unnecessary transportation (3.1) occurs at a moderate level within the facility and has a relatively lower impact. Unnecessary inventory (2.7) and overproduction (2.6) are less dominant but still indicate inefficiencies related to work-in-process accumulation. Based on these findings, the root causes of the identified wastes will be further analyzed.

D. Value Stream Analysis Tools (VALSAT)

Value Stream Analysis Tools (VALSAT) is an approach used to evaluate waste by assigning weights and selecting the most appropriate analysis tool based on a scoring matrix [16].

The VALSAT matrix is obtained by multiplying the average score of each type of waste with its corresponding correlation value, allowing the relevance of each tool to be determined as shown in Table 4.

Table 4. Value Stream Analysis Tools

Waste Type	Score	VALSAT Tools						
		PAM	SCRM	QFF	DAM	DPA	PVF	PS
Defects	4.6	4.6	-	41.4	-	-	-	-
Waiting	4.4	39.6	39.6	-	13.2	13.2	4.4	-
Unnecessary Motion	3.7	33.3	3.7	-	-	-	-	-
Overprocessing	3.6	32.4	-	3.6	-	3.6	10.8	-
Transportation	3.1	27.9	-	-	-	-	-	3,1
Unnecessary Inventories	2.7	8.1	24.3	-	24.3	8.1	8.1	2,7
Overproduction	2.6	2.6	7.8	2.6	7.8	7.8	-	-

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Total Score	148.5	75.4	47.6	45.3	32.7	23.3	5.8
Ranking	1	2	3	4	5	6	7

Based on Table 4, Process Activity Mapping (PAM) obtained the highest score of 148.5 and was therefore selected as the primary tool for waste analysis.

E. Initial Process Activity Mapping (PAM)

Process Activity Mapping (PAM) is applied to identify waste in both physical and information flows by highlighting non-value-added activities, simplifying necessary processes, and improving process sequences to enhance overall production efficiency. The initial Process Activity Mapping of the company is shown in Table 5.

Table 5. Initial Process Activity Mapping (PAM)

Station	No.	Activity	Period (Minutes)	O	T	I	S	D	Activity Categories
Receiving	1.1	Forklift transports raw materials to production area	6.37		T				NNVA
	1.2	Document check and visual inspection of raw materials	2.05			I			NNVA
	1.3	Transport raw materials to mixing area	3.06		T				NNVA
Mixing	2.1	Waiting for mixing instructions	5.12					D	NVA
	2.2	Picking up material sacks	3.01		T				NNVA
	2.3	Load materials into high-speed mixer	2.05	O					NNVA
	2.4	Mixing process	15.04	O					VA
	2.5	Inspect mixing results	2.14			I			NNVA
	2.6	Transport mixed material to extrusion area	3.11		T				NNVA
Extrusion	3.1	Load material into hopper	2.01	O					NNVA
	3.2	Melting process in barrel	15.26	O					VA
	3.3	Extrusion and hot air blowing through die	40.14	O					VA
	3.4	Thickness and visual film inspection	1.02			I			NVA
	3.5	Transfer to forming area	1.03		T				NNVA
Film Rolling	4.1	Rolling film into rolls	12.09	O					VA
	4.2	Cutting plastic rolls	4.05	O					VA
	4.3	Inspect thickness and standards	1.41			I			NNVA
	4.4	Transport to temporary storage	2.08		T				NNVA
	4.5	Temporary storage (waiting for cutting schedule)	20.25				S		NNVA
	4.6	Transfer rolls to cutting machine	4.12		T				NNVA
Cutting & Sealing	5.1	Waiting for product size instruction	4.05					D	NVA
	5.2	Set up cutting & sealing machine	5.21	O					VA
	5.3	Retrieve hard-to-reach tools that out of range	1.40					D	NVA
	5.4	Re-inspection of roll quality	1.03			I			NVA
	5.5	Load roll into machine	2.09	O					NNVA
	5.6	Reposition roll	3.08					D	NVA
	5.7	Cutting and sealing process (bottom sealing)	1.00	O					VA
	5.8	Seal strength inspection	1.12			I			NNVA
Shaping	5.9	Transfer to shaping bag area	0.52		T				NNVA
	6.1	Handle hole punching	2.03	O					VA
	6.2	Shape and dimension inspection	1.06			I			NNVA
	6.3	Transfer rework due to defects	5.07		T				NNVA
Finishing	6.4	Transfer good products to finishing area	1.02		T				NNVA
	7.1	Folding and counting bags	0.76	O					VA
	7.2	Packaging	2.04	O					VA
	7.3	Final packaging inspection	1.03			I			NNVA
	7.4	Transport to temporary storage	2.66		T				NVA
	7.5	Temporary storage in WIP (waiting for shift to end)	29.97				S		NVA
	7.6	Transfer finished goods to warehouse	4.40		T				NNVA
TOTAL			214.94	13	12	8	2	4	

Based on Table 5, the activity data can be calculated and classified according to activity categories and activity types, as presented in Table 6.

Table 6. Percentage of Frequency and Period by Activity Type

No.	Activity Type	Frequency	Percentage	Period (Minutes)	Percentage
1.	Operation	13	33.33%	103.77	48.28%
2.	Transportation	12	30.77%	36.45	16.96%
3.	Inspection	8	20.51%	10.86	5.05%
4.	Storage	2	5.13%	50.22	23.36%
5.	Delay	4	10.26%	13.65	6.35%
Total		39	100%	214.94	100%

Based on Table 6, a total of 39 activities were identified with a total processing time of 214.94 minutes. Based on activity type, operations account for the largest proportion, with 13 activities (33.33%) and the most dominant processing time of 103.77 minutes (48.28%). Transportation ranks second with 12 activities (30.77%) and a total time of 36.45 minutes (16.96%). Inspection consists of 8 activities (20.51%) with a total time of 10.86 minutes (5.05%). Although storage only includes 2 activities (5.13%), it contributes a significant amount of time, totaling 50.22 minutes (23.36%) of the overall process time. Meanwhile, delay activities account for 4 activities (10.26%) with a total time of 13.65 minutes (6.35%). Based on these results, the next step is to classify the activities according to their activity categories, as shown in Table 7.

Table 7. Percentage of Frequency and Period by Activity Category

No.	Activity Category	Frequency	Percentage	Period (Minutes)	Percentage
1.	Value Added (VA)	10	25.64%	97.62	45.42%
2.	Necessary Non Value Added (NNVA)	21	53.85%	68.99	32.10%
3.	Non Value Added (NVA)	8	20.51%	48.34	22.48%
Total		39	100%	214.94	100%

Based on the activity classification in Table 7, Value Added (VA) activities account for 8 activities (25.64%) with a total time of 97.62 minutes (45.42%). Necessary Non-Value Added (NNVA) activities dominate in terms of frequency, with 21 activities (53.85%) and a total time of 68.99 minutes (32.10%). Meanwhile, Non-Value Added (NVA) activities consist of 8 activities (20.51%) with a total time of 48.34 minutes (22.48%) of the overall process time. The relatively high proportion of NVA time indicates the presence of significant waste within the production system, highlighting the need for further identification of its root causes.

