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Waste Evaluation in Crude Palm Oil (CPO) Production Using Lean Manufacturing Approach

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ABSTRACT

As business competition intensifies, an organization needs to streamline operations and improve plant performance, focusing on minimizing waste. At Company XYZ, inefficient processes have led to persistent waste in crude palm oil (CPO) production, particularly in the forms of motion, waiting, and transportation. The objective of this study is to identify waste in the CPO production, analyze its root causes, and propose actionable improvements. A lean manufacturing approach was employed using Value Stream Mapping (VSM), Waste Assessment Model (WAM), Waste Assessment Questionnaire (WAQ), Value Stream Mapping Tools (VALSAT), and Cause-and-Effect Diagram methodologies. The VSM analysis revealed motion, waiting, and transportation as the primary waste categories. Waste identification using WAM ranked motion as the most significant waste (19.39%), followed by waiting (14.91%), transportation (14.57%), overproduction (14.23%), defects (14.21%), inventory (14.17%), and overprocessing (8.52%). Process Activity Mapping (PAM) identified 34 activities, with 50% being value-added, 9% non-value-added, and 41% necessary but non-value-added. This research improves operational performance and productivity in CPO production using lean tools. These interventions are expected to reduce waste and enhance operational performance significantly.
Keyword: Waste Evaluation, Value Stream Mapping, Waste Assessment Model, VALSAT

ABSTRAK

Untuk dapat bertahan dalam persaingan bisnis yang ketat, perusahaan dituntut untuk merampingkan proses produksinya. Pada proses produksi CPO PT XYZ, masih ditemukan beberapa aktivitas pemborosan, dikarenakan prosesnya yang belum efisien. Penelitian ini bertujuan untuk mengidentifikasi pemborosan, menganalisis akar penyebab, dan mengusulkan perbaikan pada proses pengolahan CPO menggunakan *value stream mapping* (VSM), *waste relationship model* (WAM), *value stream mapping tools* (VALSAT), dan *cause-and-effect diagram*. Analisis VSM menunjukkan bahwa aktivitas pemborosan utama pada pengolahan CPO adalah *motion, waiting* dan *transportation*. Identifikasi menggunakan WAM menunjukkan bahwa pemborosan utama adalah *motion* (19,39%), diikuti oleh *waiting* (14,91%), *transportation* (14,57%), *over-production* (14,23%), *defects* (14,21%), *inventory* (14,17%), dan *over-processing* (8,52%). Identifikasi 34 aktivitas dengan *process activity mapping* (PAM) memperlihatkan bahwa 50% aktivitas bersifat value added (VA), 9% bersifat *non-value added* (NVA), dan 41% bersifat *necessary non-value added* (NNVA). Penelitian ini meningkatkan kinerja operasional dan produktivitas dalam produksi CPO menggunakan lean tools. Intervensi ini diharapkan dapat mengurangi pemborosan dan meningkatkan kinerja operasional perusahaan.
Keyword: Evaluasi Pemborosan, Value Stream Mapping, Waste Assessment Model, VALSAT

1. Introduction

Amid the rapid development and advancement of technology in the industrial era 4.0, the level of business competition has become increasingly intense and complex. To remain competitive, organizations need to streamline their production process, particularly by minimizing waste activities that have been proven to affect a company's profitability negatively[1]. However, the complexity and length of operations on the production floor often give rise to non-value-added activities (NVA) [2]. There are many methods and approaches that can be taken by companies to eliminate or minimize these waste activities, one of which is through a lean manufacturing (LM) approach [3]. LM is a systematic procedure aiming for identifying, reducing and eliminating waste that result from non-value-added activities [4]. Several lean tools and techniques have been widely discussed in the literature and previous studies [5]. When implementing lean manufacturing principles, an organization can opt for one specific tool or adopt it to combine several lean techniques [6]. For example, an organization may utilize a value stream mapping (VSM) concept [7], to visualize the material and information flow and identify the respective value and non-value-added activities throughout the production cycle or a process activity mapping (PAM), which identifies value-added and non-value-added activities [8]. Likewise, organizations can also choose other lean methodologies, such as the waste assessment model (WAM). The WAM methodology enables organizations to identify the source of waste and categorize and rank waste levels based on their significance using The Waste Relationship Matrix (WRM) and the Waste Assessment Questionnaire (WAQ) are utilized to evaluate and rank waste within production processes. [9][10]. In addition, the single-minute exchange of die (SMED) methodology can be utilized in order to reduce the setup or changeover time by rearranging or translating internal to external setups [11]. Furthermore, the poka-yoke or 'mistake-proof" technique can also be employed to prevent waste, particularly motion waste, by designing a fail-safe mechanism. Moreover, other tools that have been widely applied are the 5S methodology and value stream analyzing tool (VALSAT). The 5S methodology focuses on organizing, sorting, shining, setting in order, and standardizing the workplace to enhance productivity [12], while VALSAT is used to analyze production processes and identify areas for improvement.

