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Waste Analysis in the Packaging Process Using a Lean Manufacturing Approach for Improving Production Performance

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ABSTRACT

This study aims to identify and reduce waste in the Aluvo product packaging process at PT XYZ using Value Stream Mapping (VSM) and Waste Assessment Model (WAM). Data were collected through direct observation and internal company documents over the period September 2025 to February 2026. Waste identification was carried out using a Waste Assessment Questionnaire (WAQ) distributed to five respondents directly involved in the packaging line, and further prioritized through Waste Relation Matrix (WRM) analysis. The results indicate that the dominant wastes are defect (WMV = 4.701) and overprocessing (WMV = 4.650). The current state Process Cycle Efficiency (PCE) was 54.1% with a total lead time of 170 seconds. Following the implementation of improvement proposals including preventive maintenance scheduling, standard operating procedure (SOP) revision, operator training, and layout improvement the future state PCE increased to 83.3% with lead time reduced to 84 seconds. Key Performance Indicators also improved: average defect rate decreased from 12.7% to 10.2%, machine availability increased from 87.11% to 90.33%, and productivity increased from 3,611 pcs/hr to 3,972 pcs/hr.

INTRODUCTION

The food processing industry operates in an intensely competitive environment where operational efficiency and consistent product quality are non-negotiable requirements. Within this sector, every stage of production must be carefully managed to minimize waste, control costs, and fulfill market demand on time. Packaging, as the final stage of production, plays a strategically pivotal role: it not only physically protects the product but also maintains quality, safety, and consumer appeal throughout the distribution chain [1]. Any disruption in the packaging process directly impacts overall production flow and operational performance.

Despite its importance, the packaging process in many food manufacturing companies continues to suffer from inefficiencies that reduce productivity and increase waste. Lean Manufacturing has been widely recognized as a systematic approach for identifying and eliminating non-value-added activities across manufacturing systems [2]By focusing on value stream analysis and waste reduction, Lean principles enable organizations to achieve higher throughput, lower defect rates, and more stable production processes.

This study was conducted at PT XYZ, a food processing company producing biscuit products, where preliminary observations revealed significant operational challenges in

the packaging line. Data collected over a six-month period (September 2025 – February 2026) showed notable discrepancies between production targets and actual output, elevated machine downtime, and persistently high defect rates. For instance, weekly production output fluctuated considerably, with certain weeks recording output as low as 89,634 pcs against a target of 172,802 pcs a shortfall of nearly 48%. Machine downtime peaked at 842 minutes in a single week, severely limiting effective production time.

Defects were classified into three types based on their nature: metal detector rejects (associated with *waiting waste*), repack aluvo (associated with *overprocessing waste*), and empty aluvo (associated with *motion waste*). Weekly defect counts for metal detector ranged from 197 to 645 units, while repack aluvo defects reached up to 18,722 units per week indicating a systemic problem that demanded structured analysis.

Several previous studies have demonstrated the effectiveness of Lean Manufacturing in similar industrial contexts. [3] Applied VSM and RCA in the footwear manufacturing sector and successfully identified non-value-added activities that prolonged lead time. [4] Utilized WAM and VALSAT in packaged tea production, revealing dominant waste types that guided targeted improvement strategies. [5] Combined VSM and WAM at PT XYZ in a different production context, effectively ranking and addressing waste priorities. More recently, [6] Showed that integrating VSM, Process Activity Mapping (PAM), and 5 Whys in the same organizational setting reduced cycle time by over 17% and achieved full compliance with production targets.

Building on this body of knowledge, the present study integrates three complementary tools: VSM to map current-state production flows, WAM to quantify and rank waste types, and RCA to uncover root causes. The objective is twofold: (1) to identify the most dominant waste in the PT XYZ biscuit packaging process, and (2) to formulate actionable improvement recommendations that enhance KPI performance on the packaging line.

MATERIALS AND METHODS

This research employs a descriptive-quantitative approach grounded in the Lean Manufacturing framework. The study was conducted at the biscuit packaging line of PT XYZ, located in Driyorejo, Gresik, East Java, Indonesia, over the period January 2026 to June 2026. The packaging line consists of four machines (Machine 99, 98, 97, and 47) operating in a single shift.