F. Identifying Causes of Waste Using Fishbone Diagram

The Fishbone Diagram, also known as a cause-and-effect diagram, is a tool used to identify and analyze the relationship between causes and a specific problem to determine its root causes. It supports backward analysis by tracing problems from observed outcomes to their underlying factors. These causes are typically identified through brainstorming and categorized into major factors such as man, machine, method, material, measurement, and environment. The main problem is placed at the head of the diagram, while the causes are structured as branches and sub-branches to represent contributing factors in detail [17]. The following figure presents the causes and effects of each type of waste, illustrated using the 6M factors.

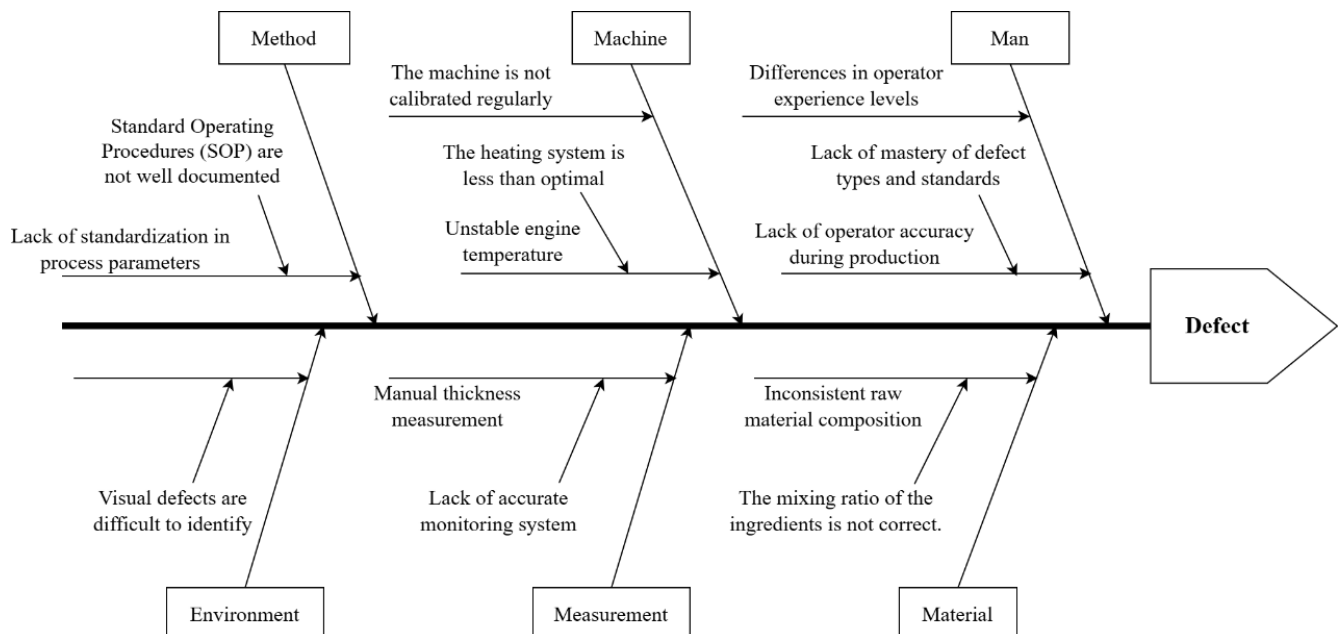


Figure 3. Fishbone Diagram Waste Defect

Inconsistent production results are influenced by operator inaccuracy and differences in experience in setting and controlling machine parameters. These conditions are supported by unstable machine performance, lack of regular

calibration, and component wear, which lead to defects during extrusion, cutting, and sealing processes. The absence of clearly defined standard parameters and inconsistent implementation of SOPs also reduce the effectiveness of quality control. Variations in raw material quality and improper mixing ratios affect production stability and waste of defect product. Next is a fishbone diagram for waste waiting is presented in Figure 4.

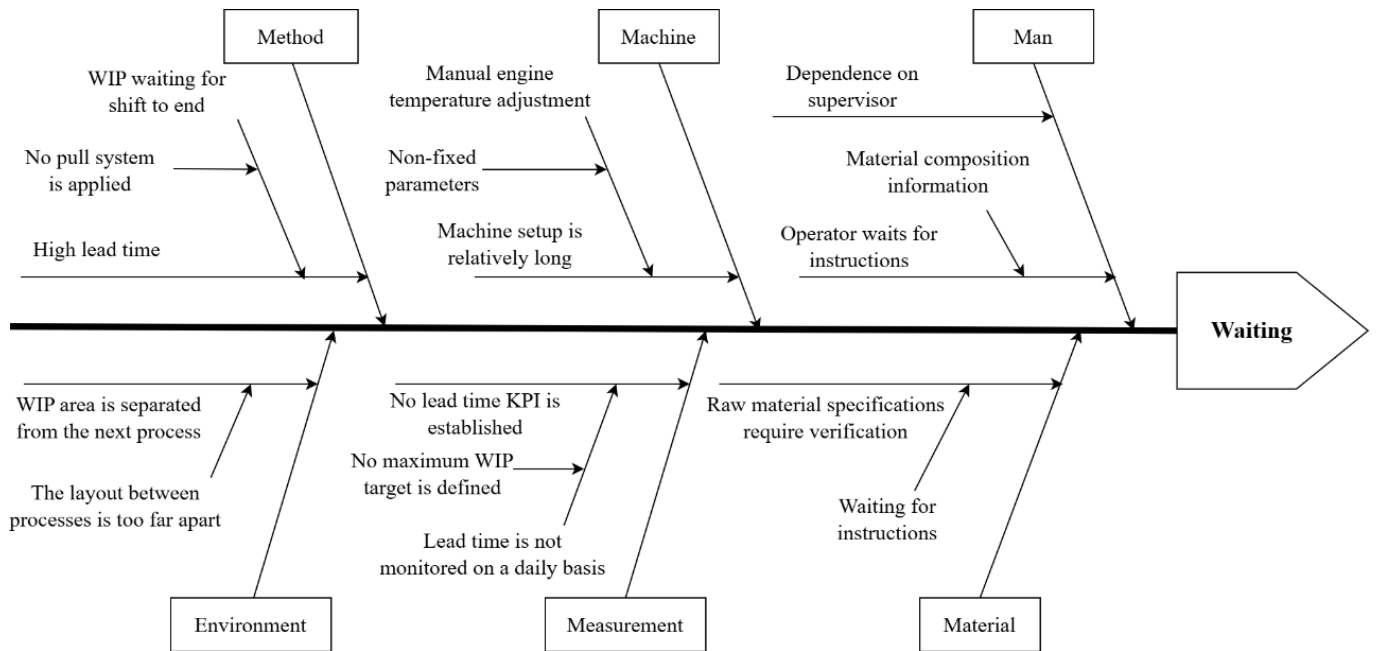


Figure 4. Fishbone Diagram Waste Waiting

The factor of waste waiting caused by operator dependence on supervisors and the need to wait for instructions or material information before continuing the process. This is reinforced by machine-related issues, including manual temperature adjustment, non-fixed parameters, and long setup times, which slow down production flow. In addition, the absence of a pull system, high lead time, and inadequate production control, such as undefined WIP limits, lack of KPIs, and no daily monitoring that leads to WIP accumulation. Layout inefficiencies, including separated WIP areas and long distances between processes, further increase waiting time, while additional verification of raw material specifications contributes to process delays. Next, the following figure presents the Fishbone Diagram for unnecessary motion waste, as shown in Figure 5.