PT XYZ is one of the palm oil companies in West Sumatera specializing in producing two main palm related products: CPO and kernel. The company has a production capacity of 80 tons of processed CPO per hour. The CPO and palm kernel production requires several stages, including weighing fresh fruit bunches (FFB), unloading FFB, loading ramp, sterilizing, hoisting crane, threshing, pressing, and clarification. Based on observations and field studies, PT XYZ experienced production problems in the form of process inefficiencies due to high oil losses as shown in Table 1. One of the main contributors to these oil losses is waste-related activities in the CPO production process [13]. Waste is a non-value-added activity that affects the performance of the palm oil processing production system [14].

Table 1. Plan and Realization Data

Year	Raw Material Plan	CPO Production Plan	Raw Material Realization	CPO Production Realization	Target Yield	Yield realization	Description
2018	441.861	83.953,612	432.7692,80	73.836,717	19%	17.06%	Not Efficient
2019	427.008	81.131,520	360.073,020	63.939,741	19%	17.76%	Not Efficient
2020	430.080	81.715,200	380.930,490	67.754,469	19%	17.79%	Not Efficient
2021	433.152	82.298,880	401.518,940	70.136,972	19%	17.47%	Not Efficient
2022	453.120	86.092,800	445.810,640	75.117,356	19%	16.85%	Not Efficient

Observations conducted in the PT XYZ process department showed several waste activities during the CPO processing process. One identified waste was a technical error involving the placement of lorries using the hoisting crane outside the designated lane, necessitating rework to correct the placement. This re-laying process results in waste in the form of unnecessary motion and waiting, which prolongs the production lead time. Similarly, the waste also occurs at the loading ramp station, where the transfer carriage operator repeatedly moves back and forth when moving the lorry from the rail to the sterilizer station. This excessive motion leads to waste in the form of excessive transportation as this activity does not any value for the final product or system. The existence of waste in the CPO production process will undoubtedly cause losses for the company.

2. Research Methodology

A mixed-method research methodology was employed in this research, incorporating the data collection and analysis for qualitative and quantitative data. Brainstorming and interview sessions with relevant parties were performed in order to acquire qualitative data. In contrast, quantitative data were obtained through various measures such as direct observation, motion and time study, WRM and WAQ. Two data types (primary and secondary) were employed in the research. While the secondary data were obtained from the literature study, the organization’s production record, and other relevant information, the primary data were acquired through direct observations of the production process, including process times and waste identification

The outline of the research is as follows. The first stage of the research is the preliminary study in which the relevant literature and previous studies were reviewed in order to acquire essential information and general knowledge of the research topic. Once the basic and general understanding was obtained, the research process would move to the problem formulation and identification stage. This phase includes defining problems into clear questions that guide the researcher in their research pursuits. Once the problem formulation was clearly defined, the data collection and processing stage took place. The relevant data and information included the general overview or information of the company, production data, cycle time, waste identification, and waste relationships, which were collected through direct observations, questionnaires, and mapping tools such as the WRM, WAM, and VALSAT. Once data were collected, documented, processed, and analyzed to extract insight or research implications. Finally, the research culminated in a conclusion phase, where the research results were summarized.