1. Research Framework

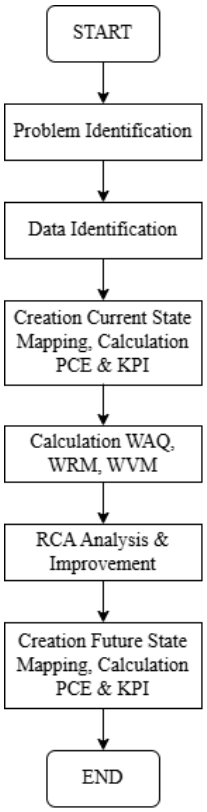


Figure 1 Research Flowchart

The research was structured as a sequential, multi-stage process as illustrated in the research flowchart (Figure 1). The stages proceeded from problem identification through data collection, data processing, root cause analysis, and finally the formulation of improvement proposals and future-state mapping.

2. Problem Identification

The initial stage involved direct observation of the packaging line and review of historical production data including weekly output, machine downtime, and defect records. Through this process, a gap was identified between actual performance and company targets, establishing the basis for the research problem statement. The key research questions addressed were: (1) What is the most dominant waste type in the packaging process based on VSM and WAM analysis? and (2) How can proposed improvements derived from VSM and WAM analysis enhance KPI performance on the packaging line?

3. Literature Study

A comprehensive literature review was conducted to establish the theoretical foundation for the study. Sources included peer-reviewed journals, textbooks, and prior theses pertaining to Lean Manufacturing, Value Stream Mapping, Waste Assessment Model, Root Cause Analysis, Fishbone Diagram, and 5 Whys methodology. This review ensured scientific rigor in method selection and analytical interpretation.

4. Field Study and Data Collection

Field observations were carried out to collect primary data directly from the production environment. Activities included process observation, structured interviews with operators and supervisors, and retrieval of company historical records. The following data types were gathered:

a) *Cycle time* measured for each workstation in the packaging process.
b) *Weekly production output* actual vs. target output over 24 weeks.
c) *Machine downtime* recorded weekly against planned operating time of 2,640 minutes per week.
d) *Defect data* categorized into three types: metal detector rejects, repack aluvo, and empty aluvo.

Data collection covered the period September 2025 to February 2026, spanning 24 observation weeks across four machines.

5. Data Processing Procedures

Data processing followed a structured sequence of analytical steps:

Step 1 Current State Value Stream Mapping (VSM).

The current state of the packaging process was mapped using VSM symbols to capture all material and information flows. Each process station was documented with its cycle time, wait time, and classification as value-added (VA), non-value-added (NVA), or necessary non-value-added (NNVA) activities[1]. The resulting current-state map served as the baseline for waste identification.

Step 2 Waste Assessment Model (WAM).

The WAM framework was applied to quantify and rank the seven types of waste. The process comprised three sub-steps[7]:

a) Waste Assessment Questionnaire (WAQ): WAQ scores were derived by normalizing WRM weights across human, machine, and material factor categories. Each waste type received a weighted score reflecting its relative contribution to inefficiency.
b) Waste Relationship Matrix (WRM): A matrix was constructed to analyze inter-waste relationships. Respondents (operators and supervisors) completed a structured questionnaire evaluating how each waste type influences others, using a scoring scale of 0, 0.5, or 1. Responses were converted and aggregated to produce the WRM.
c) Waste Matrix Value (WMV): The Waste Matrix Value (WMV) is determined by combining the waste score obtained from the Waste Assessment Questionnaire (WAQ) and the waste weighting factor derived from the Waste Relationship Matrix (WRM), following the Waste Assessment Model (WAM) proposed by Rawabdeh [8] :

$$WMV = (WAQ\ score) \times (WRM\ factor)$$

Yielding a numerical ranking of waste severity. The waste type with the highest WMV was identified as dominant.

Step 3 Root Cause Analysis (RCA).

