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Waste Analysis in the Production of Packaged Beverages with Lean Manufacturing and FMEA Methods at PT XYZ

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Abstract

The packaged beverage industry is experiencing rapid growth in response to demand. This study aims to identify, analyze, and minimize various types of waste in the production process packaged beverages at PT XYZ using a Lean Manufacturing approach that integrates Value Stream Mapping (VSM), and Failure Mode and Effect Analysis (FMEA). Waste weighting analysis showed that unnecessary motion was the most critical waste with the highest weight of 4.71, followed by waiting with a weight of 4.14, overprocessing with a weight of 3.86, overproduction with a weight of 3.57, excessive motion with a weight of 2.86 and excess inventory with a weight of 2.57. Mapping the current state process using VSM succeeded in minimizing the initial lead time from 687 minutes to 568 minutes by reducing the process time. The implementation of improvement proposals that include the implementation of visual control with work standardization, as well as the integration of information systems and quality control resulted in an increase in Process Cycle Efficiency (PCE) from 25% to 30%. This study proves that the integration of Lean Manufacturing and improvement recommendations with FMEA is effective in reducing waste, shortening lead time, and improving the efficiency of the packaged beverage production process in a sustainable manner.

Keywords: Lean manufacturing; production process efficiency; seven waste

1. Introduction

The packaged beverage industry is experiencing rapid growth in response to demand [1]. The packaged beverage industry needs to implement an efficient production process to produce quality products and minimize losses, one of which is due to the problem of waste (waste) [2]. Waste has a direct impact on increased operational costs, decreased productivity, and non-conformance Output actual and set targets [3]. One approach that can be used to minimize a waste (waste) namely lean manufacturing [4].

Lean manufacturing focusing on efficiency by eliminating non-value-added activities and optimizing the production process. Lean manufacturing used to identify waste (waste) or activities that are not value-added (no value adding activities) through radically continuous improvement through product flow (material, work in process, output) and information using a pull system from internal and external customers in pursuit of excellence and perfection in the manufacturing industry. Waste analysis is carried out using the concept of seven waste namely, defect, overproduction, waiting, transportation, inventory, motion and extra processing [5], [6].

Ideally, the packaged beverage industry operates with a lean-based production system that prioritizes smooth process flow, minimal non-value-added activities, and is supported by work standardization, machine reliability, and continuous improvement to achieve optimum efficiency and quality [7]. However, in actual conditions, PT. XYZ as a packaged beverage manufacturer has implemented a production system based on customer demand with an integrated and sustainable process of Water Treatment to finished products. However, the dominance of the use of machines in the production process makes the system vulnerable to waste.

To identify the production problems occurring at PT XYZ, production data from September to February were collected, covering product defects, rework activities, and overproduction. These data were analyzed to determine the extent of waste occurring during the production process and to identify potential problems affecting production efficiency. The production data are presented in Table 1.

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Table 1. Production data

No	Month	Demand (pcs)	Defect			Rework		Overproduction (pcs)
			1	2	3	Sraw	Code	
1	September	16,512	184	109	167	316	338	176
2	October	15,600	299	40	79	392	424	143
3	November	19,536	127	160	246	344	488	305
4	December	16,032	255	70	130	356	458	260
5	January	18,552	130	94	89	319	243	541
6	February	22,560	303	220	219	634	347	319
Total		108,792	1,298	693	930	2,361	2,298	1,744
Average				2.56%		4.14%		1.52%

Table 1 shows that production activities from September to February experienced several issues related to quality and efficiency, particularly defects, rework, and overproduction. The company has established a maximum tolerance limit of 1.5% for each indicator. However, the average defect rate reached 2.56%, the rework rate was 4.14%, and the overproduction rate was 1.52%. These figures indicate that all three indicators exceeded the company's established tolerance limit. Rework recorded the highest percentage, indicating inefficiencies in the production process that require additional processing. This condition can increase production lead time, resource utilization, and operational costs. Meanwhile, the defect rate reflects quality control issues, while overproduction indicates a mismatch between production output and actual demand. These findings highlight the need to evaluate the production process to identify sources of waste and develop appropriate improvement strategies to enhance production efficiency.