3. Results and Discussion

The palm oil (CPO) production process comprises several stages, including weighing fresh fruit bunches (FFB) as raw materials, unloading FFB, the loading ramp process, sterilization (boiling/softening of FFB), threshing, pressing, oil refining (clarifying), and finally, storage. Based on field observations, the cycle time for each of these processes was recorded. The collected cycle time data was subsequently analyzed for adequacy and uniformity to determine the standard time, as shown in Table 2.

Table 2. Standard Time Data of CPO Production Process

Processing Stages	Processing Time (s)	Data Adequacy	Data Uniformity
Weighing	397,67	sufficient	uniform
Unloading	3833,63	sufficient	uniform
Loading ramp	2431,47	sufficient	uniform
Sterilizing	7256,43	sufficient	uniform
Hoisting crane	323,7	sufficient	uniform
Threshing	3175,53	sufficient	uniform
Pressing	3175,53	sufficient	uniform
Clarifying	303,11	sufficient	uniform

3.1. Current Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a diagrammatic tool designed to identify and analyze activities in a production process that either add value or do not contribute to value creation [15]. The VSM diagram serves as an initial step in visualizing the flow within the production process, encompassing both material and information flows [7]. In designing or developing the current VSM diagram for PT XYZ's CPO production, data was collected through various methods, including field observations, brainstorming sessions, interviews with relevant stakeholders, and other approaches. The resulting VSM of PT XYZ's current production process is illustrated in Figure 1.

3.2. Waste Evaluation using WAM

This research adopts the WAM approach to assess and identify waste in the production process. The WAM framework, developed by [10], comprises three stages: the Seven Waste Relationships (7S), the WRM, and the WAQ. According to Rawabdeh, the seven types of waste can be grouped into three primary categories: human-related waste (motion, waiting, and overproduction), machine-related waste (over-processing), and material-related waste (transportation, inventory, and defects).