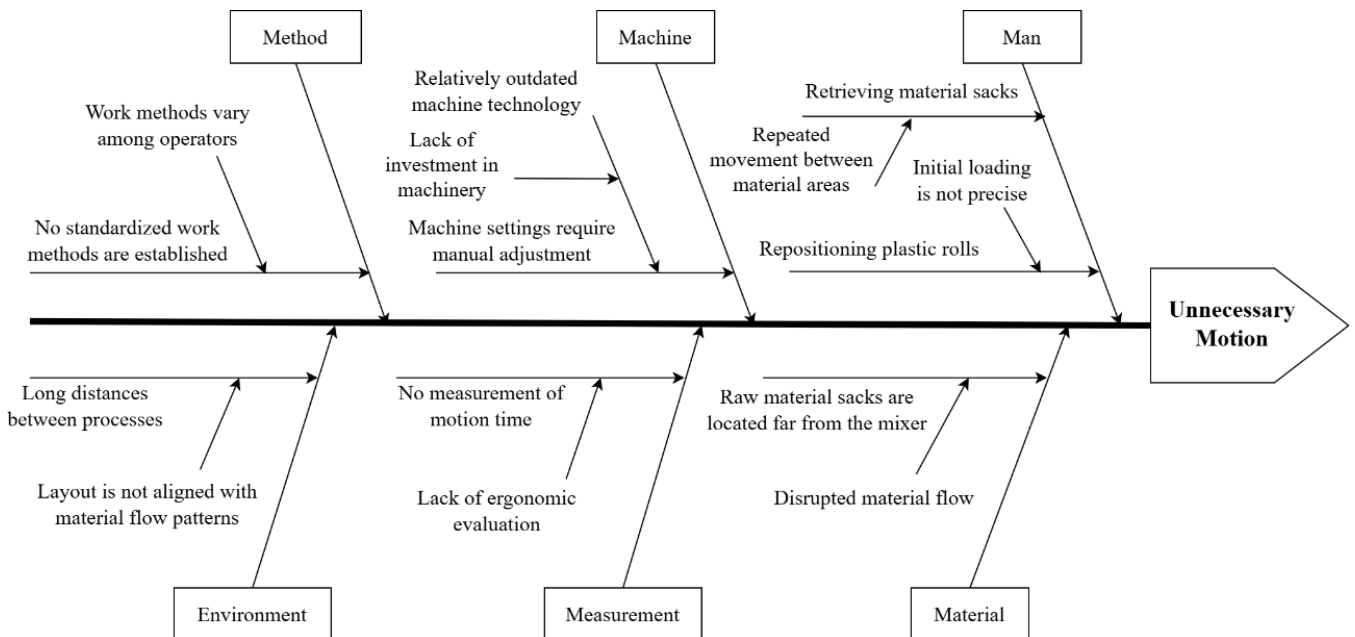


Figure 5. Fishbone Diagram Waste Unnecessary Motion

Unnecessary motion waste is caused by non-standardized work methods and variations in operator practices, leading to repetitive and inefficient movements. This is supported by outdated machines and manual adjustments that increase operator involvement. Layout inefficiencies, such as long distances and poor alignment with material flow, as well as improper material placement, further increase movement. The absence of motion measurement and ergonomic evaluation also limits efforts to reduce unnecessary motion. The fishbone diagram for waste overprocessing is presented in Figure 6.

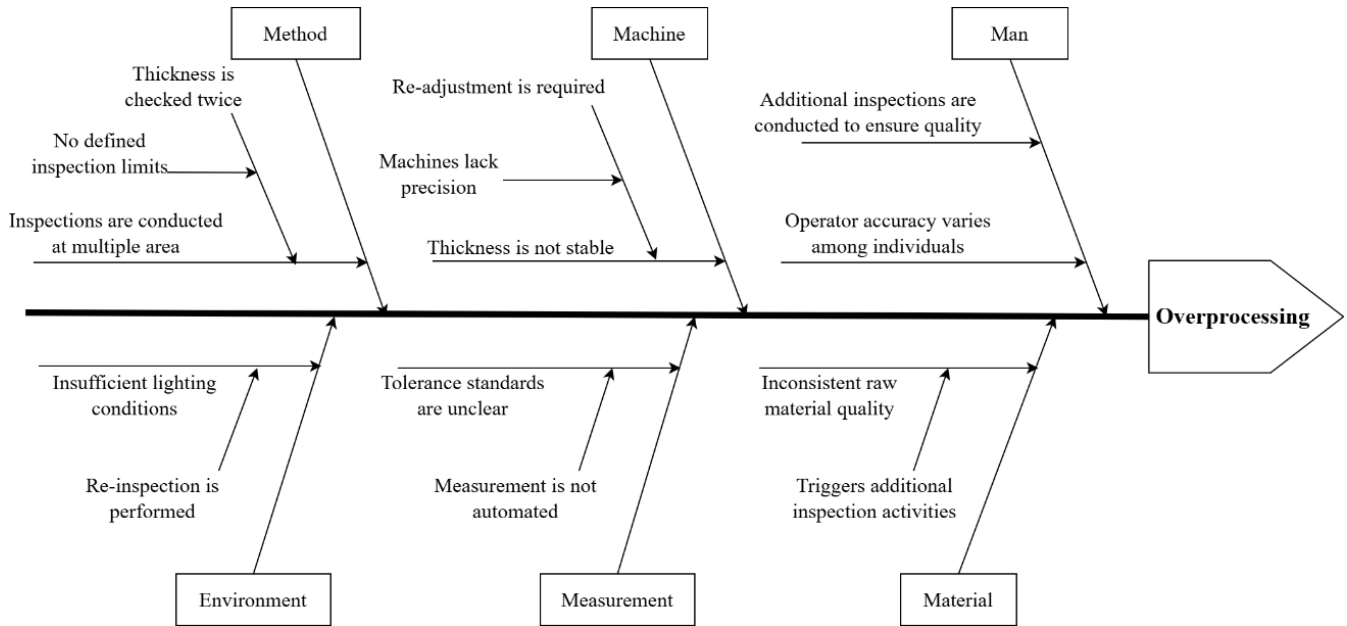


Figure 6. Fishbone Diagram Waste Overprocessing

Overprocessing waste is caused by unclear inspection standards and repeated inspection activities, such as double thickness checking and inspections conducted at multiple stages. This is supported by machine limitations, including low precision, unstable thickness, and the need for re-adjustment. Operator variability also contributes to additional inspections to ensure quality. In addition, non-automated measurement systems and unclear tolerance standards reduce efficiency, while inconsistent raw material quality further triggers unnecessary inspection processes. The following fishbone diagram for unnecessary transportation is presented in Figure 7.