Dominant waste types identified by WAM were subjected to RCA using two complementary tools [9]:

a) *Fishbone Diagram:* Cause-and-effect diagrams were constructed for each dominant waste type, categorizing potential causes under six dimensions: Man, Machine, Method, Material, Measurement, and Environment. This visual tool enabled the research team to systematically map all contributing factors[10].
b) *5 Whys Analysis:* Following fishbone analysis, the 5 Whys technique was applied to drill down from surface-level symptoms to root causes. For each dominant waste, a chain of 'why' questions was posed iteratively until the fundamental cause where intervention would be most impactful was reached. Results were documented in tabular form for traceability[11].

Step 4 Improvement Proposals and Future State VSM.

Based on RCA findings, improvement recommendations were formulated targeting the dominant waste types (defect, waiting, overprocessing, and motion). The primary intervention was a revision of the Work Instructions (WI) for the packaging line, incorporating sealing quality standards, a machine parameter checklist, reject-product handling procedures, and a scheduled periodic inspection protocol. The proposed future state was then mapped using VSM to quantify expected improvements, and Process Cycle Efficiency (PCE). According to Rother and Shook [12], Process Cycle Efficiency (PCE) is calculated by dividing the value-added time by the total production lead time, as shown in Equation:

$$PCE = (Value\text{-}Added\ Time / Total\ Lead\ Time) \times 100\%$$

In addition, operational performance was assessed through three Key Performance Indicators (KPIs), namely Defect Rate, Machine Availability, and Production Productivity. These indicators were selected to measure quality performance, equipment utilization, and production efficiency, respectively [13], [14]. Comparisons between the current-state and future-state conditions, including non-value-added time, lead time, PCE, Defect Rate, Machine Availability, and Production Productivity, were conducted to evaluate the effectiveness of the proposed improvements and their impact on the overall packaging process performance. Comparisons between current-state and future-state indicators including non-value-added time, lead time, and PCE were used to evaluate the effectiveness of the proposed improvements.

6. Research Scope and Assumptions

The study was bounded to the biscuit packaging process at PT XYZ, covering one production shift. Analysis was limited to the seven classic waste types defined under Lean Manufacturing. KPI indicators assessed included defect rate, machine downtime, and production output. Financial cost analysis was excluded from the scope. It was assumed that production conditions remained stable throughout the data collection period and that all data provided by the company were accurate and reliable.

RESULTS AND DISCUSSIONS

Data collection was conducted to obtain the information needed for the study. The data collected included cycle time, packaging targets and output, packaging machine downtime, as well as data on metal detector defects, Aluvo repackages, and empty Aluvo containers. The data was obtained through direct observation and internal company documents to describe the actual conditions of the packaging process and to identify bottlenecks and product defect rates in the production process.

Packaging Process Flow and Cycle Time

The packaging process at PT XYZ consists of eight sequential workstations: (1) Product Feeding, (2) Cooling Tunnel + Metal Detector, (3) Sealing, (4) Packaging QC, (5) Secondary Packaging, (6) Coding, (7) Final QC, and (8) Palletizing. Table 1 presents the cycle time measured at each workstation.

Table 1. Cycle Time Workstation

No	Process	Cycle Time (sec)
1	Feeding to Packaging Machine	15
2	Cooling Tunnel + Metal Detector	18
3	Sealing	11
4	QC pack	10
5	Secondary Packaging	14
6	Coding	6
7	QC Final	8
8	Pallet	10

The Cooling Tunnel + Metal Detector stage recorded the longest cycle time (18 seconds), making it the potential bottleneck of the process. The Coding stage had the shortest cycle time (6 seconds). Total value-added time across all workstations was 92 seconds, out of a total lead time of 170 seconds.

Current State Mapping

The initial step in data processing involved creating a Current State Value Stream Map (Current State VSM) to illustrate the actual state of the packaging process flow, from product intake to completion on the pallet. This map identifies process times, wait times, and waste at each stage, thereby pinpointing the issues causing process delays, reduced output, and high defect rates in the packaging area. The current state value stream map for PT XYZ's packaging process is shown in the following figure.