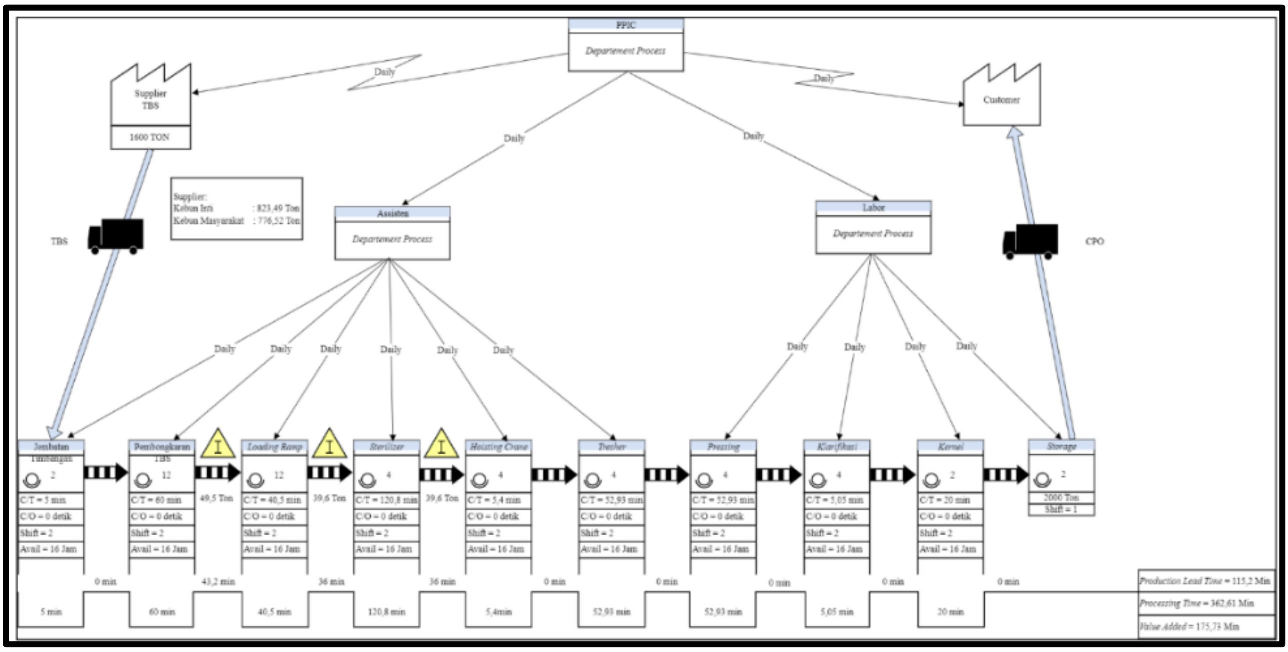

Figure 1. Current Value Stream Mapping

The WRM serves as a tool to identify relationships between different types of waste. Meanwhile, the WAQ is used as a diagnostic tool to determine the dominant type of waste [10]. In identifying waste within the CPO production process using the WAM approach, data was collected by distributing the WRM and WAQ questionnaire forms to four employees in the process department. The data obtained from these questionnaires were processed, and the results were used to create the WRM and WAQ recapitulations, as shown in Table 3 and Table 4 below.

When using the waste assessment model (WAM) methodology, several questionnaires must be distributed to assess the waste relationship matrix. In doing so, this research utilized inputs derived from three respondents involved in this research to evaluate the waste relationships. These respondents are from various background and position. They are the production supervisor, assistant supervisor, hoisting crane operator, and press operator from the production department of PT XYZ. They were selected based on their expertise and experience.

Table 3. Waste Relationship Matrix

F/T	O	I	D	M	T	P	W	Skor	%
O	10	2	2	6	6	0	6	32	14,68
I	4	10	4	8	6	0	0	32	14,68
D	4	2	10	6	8	0	4	34	15,60
M	0	4	2	10	0	6	8	30	13,76
T	4	4	2	8	10	0	8	36	16,51
P	2	4	2	6	0	10	8	32	14,68
W	4	4	4	0	0	0	10	22	10,09
Skor	28	30	26	44	30	16	44	218	100
%	12,84	13,76	11,93	20,18	13,76	7,34	20,18	100	

Table 4. WAQ Recapitulation

	O	**I**	**D**	**M**	**T**	**P**	**W**
Score (Yj)	0,6288	0,584	0,637	0,582	0,601	0,659	0,610
Pj Factor	188,536	202,0032	186,0113	277,7544	202,0032	107,735	203,687
Yj Final	118,549	118,0474	118,4111	161,5748	121,4618	70,966	124,243
Final Result (%)	14,227	14,167	14,211	19,391	14,577	8,517	14,911
Rangking	4	6	5	1	3	7	2

3.3. VALSAT

Once the final results of waste identification are obtained using the WAM approach, the next step involves selecting detailed mapping tools through the VALSAT matrix. There are specific guidelines to follow when using VALSAT matrix: a score of 1 indicates low correlation, 3 indicates medium correlation, and 9 indicates high correlation. The data processing procedure with VALSAT approach involves multiplying VALSAT matrix by the weight of each waste. The results of these calculations will reveal which tools have the highest score, and these tools will be used for conducting detailed mapping. The recapitulation of VALSAT calculation results and rankings is shown in Table 5.

Table 5. Results of Selection and Ranking of VALSAT

Waste/Structure	Weight	PAM	SCRM	DAM	DPA	PVF	QFM	PS
Overproduction	14,23	14,23	42,68	0,00	14,23	42,68	42,68	0,00
Inventory	14,17	42,50	127,50	42,50	0,00	127,50	42,50	14,17
Defects	14,21	14,21	0,00	0,00	127,90	0,00	0,00	0,00
Motion	19,39	174,52	19,39	0,00	0,00	0,00	0,00	0,00
Transportation	14,58	131,19	0,00	0,00	0,00	0,00	0,00	14,58
Overprocessing	8,52	76,65	0,00	25,55	8,52	0,00	8,52	0,00
Waiting	14,91	134,20	134,20	14,91	0,00	44,73	44,73	0,00
Total	100,00	587,49	323,77	82,96	150,64	214,92	138,43	28,74

From Table 5 above, it is evident that the PAM ranks as the highest-scoring tool, with a score of 587.49. PAM will subsequently be utilized as a detailed mapping tool for the production process. This mapping serves to identify VAs, NNVAs, and NVAs. The data required for detailed PAM mapping is gathered through direct measurements, observations, and interviews. The results of the PAM mapping for PT XYZ's CPO processing activities are presented in Table 6.