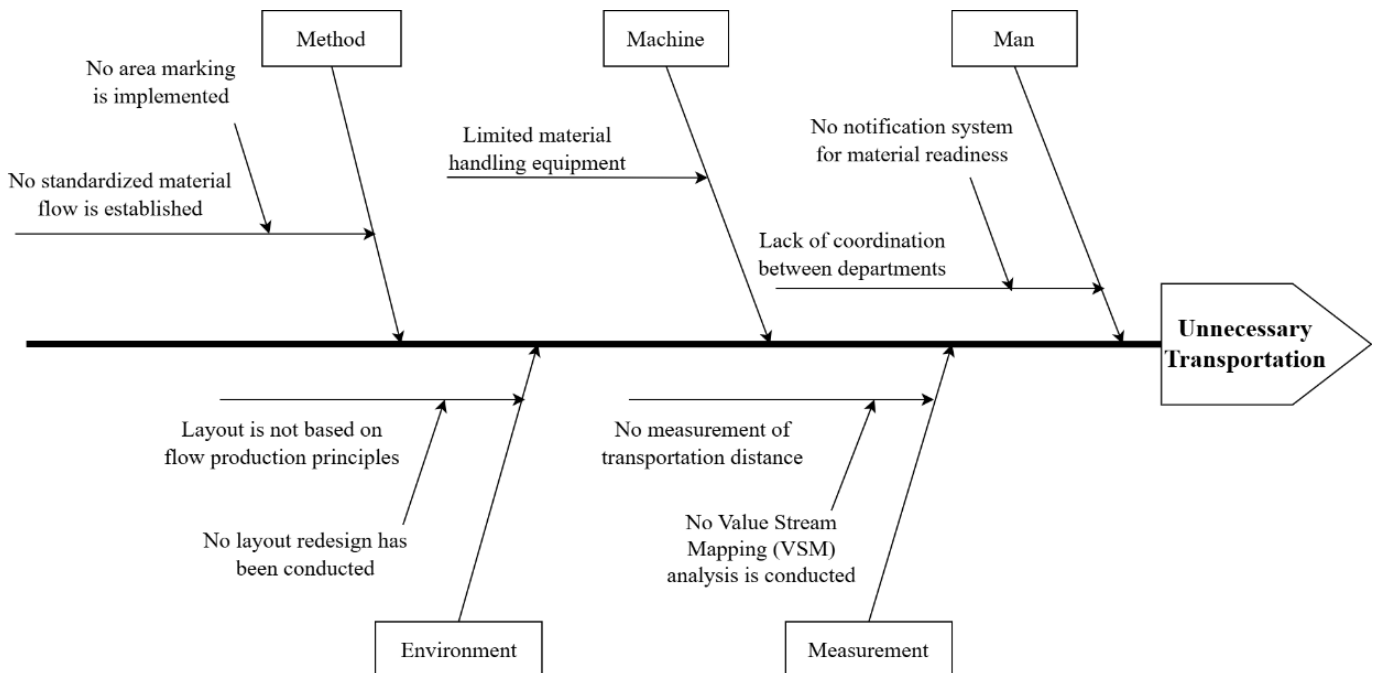


Figure 7. Fishbone Diagram Waste Unnecessary Transportation

Unnecessary transportation waste is caused by the absence of standardized material flow and area marking, leading to inefficient material movement. This is supported by limited material handling equipment and poor coordination between departments, including the lack of a material readiness notification system. Layout issues, such as arrangements not based on production flow principles and the absence of layout redesign, further increase transportation distance. In addition, the lack of transportation distance measurement and the absence of VSM analysis limit efforts to identify and reduce unnecessary transport. The following fishbone diagram for unnecessary inventory is presented in Figure 8.

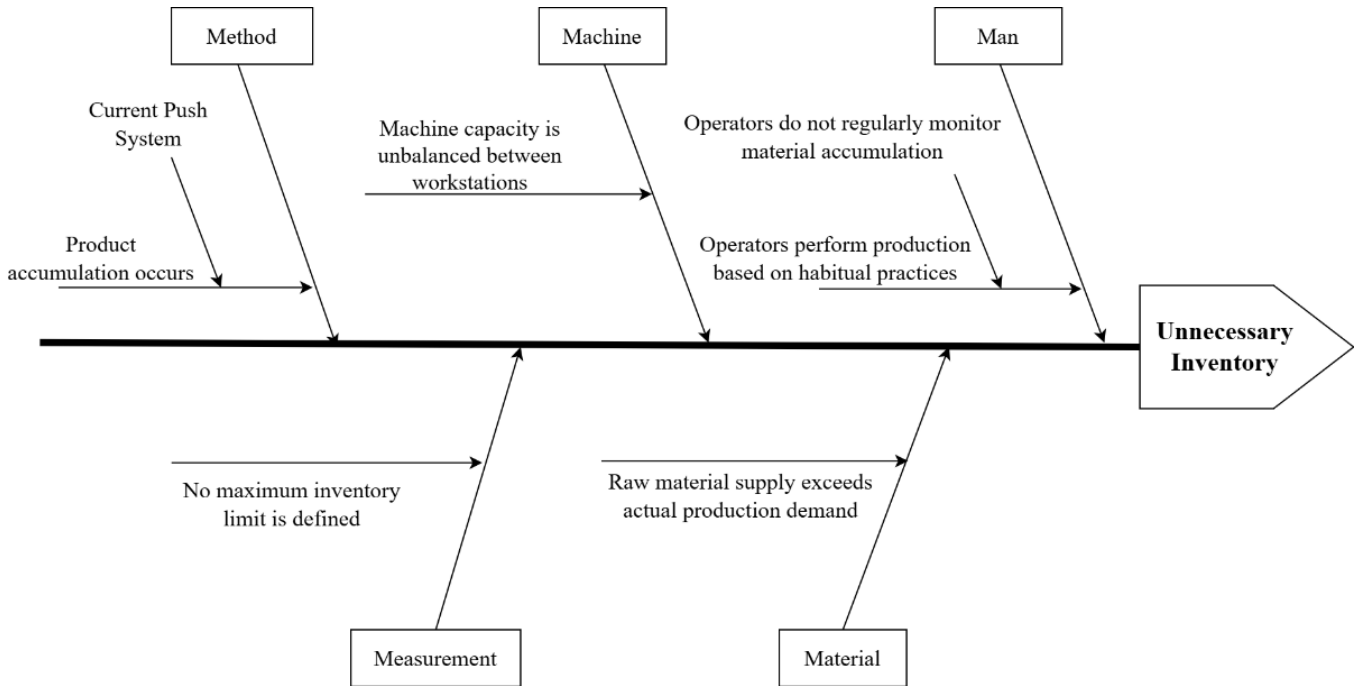


Figure 8. Fishbone Diagram Waste Unnecessary Inventory

Unnecessary inventory waste is caused by the use of a push system, leading to product accumulation between processes. This is reinforced by unbalanced machine capacity across workstations and operators who do not consistently monitor inventory levels, resulting in overproduction based on habitual practices. The absence of defined inventory limits further weakens control, while raw material supply exceeding actual production demand contributes to excess inventory. Next fishbone diagram of waste overproduction is presented in Figure 9.