Previous research has shown that the lean manufacturing with the Value Stream Mapping It has advantages in mapping production flows comprehensively, identifying value-added and non-value-added activities, and systematically analyzing wastes based on data. In addition, this method is able to integrate root cause analysis with the design of repair conditions (future state), thus producing applicable recommendations to improve production efficiency [8].

This research offers novelty through the application of waste weighting to determine the most critical waste priorities in the production process at PT XYZ, which are then analyzed and corrected using Value Stream Mapping (VSM). This approach allows for the identification of more specific problems according to the company's actual conditions, as well as generating targeted improvement proposals that can reduce lead time and increase the value of Process Cycle Efficiency (PCE). Thus, this research makes a practical contribution to improving the efficiency of the production process in the beverage processing industry.

2. Literature Review

2.1. Lean manufacturing

Lean manufacturing is an approach to minimize waste that occurs in the production flow process. Lean manufacturing often referred to as "Just in time manufacturing". Lean manufacturing aims to continuously increase customer value by increasing the ratio between added value and waste. Basically Output What to expect from the concept Lean Manufacturing is minimizing total Lead Time and improve Output to reduce or eliminate all forms of waste that exist [9]. Lean manufacturing used to identify waste (or activities that are not value-added (No value adding activities) through radically continuous improvement (Radical Continuous Improvement) through product flow (material, work in process, output) and information using a pull system (Pull System) from internal and external customers in pursuit of excellence and perfection in the manufacturing industry [10].

2.2. Waste

Waste or waste is any activity that does not provide added value throughout the flow of the process Input become Output. Where waste means the form of material that is wasted, including time, energy, and work area. Previously, in terms of added value, manufacturing companies had 3 major activities, including [11]:

1. The influence of value-added activities or referred to as value-added activities (VA).
2. The influence of activities that are not value-added or referred to as non-value-added activities (NVA).
3. The influence of activities that are not value-added, but also necessary, is referred to as necessary non-value added (NNVA).

Once the production process is classified into Value Added (VA), Non-Value Added (NVA), and Necessary Non-Value-Added (NNVA), an indicator is needed to measure the overall efficiency level of the process. One of the commonly used efficiency measures in the Lean Manufacturing approach is Process Cycle Efficiency (PCE). Process Cycle Efficiency (PCE) is a metric that shows the proportion of time that actually adds value to the product compared to the total lead time.

$$PCE = \frac{Value\ Added\ Time}{Total\ Lead\ Time} \times 10\% \quad (1)$$

Identification of Waste Done based on concept seven waste in lean manufacturing. The categories of seven wastes include [12]:

2.2.1. Overproduction

It is waste that occurs when a company produces goods in quantities that exceed customer needs or are produced ahead of the required time.

2.2.2. Defect

A type of waste in the concept of lean manufacturing that occurs due to defective products or not in accordance with quality standards, so that they require repair (rework) or even have to be thrown away (scrap).

2.2.3. Uneccessary Inventory

The occurrence of uneccessary inventory due to an excessive supply of raw materials, semi-finished goods, or finished products. Excess inventory leads to increased storage costs, risk of expiration, damage, and inhibits production flow.

2.2.4. Extra proccessing

Waste occurs due to the use of processes, methods, or technologies that do not suit customer needs.

2.2.5. Excessive transportation

Waste that arises due to unnecessary movement of materials, raw materials, or products within the production area or between facilities. Excessive transportation increases the risk of product damage, increases processing time, and increases operational costs without providing added value to the product.