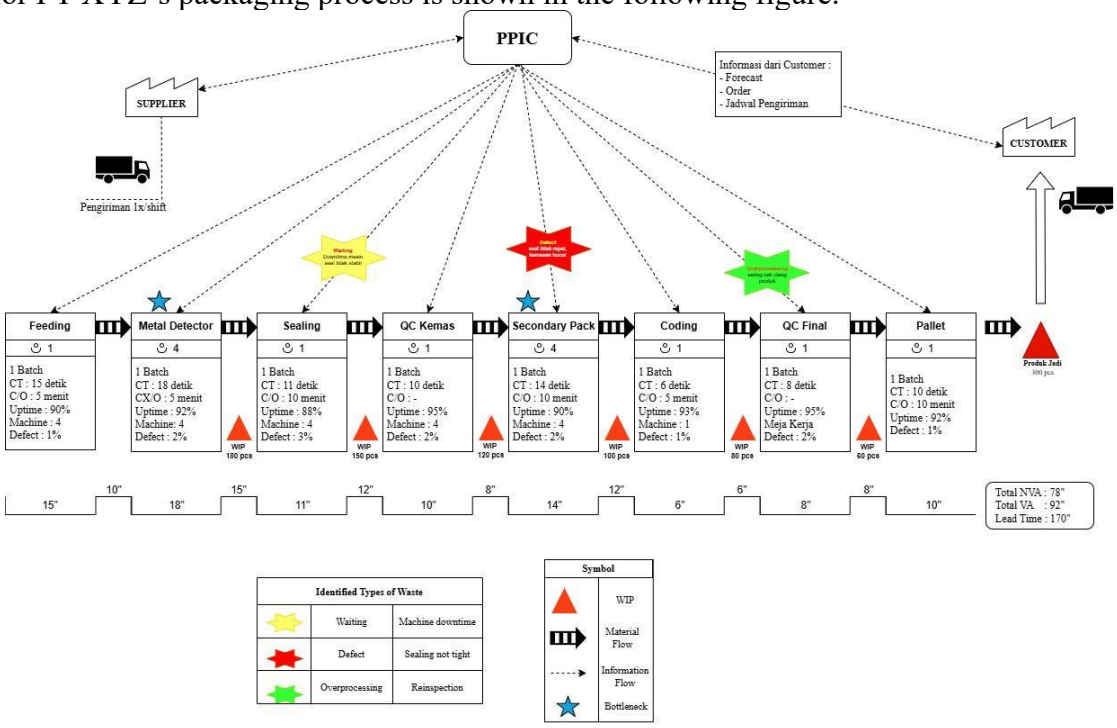


Figure 2. Current State Mapping

As shown in the figure above, the Current State Mapping of the packaging process still includes non-value-added activities such as defects and downtime, which affect the effectiveness of the packaging process.

Current Process Cycle Efficiency (PCE)

PCE was calculated to determine the proportion of total lead time that constitutes genuinely value-adding activity. It is expressed as:

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

$$\text{PCE} = \frac{(92)}{(170)} \times 100\% = 54{,}1\%$$

Current Key Performance Indicators (KPI)

Three KPI's were calculated to quantify the actual performance of the packaging line over the observation period: defect rate, machine availability, and production productivity. Defect Rate was used to measure the proportion of defective products generated during the packaging process and to evaluate the quality performance of the production line [13]. The Defect Rate was calculated using Equation :

$$Defect\ Rate = \left(\frac{Defect}{Output}\right) \times 100\%$$

Table 2. KPI Defect Rate

Month	Defect (pcs)	Output (pcs)	KPI
Sept'25	93632	472934	19,8%
Oct'25	93624	714412	13,1%
Nov'25	80495	659102	12,2%
Dec'25	83771	712096	11,8%
Jan'26	101027	1103904	9,2%
Feb'26	64396	628116	10,3%
	Average		12,7%