Table 6. Process Activity Mapping

No	Station	Activity	Machine	Time	Number of Worker	Type of Activity					VA/NVA/NNVA
						O	I	T	S	D	
1	Weighing	Weighing FFB	Scales	300	2	X					VA
2	Weighing	Transportation of FFB to unloading station	Truck	97,8	0			X			NNVA
3	Unloading	Unloading FFB	Truck	1213,8		X					VA
4	Unloading	Sorting TFFB	Truck	321,6	12		X				VA
5	Unloading	Temporary stacking of FFB	*Bulldozer*	2298						X	NVA
6	*Loading ramp*	Process of loading ramp FFB	*Loading ramp*	679,2		X					VA
7	*Loading ramp*	Process loading FFB into lorry	*Loading ramp*	312,6		X					VA
8	*Loading ramp*	Carrying FFB to sterilizer station	*Loading ramp*	900	4			X			NNVA
9	*Loading ramp*	Controlling transported FFBs	*Conveyor*	540						X	NVA
10	*Loading ramp*	Transporting FFB with conveyor chain	*Conveyor*	120				X			NNVA
11	*Sterilizer*	Temporary stacking of FFB	*Sterilizer*	1356,6						X	NVA
12	*Sterilizer*	Load the lorry into the sterilizer for FFB boiling	*Sterilizer*	5400	4	X					VA
13	*Sterilizer*	Pulling the lorry out of the sterilizer station	*Conveyor*	126				X			NNVA
14	*Sterilizer*	Waiting for the hoisting crane to lift the FFB lorry	*Conveyor*	253,8	4			X			NNVA
15	*Hoisting crane*	Attaching the hoisting crane chain to the lorry	*Thresher*	45		X					VA
16	*Hoisting crane*	Transporting the boiled FFBs to the thresher machine	*Thresher*	150		X					VA
17	*Hoisting crane*	Positioning the lorry parallel on the main rail	*Thresher*	114	4			X			NNVA
18	*Hoisting crane*	Attaching the hoisting crane chain to the lorry	*Thresher*	30		X					VA

No	Station	Activity	Machine	Time	Number of Worker	Type of Activity					VA/NVA/NNVA
						O	I	T	S	D	
19	*Thresher*	Separation of palm kernels from palm kernel baskets	*Thresher*	1328,4		X					VA
20	*Thresher*	Checking the palms that still have loose palm kernels	*Bunch press*	630			X				VA
21	*Thresher*	Carrying empty baskets to landfill	*Bunch press*	318		X					VA
22	*Thresher*	Transporting kernels to the screw press	*Conveyor*	900				X			NNVA
23	*Pressing*	Pressing the crushed fruit	*Screw press*	2832				X			NNVA
24	*Pressing*	Bring dirty CPO to clarification station for refining	*Screw press*	344,4				X			NNVA
25	Clarification	Separation of palm oil from impurities	*Clarifier*	60	4	X					VA
26	Clarification	Screening CPO with vibrating screens	*Vibrating scree*n	84		X					VA
27	Clarification	Temporary storage of CPO oil in crude oil tanks	-	48					X		NNVA
28	Clarification	Transport dirty CPO to continuous storage tank for further separation	-	30		X					VA
29	Clarification	Storage of CPO into pure oil tanks	-	36					X		NNVA
30	Clarification	Put the oil into a vacuum dryer to reduce the moisture content	-	48		X					VA
31	Kernel	Processing the kernel	-	1224	0	X					VA
32	Storage	Filling CPO into storage tanks.	*storage tank*	0	1				X		NNVA
33	Storage	Waiting for pure CPO to be loaded into delivery tanks	-	0	0				X		NNVA
34	Storage	Filling pure CPO into delivery tanks	truk	0	1			X			NNVA
	Total lead time process CPO			**22141,2**	**40**	**15**	**2**	**10**	**4**	**3**	