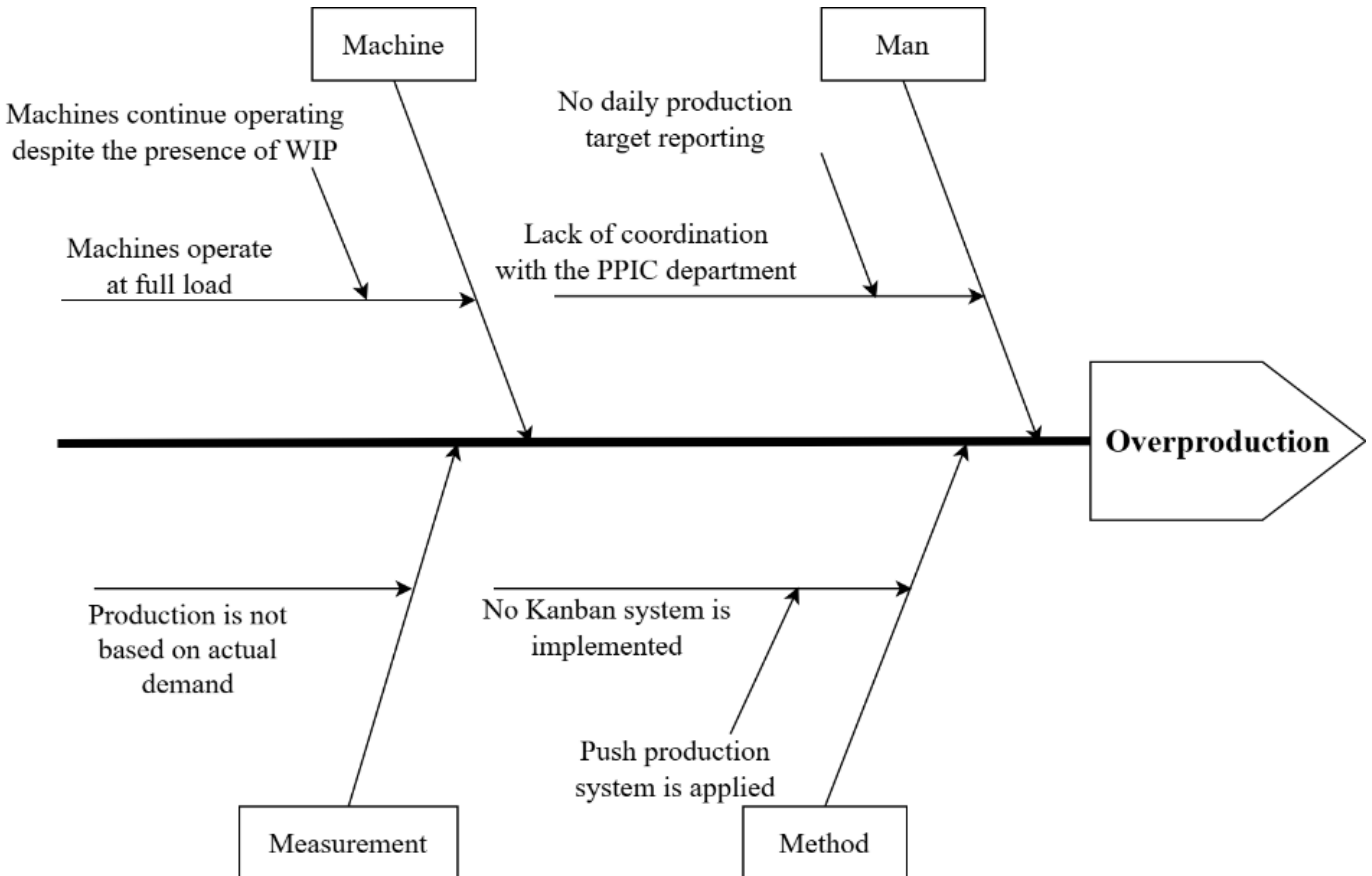


Figure 9. Fishbone Diagram Waste Overproduction

Overproduction waste is primarily driven by the absence of clear customer demand data, causing production to proceed without accurate demand reference. This condition is reinforced by poor coordination between production and PPIC and the lack of daily target reporting, leading to output that exceeds actual needs. In addition, machines continue to operate at full load despite WIP accumulation, while the use of a push production system without Kanban control further exacerbates overproduction.

Overall, the root cause analysis based on the Fishbone Diagram (6M) reveals that process inefficiencies are driven by interconnected factors across method, machine, human, material, measurement, and environmental dimensions.

1. Method-related issues indicate the absence of well-documented SOPs, lack of standardized work methods, and production planning that is not based on actual demand, resulting in inconsistent processes and inefficiencies.
2. Machine-related factors show unstable machine settings, lack of regular calibration and preventive maintenance, and dependence on manual adjustments, which affect process stability and product quality.
3. Human operator factors reveal gaps in operational discipline and capability, including limited operator skills, low accuracy, and ineffective coordination. These issues amplify variability in execution, increase the likelihood of defects, delays, and inconsistent performance.
4. Material-related issues involve inconsistent raw material quality, excess inventory (raw materials, WIP, and finished goods), and frequent material movement, leading to inefficiencies and rework.
5. Measurement system weaknesses reflect the lack of a robust performance control framework, evidenced by lack of standardized measurement systems, absence of key performance indicators, such as lead time KPI, and reliance on manual monitoring. This limits the ability to detect early waste real-time decision making.
6. Environmental or mother nature constraints reflect inefficient layout, poor workplace organization, and inadequate inspection conditions. These factors increase unnecessary motion and transportation while prolonging process time and reducing overall operational effectiveness.

G. Failure Mode and Effect Analysis (FMEA)

After identifying root causes using the Fishbone Diagram, the next step is to apply Failure Mode and Effects Analysis (FMEA). FMEA is a systematic method used to identify potential failures, analyze their effects, determine root causes, and evaluate existing controls to prioritize improvement actions. The assessment of severity, occurrence, and detection parameters is based on interviews and questionnaires involving field supervisors, the Quality Control team, and the Human Resource Department of PT XYZ. The following table summarizes the calculated Risk Priority Number (RPN), shown in Table 8.