The average defect rate of 12.7% is notably high. The peak occurred in September 2025 at 19.8%, likely associated with machine instability at the start of the observation period. A gradual downward trend was observed through January 2026 (9.2%), suggesting partial natural improvement during the period. Machine Availability was used to assess the percentage of planned production time during which the machine was available for operation [14]. Machine Availability was calculated using Equation:

$$Availability\ = \left(\frac{Plan\ Production\ Time - downtime}{Plan\ Production\ Time}\right) \times 100\%$$

Table 3. KPI Machine Availability

Month	Production Time (hrs)	Downtime (hrs)		KPI
Sept'25	192	2701	45,02	76,55%
Oct'25	192	2246	37,43	80,50%
Nov'25	192	884	14,73	92,33%
Dec'25	144	496	8,27	94,26%
Jan'26	288	1426	23,77	91,75%
Feb'26	192	1470	24,50	87,24%
	Average			87,11%

Average machine availability was 87.11%. The lowest availability 76.55% was recorded in September 2025, coinciding with the highest defect rate, strongly suggesting a causal relationship between machine downtime and product defects. By December 2025, availability peaked at 94.26% following partial maintenance interventions. Production Productivity was used to evaluate the efficiency of the packaging process by measuring the amount of output produced per unit of production time [13]. Production Productivity was calculated using Equation:

$$Defect\ Rate = \left(\frac{Output\ Total}{Production\ Time}\right) \times 100\%$$

Table 4. KPI Production Productivity

Month	Output (pcs)	Production Time (hrs)	KPI
Sept'25	472934	192	2463
Oct'25	714412	192	3721
Nov'25	659102	192	3433
Dec'25	712096	144	4945
Jan'26	1103904	288	3833
Feb'26	628116	192	3271
	Average		3611

Average productivity was 3,611 pcs/hr. The highest productivity (4,945 pcs/hr) occurred in December 2025, correlating with the highest machine availability in that month. September 2025 showed the lowest productivity at 2,463 pcs/hr, consistent with its high downtime and defect rate.

Waste Assesment Questionnaire (WAQ)

The Waste Assessment Questionnaire (WAQ) was employed to identify and evaluate the occurrence of waste within the packaging process. The questionnaire was distributed to personnel directly involved in production activities, and the responses were subsequently analyzed to determine the relative significance of each waste type. According to Rawabdeh [8], WAQ is designed to systematically assess waste by evaluating its occurrence and impact on operational performance. The resulting scores were then used as input for further waste prioritization and relationship analysis.

Table 5. WAQ Result Summary

Waste	Total Score	WAQ Score
Defect - Waiting	94	15,67
Waiting - Motion	87	14,50
Motion - Defect	93	15,50
Defect - Overprocessing	93	15,50
Overprocessing - Waiting	93	14,50

The Defect - Waiting relationship recorded the highest WAQ value 15.67, indicating that defect occurrences are the strongest driver of waiting time in the packaging line. This is consistent with field observations showing that product rejection triggers repack activities and process interruptions.

Waste Relation Matrix (WRM)

Based on the findings of the Waste Assessment Questionnaire (WAQ), field observations, and conversations with respondents, the Waste Relationship Matrix (WRM) is used to determine the links between various waste kinds in the packaging process. By identifying the waste categories that have the biggest effects on others, the WRM makes it possible to prioritize production process improvements. The average relationship scores were subsequently converted into AEIOUX relationship categories to facilitate the construction of the Waste Relationship Matrix (WRM), as commonly applied in recent Waste Assessment Model studies [15],[8]. The following shows the conversion of scores to WRM letter grades in Table 6.

Table 6. WRM Score-to-Letter Conversion Table

Range	Type Relatione	Symbol
0 – 1	Absolutely Necessary	A
1,1 – 2	Especially Important	E
2,1 – 3	Important	I
3,1 – 4	Ordinary Closennes	O
4,1 – 5	Unimportant	U
5,1 – 6	No Realtion	X

The relationship scores obtained from the respondents were averaged to determine the final relationship value for each waste pair. The average score was calculated by dividing the total score by the number of respondents. Subsequently, the resulting values were converted into AEIOUX relationship categories according to the predefined classification intervals shown in Table 7.