Based on the detailed mapping above, activities can be grouped according to the level of value they add to the production process. This grouping revealed 17 VAs, accounting for 50%, 3 NVAs, representing 8.82%, and 14 NNVAs, making up 41.18%. From the waste identification process using VSM, the process cycle efficiency (PCE) of the CPO processing process was calculated as follows.

$$PCE = \frac{Total\ value\ added}{Total\ lead\ time}\ x\ 100\% = 55\% \quad (1)$$

The process cycle efficiency (PCE) value of 55% in the current VSM indicates that the efficiency of the CPO processing process is not yet optimal. Detailed mapping using the PAM technique highlights the presence of 3 NVAs and 14 NNVAs, underscoring the need for improvements to enhance process efficiency. Waste identification using the WAM approach revealed that the three most significant types of waste in CPO processing are motion, waiting and transportation. Based on the findings, the root causes of these wastes we further analyzed using a fishbone diagram as shown in Figure 2.

The fishbone diagram analysis reveals that waste motion arises from unnecessary movements, such as errors by the hoisting crane operator that result in the lorry being improperly positioned on the rail and the placement of bulldozer tools far from the workstation. Waste related to waiting occurs due to additional time required for unloading the lorry from the hoisting crane because of the presence of errors, such as lorry wheels slipping off the rails, necessitating tools to reposition the lorry correctly. Meanwhile, waste transportation is identified at the loading ramp station, where a limited number of transfer carriages necessitate repetitive lorry transfers.