2.2.6. Waiting

Is a waste that occurs when an operator, machine, or material is in a waiting condition due to a process imbalance, machine failure, or supply delay. Waiting causes longer production times and lower productivity levels. This waste is often caused by suboptimal production planning and scheduling.

2.2.7. Uneccessary Motion

Waste caused by excessive or unergonomic operator movements during the work process. Examples are walking too far to pick up tools, uncomfortable working positions, or poor work area layout. This waste not only decreases work efficiency, but also increases the risk of fatigue and work injuries.

2.3. Fishbone diagram

One of the quality cycles proposed by Ishikawa is the cause-and-effect diagram or better known as fish bone diagrams, although some also call it Ishikawa diagrams. Diagram Fishbone It is an easy tool that can be used by anyone to analyze the causes and solutions of problems. Fishbone diagram In general, it is a graphical picture that displays data about the causative factors from failures or inconsistencies to analyzing the deepest sub of the factors that cause problems. Form of analysis Fishbone Diagram that is, in the form of data that is predominantly collected in a subjective way for observation and analysis that may come from objective or subjective things using quantitative or qualitative data [13].

2.4. FMEA (Failure Mode and Effect Analysis)

FMEA was first introduced in the late 1940s for use in the military field by the U.S. Armed Forces. At the time, FMEA was used for rocket development to avoid errors in small sample sizes of expensive rocket technology. Although originally developed by the military, the FMEA methodology is now widely used in various industries including manufacturing, services and construction. FMEA allows teams to design such failures out of the system with minimal effort and resource expenditure, reducing development time and costs [14]. Failure Mode and Effect Analysis (FMEA) is one of the methods that looks for various problems not only in the process, but also in suggestions for improvement in work as well as in data collection. Failure Mode and Effect Analysis (FMEA) is a systematic approach that applies a pentadefense method to help the thought process used by engineers to identify potential failure modes and their effects [15].

3. Research Methodology

This research was carried out at PT. XYZ with an implementation period from September 2025 to March 2026. In this study, there are two types of variables, namely bound variables and independent variables. The bound variable is the affected variable, namely the level of waste in the production process in the company, while the free variable is the influencing variable, namely the analysis of 7 wastes that occur in manufacturing activities.

The data collection method in this study uses primary and secondary data. Primary data was obtained directly through observation, interviews, and questionnaires to identify the flow and time of the production process, the type and cause of waste, production constraints, and defect factors, by involving parties related to the production process. Meanwhile, secondary data comes from company documents, in the form of historical production data for the period September 2025 to February 2026 and final product specifications to support the analysis.

This research begins with the data collection stage through observation, interviews, documentation studies, and process time measurement to understand the actual conditions and potential waste. Furthermore, the data was processed by calculating cycle time and lead time, classifying activities into VA, NVA, and NNVA, and compiling the initial Big Picture Mapping. The analysis stage was carried out using the Lean Manufacturing approach through the identification of 7 wastes, Value Stream Mapping (current state), VALSAT weighting to determine dominant waste, and FMEA to determine improvement priorities based on RPN values. Finally, an evaluation was carried out using Root Cause Analysis (fishbone) to identify the root cause, compile recommendations for improvement, and make a proposed Big Picture Mapping (future state) to assess efficiency improvements and waste reductions.

4. Results and discussion

4.1. Production flow

As illustrated in Fig. 1, the beverage production flow at PT XYZ takes place in an integrated manner from upstream to downstream. The process starts from water treatment to ensure water quality, continuing to mixing and blending for mixing ingredients. The product then goes through the Quality Assurance (QA) stage before being streamed through the transfer line to the sterilization/UHT process. After sterilization, the product is stored in a balance tank and then entered the filling area for aseptic filling. The packaging is then coded in the code area, a straw is installed in the straw machine area, then packaging is carried out and ended with palletizing for distribution.