Table 8. Failure Mode and Effect Analysis (FMEA)

Potential Failure Mode (Waste)	Potential Effect of Failure	Potential Cause	Current Controls	S	O	D	RPN	Level	Rank
Defect	Reduces product quality, increases rework, and may lead to customer complaints	1. SOP not well documented	<ul style="list-style-type: none"> • Visual inspection and thickness checking by operators • Defective products are separated and reworked • Standard weight tolerance used for inspection 	7	9	7	441	Very High	1
		2. Unstable machine settings							
		3. Operator inaccuracy during production process							
		4. Inconsistent raw material composition							
Waiting	Production process delays increase lead time and reduce machine and labor utilization.	1. Semi-finished products wait to be processed at the next station.	<ul style="list-style-type: none"> • Verbal coordination between operators and supervisors • Manual production scheduling adjustments 	6	8	7	336	Very High	2
		2. Delay in sending work instructions.							
		3. There is no lead time Key Performance Indicator.							
		4. Imbalance of processing time between							

Potential Failure Mode (Waste)	Potential Effect of Failure	Potential Cause	Current Controls	S	O	D	RPN	Level	Rank
		workstations.							
Unnecessary Motion	Increases processing time, reduces productivity, and raises risk of fatigue and injury	1. Placement of tools and materials that are difficult to reach (not ergonomic)	<ul style="list-style-type: none"> Operators adjust work position and tools manually, according to each individual's behaviour 	5	7	7	245	Very High	3
		2. There is no standard working method.							
		3. The need for manual adjustment.							
Overprocessing	Increases process time and energy consumption, reducing efficiency on repeated process that can be reduced	1. Additional activities such as re-inspections or repairs that could have been prevented.	<ul style="list-style-type: none"> Re-inspection before next process even occurs Manual machine parameter adjustment after findings 	4	7	8	224	Very High	4
		2. Previously undetected process error.							
		3. The operator doubted the quality of the results of the process.							
Unnecessary Transportation	Increases processing time and risk of material damage without adding value	1. The repeated movement of materials between processes and work locations.	<ul style="list-style-type: none"> Moving materials using forklifts or simple transport equipment. The shift path setting is done manually without fixed flow standards. 	5	5	6	150	High	5
		2. The distance of movement is too far due to the layout of the facilities.							
		3. There is no well-planned standard material flow.							
Unnecessary Inventory	Accumulation of raw material or work in process (WIP) and increases storage needs along with damage risk	1. Excess raw materials, work in process, or finished products that are not needed.	<ul style="list-style-type: none"> Storage of materials, WIP, and finished products is done in the area around the machine. Stock calculations are still done manually. 	4	5	5	100	Medium	6
		2. Production does not match actual needs and uses a push system.							
		3. Lack of periodic evaluation of inventory levels.							
Overproduction	Leads to excess finished goods, inefficient storage, and higher holding cost	1. Production is carried out in excess of actual needs due to the lack of clear demand.	<ul style="list-style-type: none"> Production based on schedule and needs estimation Excess products are stored in work in process area and deliveries are adjusted manually. 	3	5	6	90	Medium	7
		2. Production planning is not based on customer demand.							
		3. Lack of synchronizatio							

Potential Failure Mode (Waste)	Potential Effect of Failure	Potential Cause	Current Controls	S	O	D	RPN	Level	Rank
		n between production and distribution.							

H. Proposed Improvements

The evaluation results of the production process indicate the presence of significant waste, requiring improvement proposals to minimize process failure risks, reduce waste levels, and enhance efficiency. Based on the FMEA analysis, wastes categorized as very high risk include defects, waiting, unnecessary motion, and overprocessing, which are therefore prioritized in the following improvement proposals. Proposed improvements are shown in Table 9.

Table 9. Improvement Proposal with FMEA

Waste	Subwaste	RPN	Proposed Improvement
Defects	Defective products reduce product quality, increase rework activity, and have the potential to cause customer complaints.	441	<ol style="list-style-type: none"> 1. Standardization of process and inspection parameters. 2. Perform preventive maintenance calibration of the machine. 3. Providing operator competency training. 4. Implementation of real-time monitoring.
Waiting	The production process is temporarily halted so that lead times increase, machine and labor utilization is not optimal, and daily production targets have the potential to not be achieved.	336	<ol style="list-style-type: none"> 1. Application of the pull system principle. 2. Determining KPI Lead Time. 3. Analysis of time balance between work stations.
Unnecessary Motion	Process times increase, productivity decreases, and the risk of operator fatigue and injury increases.	245	<ol style="list-style-type: none"> 1. Improvement of work layout and ergonomics. 2. Standardization of work methods and implementation of 5S. 3. Reduction of manual machine adjustments.
Overprocessing	Process time and energy consumption increase due to repetitive work or unnecessary processes, thus decreasing production efficiency.	224	<ol style="list-style-type: none"> 1. Ensure quality before continuing process. 2. Standardization of the inspection process. 3. Increased accuracy of machines and measuring instruments. 4. Improvement of work environment lighting.

The proposed improvements focus on process standardization, quality control, and operational efficiency to reduce critical wastes. Defects are minimized through SOP implementation, machine calibration, preventive maintenance, and operator training, while waiting is reduced through capacity-based scheduling and pull systems. Unnecessary motion is addressed through layout improvement and 5S, and overprocessing is reduced by strengthening early-stage quality control. Overall, these actions aim to streamline production flow and improve efficiency.

I. Simplification of Process Activity Mapping (PAM) After Improvements

Based on the Process Activity Mapping (PAM) analysis, several activities are identified as non value added (NVA) and necessary non value added (NNVA) within the production process flow. These activities contribute to increased lead time and low Process Cycle Efficiency (PCE). Therefore, process simplification is carried out by reducing or eliminating non-value-added activities without disrupting the overall production flow.

The proposed improvements and the rationale for activity elimination are presented in Table 10 and Table 11.