Table 7. Classification Criteria

Waste	WAQ Score	Average Score
Defect - Waiting	15,67	3,13
Waiting - Motion	14,50	2,9
Motion - Defect	15,50	3,1
Defect - Overprocessing	15,50	2,93
Overprocessing - Waiting	14,50	2,9

To determine the significance of each waste type, the WRM was further analyzed to calculate the final waste relationship weights. The resulting weights indicate the relative influence of each waste on the overall production process and serve as an input for the Waste Value Matrix (WVM) analysis. The calculated WRM weights are presented in Table 8.

Table 8. Scoring WRM

From / To	Waste D	Waste W	Waste M	Waste P
D		3,13	-	2,93
W	-		2,9	-
M	3,1	-		-
P	-	2,9	-	

Following the computation of the overall scores, a chart illustrating the connections between various waste categories was created by allocating WRM codes, as displayed in Table 9 below.

Table 9. Conversion to Waste Relationship Matrix Symbols

From / To	D	W	M	P
D	A	O	-	I
W	-	A	I	-
M	O	-	A	-
P	-	I	-	A

Utilizing the conversion values A = 10, E = 8, I = 6, O = 4, U = 2, and X = 0, to determine the waste effect score. The final WRM scores' weighting is displayed in the following table 10:

Table 10. Final Weight WRM

From / To	D	W	M	P	Score	(%)
D	10	4	-	6	20	30,30%
W	-	10	6	-	16	24,24%
M	4	-	10	-	14	21,21%
P	-	6	-	10	16	24,24%
Skor	14	20	16	16		
(%)	21,21	30,30	24,24	24,24	66	100%

Based on Table 10, the final WRM weights, defect waste (D) has the highest weight at 30.30%, making it the most dominant form of waste in the packaging process. Waste (W) and overprocessing (P) each have a weight of 24.24%, while motion waste (M) has the lowest weight at 21.21%. These results indicate that improvements should prioritize reducing defects, as they have the greatest impact on other types of waste.

Waste Matrix Value

The Waste Matrix Value (WMV) is used to prioritize waste based on the product of the WAQ value and the WRM weight in the packaging process.

Table 11. Calculation WMV

Waste	WAQ Score	Weight WRM	WMV	Priority
Defect	15,67	0,30	4,701	1
Overprocessing	15,5	0,24	4,65	2
Waiting	14,5	0,24	3,48	3
Motion	15,5	0,21	3,255	4

The WMV calculation results show that waste due to defects has the highest value at 4.701, making it the top priority for improvement. Next are waste due to overprocessing at 4.650, waiting at 3.480, and motion at 3.255.

Cause and Effects Analysis

Based on the elements of man, machine, method, material, and environment, the following fishbone diagram can be used to pinpoint the primary causes of waste in the packing process.