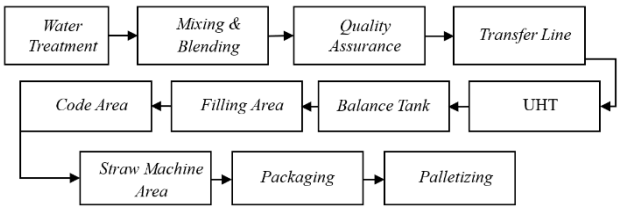


Figure 1. Production flow

4.2. Production time

Table 2 presents the production activities identified through direct observations of the production process. A total of 46 activities were identified, starting from Water Treatment and continuing through Mixing, Quality Assurance, Transfer Line, UHT Sterilization, Balance Tank, Filling Area, Code Area, Straw Machine Area, Packaging, and Palletizing.

Table 2. Production time

No	Activities	Time (Minutes)	Categories
	Water Treatment		
1	Raw water intake	14	VA
2	Water pressure check	9	NNVA
3	Initial filtration	10	VA
4	Reverse Osmosis	10	VA
5	Waiting for operator instructions	4	NVA
6	Waiting for the tank to be full	13	NNVA
	Mixing		
7	Preparation of materials	50	NNVA
8	Tank mixing preparation	7	NNVA
9	Agitator inspection	5	NNVA
10	Initial stirring	18	VA
11	Waiting for the head of production instructions	5	NVA
12	Agitator speed adjustment	5	NVA
13	Advanced stirring	10	VA
14	Waiting for homogeneous dissolution	13	NNVA
15	Product sampling	10	NNVA
	Quality Assurance		
16	QC towards testing lab	7	NVA
17	Ph Testing	13	NNVA
18	Brix Testing	13	NNVA
19	Waiting for QC/operator approval	4	NVA
	Transfer Line		
20	Preparation of the transfer route	4	NNVA
21	Waiting for qc clearance for transfer to UHT	5	NVA
	UHT Sterilization		
22	UHT preheating	10	NNVA
23	UHT (Heating & Holding) Process	1	VA
	Balance Tank		
24	Temporary shelter	10	NNVA
25	Waiting for filling instructions	4	NVA
	Filling Area		
26	Sterilization of filling areas	10	NNVA
27	Re-checking the sterilization of the filling area	10	NVA
28	Machine parameter setting	5	NNVA
29	Packaging filling	38	VA
30	Sealing process	36	VA
31	Leak inspection and test	15	NNVA
32	Waiting for the rejection decision	4	NVA
	Code Area		
33	Production code assignment	16	VA
34	Verify code results	7	NNVA
35	Inspection and re-sorting	10	NVA
36	Rework of production codes	10	NVA
	Straw Machine Area		
37	Automatic straw installation	17	VA
38	Straw rework	10	NVA
	Packing		
39	Random visual re-checks and leaks	15	NVA
40	Waiting for the rejection decision	15	NVA
41	Putting the product in the carton	54	NNVA
42	Carton arrangement	40	NNVA
43	Wrapping Carton	39	NNVA
	Palletizing		
44	Waiting for the forklift	9	NVA
45	Pallet carton arrangement	43	NNVA
46	Pallet transfer to finished material inventory	30	NNVA

The table provides detailed information regarding each production activity, including its corresponding processing time in minutes and its classification into three categories: Value Added (VA), Non-Value Added (NVA), and Necessary Non-Value Added (NNVA). The recorded processing times represent the duration required to perform each activity, while the classification distinguishes activities based on their contribution to product value and their necessity within the production process.

The identification of production activities, their processing times, and their respective classifications provides the necessary input for developing the Current State Value Stream Mapping (VSM). These data will subsequently be used to illustrate the actual production flow and analyze the efficiency of the existing production system.