Table 10. Simplification of NVA Activities in PAM After Improvement

No. Activity	Activity Details	Period/Time Adjustment	Category	Proposed Improvement	Adjustment Basis
2.1	Waiting for mixing instructions	5.12 minutes to 0 minutes	NVA	Establish SOP for material composition parameters in writing and before starting the shift, so that operators can immediately carry out the process without waiting for instructions.	By implementing written SOPs for material composition, the need to wait for instructions from superiors can be eliminated so that the process can run smoothly.
3.4	Thickness and visual film inspection	1.02 minutes to 0 minutes	NVA	Integrate inspection activities to the next station and eliminate duplicate inspections by aligning quality standards between processes.	Since the inspection has been integrated and performed at the next station, this additional inspection activity is no longer necessary.
5.1	Waiting for product size instruction	4.05 minutes to 0 minutes	NVA	Enforce standardization of product size	By standardizing the size parameters and work

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No. Activity	Activity Details	Period/Time Adjustment	Category	Proposed Improvement	Adjustment Basis
				parameters and the use of integrated work instruction forms in the production area.	instruction forms, operators no longer need to wait for instructions so delay time can be eliminated.
5-3	Retrieve hard-to-reach tools that out of range	1.4 minutes to 0 minutes	NVA	Rearranging the work area using the 5S principle and placing equipment at points of use according to ergonomics.	By rearranging the work area and implementing 5S, inefficient searching and picking activities can be eliminated.
5-4	Re-inspection of roll quality	1.03 minutes to 0 minutes	NVA	Align quality control systems between processes so that inspections are only performed once after a material change with clear standards.	Because quality checks have been carried out in the previous process with clear standards, re-checks are no longer necessary.
5-6	Reposition roll	3.08 minutes to 0 minutes	NVA	Improve the accuracy of initial machine settings and standardize work methods to ensure material positioning is correct from the start of the process.	With increased accuracy of machine settings and standardization of work methods, the roll position is correct from the start so that repositioning is not necessary.
7-4	Transport to temporary storage	2.66 minutes to 0 minutes	NVA	Changing the material flow with a direct flow system to the finished product warehouse without going through temporary storage.	With the change in material flow directly to the warehouse, transportation activities to temporary storage become unnecessary.
7-5	Temporary storage in WIP (waiting for shift end).	29.97 minutes to 0 minutes	NVA	Perform a pull system and direct delivery to the warehouse so that there is no accumulation of WIP.	By performing a pull system and direct delivery to the warehouse, the existence of WIP can be avoided so that temporary storage activities can be eliminated.

Based on Table 10, Non-Value Added (NVA) activities in the production process are identified as activities to be eliminated through the proposed improvements. Meanwhile, Necessary Non-Value Added (NNVA) activities are retained but their processing time is reduced through improvement proposals, as presented in Table 11.

Table 11. Simplification of NNVA Activities in PAM After Improvement

No. Activity	Activity Details	Period/Time Adjustment	Category	Proposed Improvement	Adjustment Basis
2.2	Retrieve material sacks	3.01 minutes to 1.5 minutes	NNVA	Rearrange the storage location of raw material sacks in the production area to minimize the frequency of operator movement	Reduction of inefficient movements through improved layout and provision of raw materials at the point of use.
4.5	Temporary storage (waiting for cutting schedule)	20.25 minutes to 8.86 minutes	NNVA	Perform a pull system and line balance to reduce storage time in WIP and smoother material flow.	Reduction of waiting time due to WIP buildup through the implementation of a pull system and line balancing (estimated reduction of 11.39 minutes)
6.3	Transfer rework due to defects	5.07 minutes to 2.51 minutes	NNVA	Reducing defect rates through parameter standardization and operator training. As defects decrease, the need for rework automatically decreases.	Reduction in rework activity due to reduced defects and overprocessing, so that the frequency of additional movements becomes less and activity time can be reduced significantly (estimated reduction to 2.51 minutes).

After simulating the proposed improvements, a simplified Process Activity Mapping (PAM) is obtained, as shown in Table 12.

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Table 12. Process Activity Mapping (PAM) After Proposed Improvements

Station	No.	Activity	Period (Minutes)	O	T	I	S	D	Activity Categories
Receiving	1.1	Forklift transports raw materials to production area	6.37		T				NNVA
	1.2	Document check and visual inspection of raw materials	2.05			I			NNVA
	1.3	Transport raw materials to mixing area	3.06		T				NNVA
Mixing	2.1	Picking up material sacks	1.50		T				NNVA
	2.2	Load materials into high-speed mixer	2.05	O					NNVA
	2.3	Mixing process	15.04	O					VA
	2.4	Inspect mixing results	2.14			I			NNVA
	2.5	Transport mixed material to extrusion area	3.11		T				NNVA
Extrusion	3.1	Load material into hopper	2.01	O					NNVA
	3.2	Melting process in barrel	15.26	O					VA
	3.3	Extrusion and hot air blowing through die	40.14	O					VA
	3.4	Transfer to forming area	1.03		T				NNVA
Film Rolling	4.1	Rolling film into rolls	12.09	O					VA
	4.2	Cutting plastic rolls	4.05	O					VA
	4.3	Inspect thickness and standards	1.41			I			NNVA
	4.4	Transport to temporary storage	2.08		T				NNVA
	4.5	Temporary storage (waiting for cutting schedule)	8.86				S		NNVA
	4.6	Transfer rolls to cutting machine	4.12		T				NNVA
Cutting & Sealing	5.1	Set up cutting & sealing machine	5.21	O					VA
	5.2	Load roll into machine	2.09	O					NNVA
	5.3	Cutting and sealing process (bottom sealing)	1.00	O					VA
	5.4	Seal strength inspection	1.12			I			NNVA
	5.5	Transfer to shaping bag area	0.52		T				NNVA
Shaping	6.1	Handle hole punching	2.03	O					VA
	6.2	Shape and dimension inspection	1.06			I			NNVA
	6.3	Transfer rework due to defects	2.51		T				NNVA
	6.4	Transfer good products to finishing area	1.02		T				NNVA
Finishing	7.1	Folding and counting bags	0.76	O					VA
	7.2	Packaging	2.04	O					VA
	7.3	Final packaging inspection	1.03			I			NNVA
	7.4	Transfer finished goods to warehouse	4.40		T				NNVA
TOTAL			151.14	13	11	6	1	0	-

After developing the updated Process Activity Mapping (PAM) based on the proposed improvements, the activities can be classified according to their types and categories. The results after the proposed improvements are presented in the following Table 13 and 14.

Table 13. Percentage of Frequency and Period by Proposed Activity Type

No.	Activity Type	Frequency	Percentage	Period (Minutes)	Percentage
1.	Operation	13	41.94%	103.77	68.66%
2.	Transportation	11	35.48%	29.71	19.66%
3.	Inspection	6	19.35%	8.80	5.82%
4.	Storage	1	3.2%	8.86	5.86%
5.	Delay	0	0.0%	0.00	0.00%
Total		31	100%	151.14	100%

The improvement results show that the total production lead time decreases to 151.14 minutes. Based on activity type classification, operations account for 13 activities (41.94%) with a total time of 103.77 minutes (68.66%) of the total process time. Transportation consists of 11 activities (35.48%) with a total time of 29.71 minutes (19.66%), while inspection includes 6 activities (19.35%) with a total time of 8.80 minutes (5.82%). Storage is reduced to 1 activity (3.2%) with a total time of 8.86 minutes (5.86%), and delay activities are estimated to be fully eliminated from the production process. The following

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table shows result after proposed improvement by activity category.