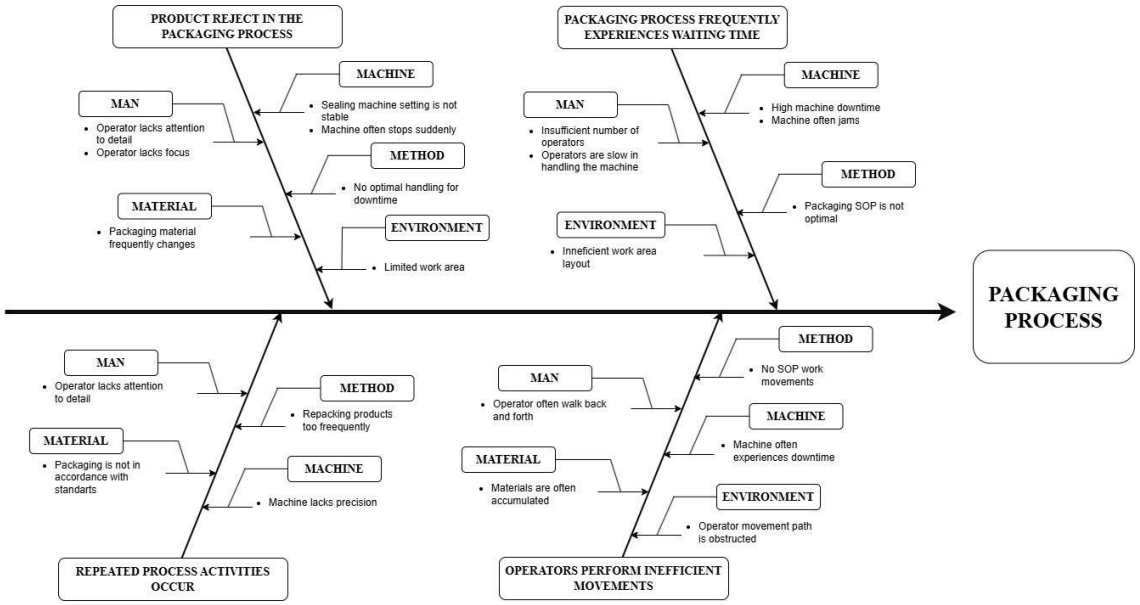


Figure 3. Fishbone Diagram 4 Waste

5 Why's Analysis

The following is a 5 Whys analysis used to identify the root causes of each major issue in the packaging process.

Table 12. 5 Why's Analysis

Problem	Why 1	Why 2	Why 3	Why 4	Why 5
Product reject	Sealing result is defective	Machine setting is unstable	Machine suddenly stops	Downtime handling is not optimal	No standard machine checking procedure
Waiting time	Packaging process is delayed	Operators respond slowly	Machine often breaks down	SOP is not optimal	Work system is ineffective
Repeated process activities	Repacking occurs repeatedly	Packaging is not standard	Machine lacks precision	Operator is less careful	No consistent quality checking standard
Inefficient operator movement	Operators walk back and forth	Movement path is obstructed	Materials pile up	Poor work layout	No SOP for material flow and movement

Improvement Recommendation

Defect, delay, overprocessing, and motion were found to be the main wastes in the packing process based on the findings of the Waste Assessment Model (WAM), Waste Relationship Matrix (WRM), Waste Assessment Questionnaire (WAQ), and Root Cause Analysis (RCA). In order to increase the efficiency of the packing process, improvement recommendations were centered on cutting these wastes.

Table 13. Improvement Recommendation

Waste	Root Cause	Improvement Recommendation	Objective
Defect	Unstable machine settings and operator inaccuracy	Standardize sealing machine settings	Reduce product defects
		Packaging operator training	Improve operator accuracy
		QC inspection checklist	Reduce inspection errors
		Preventive machine maintenance	Reduce machine breakdowns
		Visual control in packaging area	Improve process monitoring
Waiting	Machine downtime and process delays	Add one packaging operator	Reduce process queues
		Downtime handling SOP	Speed up disturbance handling
		Machine troubleshooting training	Reduce waiting time
		Scheduled preventive maintenance	Reduce machine downtime
		Daily downtime monitoring	Control machine performance
Overprocessing	Repacking and repeated activities	Inspection process standardization	Reduce repeated inspections
		Machine setting training	Reduce process errors
		Repack product SOP	Minimize overprocessing
		Regular machine parameter evaluation	Maintain process stability
		Improve quality control	Reduce rework activities
Motion	Inefficient operator movement	Improve packaging area layout	Reduce unnecessary movement
		Place materials near operators	Speed up work process
		Implement 5S method	Organize work area better
		Visual material location	Simplify material retrieval
		Improve material flow	Reduce excessive movement