4.2. Current state mapping

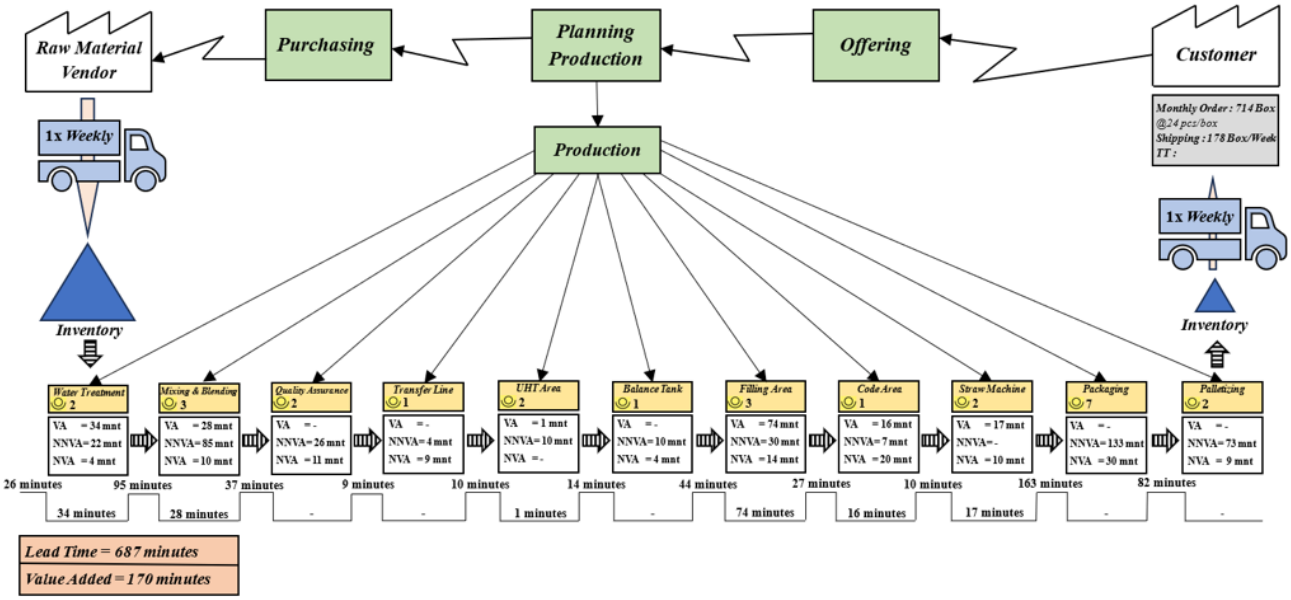


Figure 2. Current state mapping PT XYZ

Fig. 2 illustrates the Current State Value Stream Mapping of the production process at PT XYZ. The mapping describes the flow of information, starting from customer demand to production planning and purchasing, as well as the material flow from raw material suppliers through the production process, beginning with Water Treatment and ending with Palletizing. Each production area is presented with its respective processing time and classification of Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA) activities.

Based on the current state mapping, the total recorded production activity time is 687 minutes, consisting of 170 minutes of VA activities, 400 minutes of NNVA activities, and 117 minutes of NVA activities. The results indicate that NNVA activities account for the largest proportion of the total recorded time, followed by VA and NVA activities. This suggests that a considerable amount of production time is allocated to activities that do not directly add value to the product but are still required to support the production process.

Furthermore, the distribution of processing time across production areas shows that Packaging has the highest accumulated activity time of 163 minutes, followed by Mixing & Blending at 123 minutes and Filling Area at 118 minutes. These areas require further evaluation to identify opportunities for improving production efficiency.

Initial PCE (Process Cycle Efficiency) Value

$$PCE = \frac{Value\ Added\ Time}{Total\ Lead\ Time} \times 10\%$$

$$PCE = \frac{170}{687} \times 10\%$$

$$PCE = 25\%$$

Based on the Current State Value Stream Mapping, the initial Process Cycle Efficiency (PCE) was calculated by comparing the total Value Added time with the total recorded production activity time. The calculation resulted in a PCE value of 25%, indicating that only approximately one-quarter of the recorded production time contributes directly to product value. Meanwhile, the remaining 75% consists of NNVA and NVA activities.