Table 14. Percentage of Frequency and Period by Proposed Activity Category

No.	Activity Category	Frequency	Percentage	Period (Minutes)	Percentage
1.	Value Added (VA)	10	32.26%	97.62	64.59%
2.	Necessary Non Value Added (NNVA)	21	67.74%	53.52	35.41%
3.	Non Value Added (NVA)	0	0.0%	0.00	0.00%
Total		31	100%	151.14	100%

From the activity category perspective, Value Added (VA) activities increase to 10 activities (32.26%) with a total time of 97.62 minutes (64.59%). Necessary Non Value Added (NNVA) activities account for 21 activities (67.74%) with a total time of 53.52 minutes (35.41%). Meanwhile, Non-Value Added (NVA) activities are estimated to be completely eliminated and no longer contribute to the production process time.

J. Future Value Stream Mapping (VSM)

The Future Value Stream Mapping (Future VSM) is developed after simplification of PAM and indicates a significant decrease in total production lead time, driven by improvement initiatives aimed at reducing non value added activities and streamlining the process flow, as shown in Figure 10.

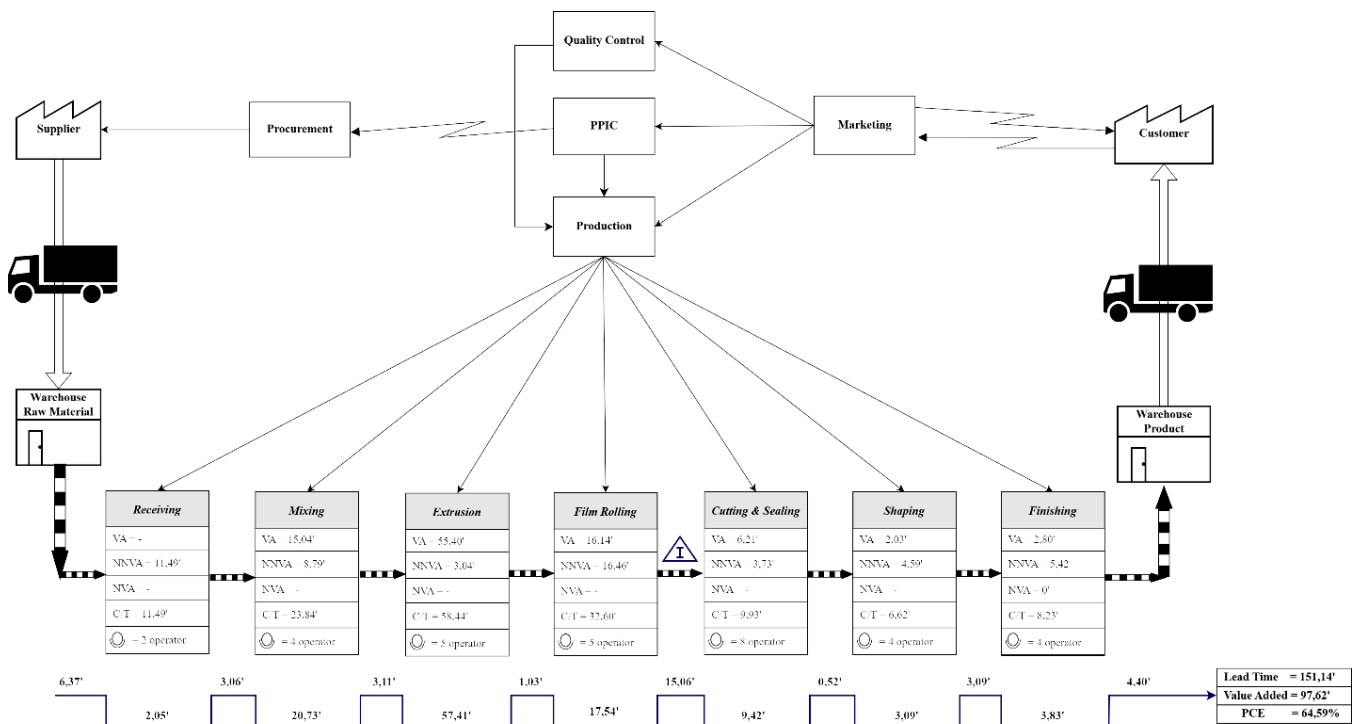


Figure 10. Future Value Stream Mapping

Based on future state value stream mapping, the total lead time is reduced to 151.14 minutes, with processing times distributed across stations as follows: Receiving (11.49 minutes), Mixing (23.84 minutes), Extrusion (58.44 minutes), Film Rolling (32.60 minutes), Cutting & Sealing (9.93 minutes), Shaping (6.62 minutes), and Finishing (8.23 minutes). This reduction indicates a more streamlined and efficient production flow.

Furthermore, the improvement is reflected in the Process Cycle Efficiency (PCE), which increases from 45.42% in the current state to 64.59% in the future state. This indicates that a greater proportion of time is allocated to value-added activities compared to non-value added activities. The elimination of non-value added (NVA) activities, particularly those related to storage and delays, along with the simplification of supporting activities, significantly contributes to the reduction in lead time and overall process performance improvement. Therefore, the proposed improvements in the Future Value Stream Mapping are considered effective in enhancing production efficiency and supporting productivity improvement at PT XYZ.

The result findings aligns with Lean Manufacturing principles that emphasize the waste elimination and flow efficiency, where reducing time and non value added activities supports smoother production flow. The observed reduction in lead time is consistent with previous studies showing that Lean-based improvements, through stream mapping and waste elimination, can significantly improve production efficiency [8]. However, compared to previous studies, this research provides more comprehensive evaluation by not only reducing lead time but also improving process cycle efficiency through integration of multiple analytical tools.

Conclusion

This study identifies seven types of waste in the production process of High-Density Polyethylene (HDPE) plastic bags with size 15 × 30 cm at PT XYZ, contributing to increased lead time and reduced efficiency. Root cause analysis using the Fishbone Diagram and FMEA indicates that the most critical wastes are defects and waiting followed by unnecessary motion and overprocessing. The proposed Lean Manufacturing improvements are expected to enhance performance by reducing activities from 39 to 31 and decreasing lead time from 214.94 to 151.14 minutes. Non value added (NVA) activities are projected to be eliminated from 9 activities (48.34 minutes) to zero, while necessary non-value-added (NNVA) time is estimated reduce by 15.67 minutes. The proportion of value added (VA) activities is expected to increase with process cycle efficiency (PCE) is projected to improve from 45.42% to 64.59%, indicating a more efficient and value-focused production system. These findings suggest that the integration of Lean Manufacturing and FMEA has strong potential to improve operational performance. It is recommended that PT XYZ prioritize high-risk wastes through standardized quality control, machine stability improvement, operator capability enhancement, and the implementation of pull systems and line balancing to achieve sustainable process efficiency. Future studies may further validate these results through direct implementation and may integrate Lean Manufacturing with approaches such as Six Sigma or ergonomic analysis, as well as expand the scope to other production lines or supply chain systems for a more comprehensive improvement strategy.

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