Future State Mapping and Comparative KPI Analysis

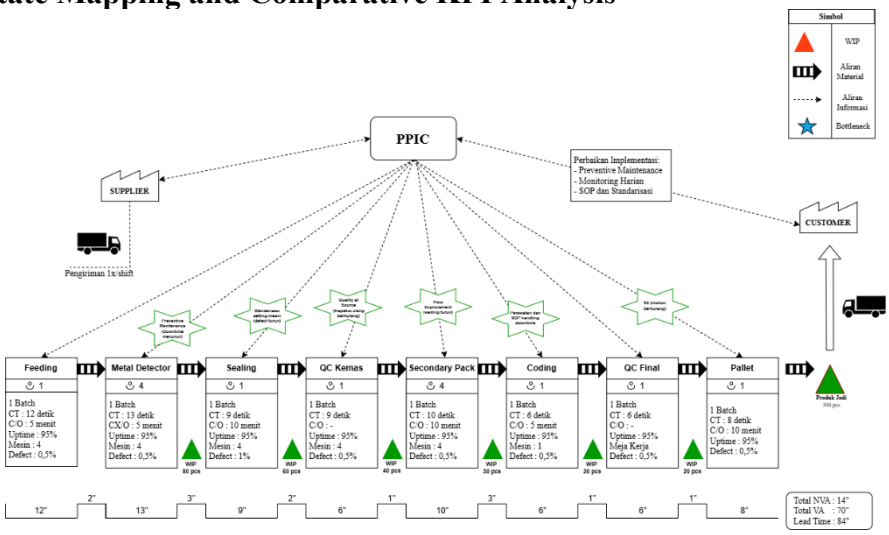


Figure 4. Future State Mapping

A Future State Value Stream Map was constructed incorporating all proposed improvements. The expected impact on PCE and lead time is quantified in Table 13, while Table 14 compares current and future KPI values

Table 14. PCE and Lead Time Comparison: Current vs Future State

Indicator	Current State	Future State	Change
Total Lead Time	170 seconds	84 seconds	−50.6%
Non-Value-Added Time	78 seconds	14 seconds	−82.1%
Value-Added Time	92 seconds	70 seconds	–
Process Cycle Efficiency (PCE)	54.1%	83.3%	+29.2 percentage points

The improvement proposals are projected to reduce non-value-added time by 82.1% (from 78 seconds to 14 seconds) and total lead time by 50.6% (from 170 seconds to 84 seconds). The resulting PCE of 83.3% represents a substantial gain and places the packaging process within an efficient operating range according to Lean benchmarks.

To evaluate the effectiveness of the proposed improvements, three Key Performance Indicators (KPI's) were estimated for the future state, namely Defect Rate, Machine Availability, and Production Productivity. The future-state values were calculated based on the proposed improvement scenarios, including a 20% reduction in defects, a 25% increase in machine availability, and a 10% increase in production productivity. The results of the KPI evaluation are presented in Table 15.

Table 15. KPI Comparison: Current State vs Future State

KPI	Current State (Avg.)	Future State (Avg.)	Change
Defect Rate	12.7%	10.2%	−2.5%
Machine Availability	87.11%	90.33%	+3.22%
Productivity	3,611 pcs/hr	3,972 pcs/hr	+10.0%

All three KPIs show meaningful improvement, validating the relevance and effectiveness of the proposed interventions.

CONCLUSION

This study applied Value Stream Mapping and Waste Assessment Model to systematically diagnose and address waste in the biscuit packaging line at PT XYZ. The principal findings and contributions are as follows:

- Defect was identified as the dominant waste (WMV = 4.701), followed by Overprocessing (4.650), Waiting (3.480), and Motion (3.255). Defects were primarily driven by unstable sealing machine settings, undertrained operators, and the absence of a preventive maintenance program.
- Root cause analysis using Fishbone Diagrams and 5 Whys confirmed that the three fundamental systemic causes lack of preventive maintenance, lack of operator training, and absence of standardized procedures underlie all four waste categories.
- The proposed improvement plan, encompassing Work Instruction (WI) revision, sealing standard checklists, periodic machine inspections, and operator training, is projected to reduce non-value-added time from 78 to 14 seconds and total lead time from 170 to 84 seconds. PCE is expected to increase from 54.1% to 83.3%.
- KPI projections indicate a defect rate reduction from 12.7% to 10.2%, machine availability improvement from 87.11% to 90.33%, and productivity growth from 3,611 to 3,972 pcs/hr.

  These results demonstrate that a structured Lean approach combining VSM and WAM is an effective and practical methodology for identifying waste priorities and guiding process improvement in food manufacturing packaging environments.

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