This result indicates that there is potential to improve production efficiency by evaluating activities that do not directly add value, particularly those that consume considerable time. Therefore, further waste analysis is necessary to identify improvement opportunities and establish the basis for developing the Future State Value Stream Mapping.

4.4. FMEA analysis

Following the identification of waste in the current production process, Failure Mode and Effect Analysis (FMEA) was conducted to evaluate and prioritize the identified wastes based on their potential risks to production performance. FMEA was used to assess each type of waste through three parameters: Severity (S), Occurrence (O), and Detection (D). The Risk Priority Number (RPN) was calculated by multiplying these three parameters to determine the priority level of each waste. This analysis aims to identify the most critical wastes that require immediate improvement actions. The results of the FMEA analysis are presented in Table 3.

Table 3. Failure mode and effect analysis (FMEA)

No	Waste	Effects of Failure	S	Causes of Failure	O	Current Control	D	RPN	Categories
1	Unnecessary Motion	Tool search times and workloads increase, potentially leading to production delays.	7	There is no labeling yet, the guava has not been separated by maturity, and the tool is not yet close to the mixing tank.	6	Centralized tools, sort the guava after production, and store and check in the production area.	4	168	Extreme
2	Overprocessing	Adjustments and checks increase, time and resources increase, and the potential for rework.	8	The filling performance is unstable, the straw and code machines are less than optimal, and the carton is damp.	5	Initial checks and settings are carried out, and cartons are stored and visually inspected before use	5	150	Extreme
3	Waiting	Downtime increases, workflows are disrupted, and machine and labor utilization decrease.	7	Engine failures, over-inspection in the code/straw, and delays in the supply of raw materials.	5	Routine machine maintenance, inspection according to standards, and procurement of raw materials according to production needs.	4	140	Extreme
4	Defect	Products that do not meet specifications are increasing and rejections are increasing.	8	The preform is not suitable, the flowmeter is inaccurate, and the filling volume is less.	4	Preform and fold checks, flowmeter calibration, and filling volume setting with sample test.	3	96	High
5	Overproduction	Output is not balanced with actual needs.	7	The UHT cycle time is long, the guava procurement schedule is not in accordance with maturity, and the flowmeter is inaccurate.	4	Production arrangements according to UHT capacity, procurement of raw materials as needed, and calibration of flowmeters before production.	3	84	High
6	Excessive Transportation	The time and distance of displacement increase, and the risk of material damage/loss increases.	6	Separate areas, spacious workspaces, and limited material handling systems.	3	Moving tools as needed, distribution by the operator, and materials are moved manually.	2	36	Low
7	Excess Inventory	Inventory buildup, storage costs increase, and the risk of expiration/damage increases.	2	The stock is not balanced with needs and the loading process is not well scheduled.	4	Periodic stock checking and loading/delivery according to product availability.	2	16	Low

Based on the FMEA results presented in Table 3, seven types of waste were identified and evaluated using Severity (S), Occurrence (O), and Detection (D) parameters to determine their respective Risk Priority Numbers (RPN). The results indicate that Unnecessary Motion has an RPN value of 168 (S = 7, O = 6, D = 4), making it the highest-ranked waste and classified as Extreme. This waste is mainly caused by the absence of proper labeling, inadequate separation of guava materials based on maturity, and the location of tools that are relatively far from the mixing tank. These conditions increase tool searching time and unnecessary operator movements, potentially resulting in production delays.

The second-highest priority is Overprocessing, with an RPN value of 150 (S = 8, O = 5, D = 5), which is also classified as Extreme. This waste is associated with unstable filling performance, suboptimal conditions of the straw and coding machines, and damp cartons. These conditions may lead to repeated adjustments and inspections, increasing processing time and resource utilization. Meanwhile, Waiting ranks third, with an RPN value of 140 (S = 7, O = 5, D = 4), classified as Extreme. The main causes include machine failures, repeated inspections in the code and straw areas, and delays in raw material supply. These conditions can disrupt production activities and reduce machine and labor utilization.

Overall, the FMEA results indicate that Unnecessary Motion, Overprocessing, and Waiting are the three main waste priorities requiring improvement at PT XYZ. Therefore, improvement efforts should initially focus on addressing the causes of these wastes to minimize unnecessary activities, reduce production delays, and improve the overall efficiency of the production process.

Furthermore, Defect has an RPN value of 96 (S = 8, O = 4, D = 3), while Overproduction has an RPN value of 84 (S = 7, O = 4, D = 3). Both are classified as High, indicating that these wastes also require attention to prevent product rejection and production output

imbalances. In addition, Excessive Transportation has an RPN value of 36 (S = 6, O = 3, D = 2), while Excess Inventory has the lowest RPN value of 16 (S = 2, O = 4, D = 2), with both classified as Low.

4.5. Recommended improvements

Following the FMEA evaluation, improvement recommendations were developed to address the identified waste in the production process. These recommendations were formulated based on the identified failure causes and their respective RPN values, with particular attention given to waste classified as Extreme and High. The purpose of presenting these recommendations is to provide appropriate corrective actions for reducing production inefficiencies and addressing the main causes of waste. The proposed improvements are summarized in Table 4.

Table 4. Recommendations for improvement based on FMEA

Yes	Waste	Effects of Failure	RPN	Categories	Proposed improvements
1	Unnecessary Motion	Tool search times and workloads increase, potentially leading to production delays.	168	Extreme	Rearrangement and labelling on each workstation
2	Overprocessing	Adjustments and checks increase, time and resources increase, and the potential for rework.	150	Extreme	Parameter standardization, inspection checklists, and adjustment of inspection SOPs are integrated directly into the production line, with criteria visualized through drawing guides in the work area
3	Waiting	Downtime increases, workflows are disrupted, and machine and labor utilization decrease.	140	Extreme	Preventive maintenance programs are scheduled regularly and quality standards are set and controlled.
4	Defect	Products that do not meet specifications are increasing and rejections are increasing.	96	High	Preventive maintenance programs are scheduled regularly and inspection SOP adjustments are integrated directly into the production line, with criteria visualized through drawing guides in the work area.
5	Overproduction	Output is not balanced with actual needs.	84	High	Production process optimization is carried out through reducing UHT cycle time, adjusting the scheduling of raw materials based on the level of maturity, and increasing the accuracy of measuring instruments.
6	Excessive Transportation	The time and distance of displacement increase, and the risk of material damage/loss increases.	36	Low	Layout adjustments made in production-related areas.
7	Excess Inventory	Inventory buildup, storage costs increase, and the risk of expiration/damage increases.	16	Low	Production monitoring and recording is carried out in an integrated manner, supported by pull-based systems, FIFO and visual control

Based on Table 4, the proposed improvements focus primarily on the three waste categories with Extreme risk levels: Unnecessary Motion, Overprocessing, and Waiting. The recommendations include workstation rearrangement and labeling, standardization of production parameters and inspection procedures, and the implementation of preventive maintenance programs. Improvements are also proposed for Defect, Overproduction, Excessive Transportation, and Excess Inventory through inspection standardization, production process optimization, layout adjustments, and inventory control. These recommendations are expected to address the identified causes of waste and improve the efficiency of the production process.

6. Future state mapping

Fig. 3 illustrates the proposed Future State Value Stream Mapping of the production process at PT XYZ. The mapping presents the improved production flow, covering all major stages from Water Treatment to Palletizing, with the respective Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA) activities in each process. Compared to the current state, the proposed mapping shows a reduction in non-value-added activities and waiting time between processes, resulting in a smoother production flow. The proposed total lead time is 568 minutes, while the value-added time remains at 170 minutes. Compared to the previous condition, which had a lead time of 687 minutes, there was a decrease in time of 119 minutes. The value-added time remains the same, so the improvements made focus on eliminating non-value added (NVA) activities. Thus, the after-conditions show a more efficient process flow and are closer to the concept of lean manufacturing.

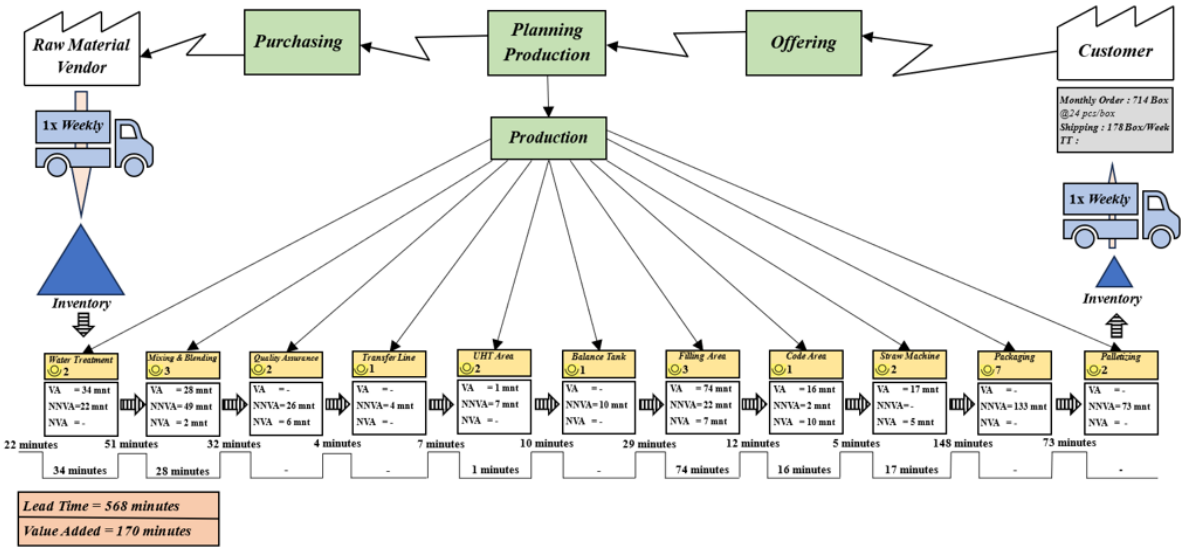


Figure 3. Future state mapping PT XYZ

Proposed PCE (Process Cycle Efficiency) Value

$$PCE = \frac{Value\ Added\ Time}{Total\ Lead\ Time} \times 10\%$$

$$PCE = \frac{170}{568} \times 10\%$$

$$PCE = 30\%$$

Based on the PCE calculation, the proposed improvement achieves a value of 30%, increasing from 25% in the initial condition. This improvement indicates an increase in production process efficiency, resulting from the reduction of non-value-added activities while maintaining the value-added time. Consequently, a greater proportion of the total production time is allocated to value-added activities..

5. Conclusion

Based on the results of the research, it was found that the most critical waste in the production process was unnecessary motion with a weight of 4.71, followed by waiting of 4.14, overprocessing of 3.86, overproduction of 3.57, defect of 3.43, excessive transportation of 2.86, and excess inventory by 2.57. These results show that the company's improvement priorities need to be focused on reducing non-value-added activities and lead times in the production process. Based on the improvement proposals formulated using the FMEA method and fishbone diagram, and supported by the application of Value Stream Mapping (VSM), non-value-added activities were successfully reduced by 119 minutes so that the production lead time decreased from 687 minutes to 568 minutes. These improvements have also increased the efficiency of the production process as shown by increasing the value of Process Cycle Efficiency (PCE) from 25% to 30%.

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