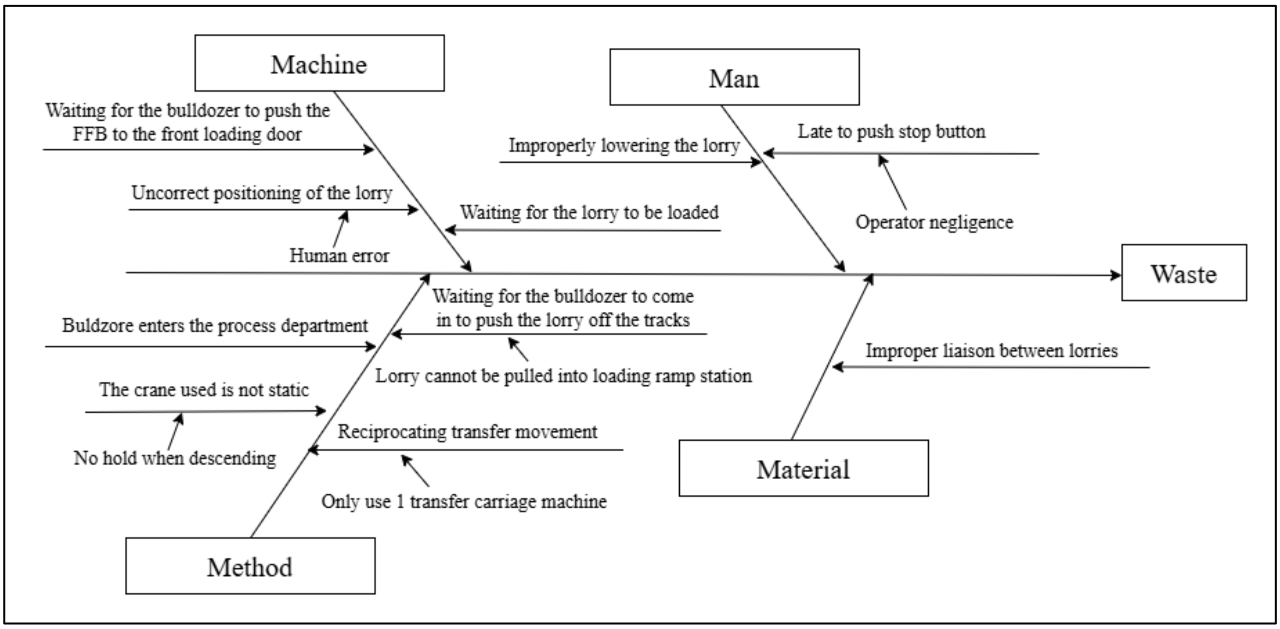

Figure 2. Fishbone Diagram

Based on the PAM analysis above, it is possible to reduce NVAs and minimize work time on NNVAs. Out of the 34 activities identified within the process department, these improvements could reduce the total number of activities to 31. Table 7 compares FFB processing production times at PT XYZ based on the PAM analysis.

Table 7. Process Activity Mapping

No	Station	Activity	Machine	Time	Number of Worker	Type of Activity					VA/NVA/NNVA
						O	I	T	S	D	
1	Weighing	Weighing FFB	Scales	300	2	X					VA
2	Weighing	Transportation of FFB to unloading station	Truck	97,8	0			X			NNVA
3	Unloading	Unloading FFB	Truck	1213,8		X					VA
4	Unloading	Sorting TFFB	Truck	321,6	12		X				VA
5	Unloading	Temporary stacking of FFB	*Bulldozer*	0						X	NVA
6	*Loading ramp*	Process of loading ramp FFB	*Loading ramp*	679,2		X					VA
7	*Loading ramp*	Process loading FFB into lorry	*Loading ramp*	312,6		X					VA
8	*Loading ramp*	Carrying FFB to sterilizer station	*Loading ramp*	900	4			X			NNVA
9	*Loading ramp*	Controlling transported FFBs	*Conveyor*	0						X	NVA
10	*Loading ramp*	Transporting FFB with conveyor chain	*Conveyor*	120				X			NNVA
11	*Sterilizer*	Temporary stacking of FFB	*Sterilizer*	0						X	NVA
12	*Sterilizer*	Load the lorry into the sterilizer for FFB boiling	*Sterilizer*	5400		X					VA
13	*Sterilizer*	Pulling the lorry out of the sterilizer station	*Conveyor*	126	4			X			NNVA
14	*Sterilizer*	Waiting for the hoisting crane to lift the FFB lorry	*Conveyor*	253,8				X			NNVA
15	*Hoisting crane*	Attaching the hoisting crane chain to the lorry	*Thresher*	45		X					VA
16	*Hoisting crane*	Transporting the boiled FFBs to the thresher machine	*Thresher*	150		X					VA
17	*Hoisting crane*	Positioning the lorry parallel on the main rail	*Thresher*	60	4			X			NNVA
18	*Hoisting crane*	Attaching the hoisting crane chain to the lorry	*Thresher*	30		X					VA
19	*Thresher*	Separation of palm kernels from palm kernel baskets	*Thresher*	1328,4	4	X					VA

No	Station	Activity	Machine	Time	Number of Worker	Type of Activity					VA/NVA/NNVA
						O	I	T	S	D	
20	*Thresher*	Checking the palms that still have loose palm kernels	*Bunch press*	630			X				VA
21	*Thresher*	Carrying empty baskets to landfill	*Bunch press*	318		X					VA
22	*Thresher*	Transporting kernels to the screw press	*Conveyor*	900				X			NNVA
23	*Pressing*	Pressing the crushed fruit	*Screw press*	2832				X			NNVA
24	*Pressing*	Bring dirty CPO to clarification station for refining	*Screw press*	344,4				X			NNVA
25	Clarification	Separation of palm oil from impurities	*Clarifier*	60		X					VA
26	Clarification	Screening CPO with vibrating screens	*Vibrating screen*	84		X					VA
27	Clarification	Temporary storage of CPO oil in crude oil tanks	-	48					X		NNVA
28	Clarification	Transport dirty CPO to continuous storage tank for further separation	-	30		X					VA
29	Clarification	Storage of CPO into pure oil tanks	-	36					X		NNVA
30	Clarification	Put the oil into a vaccum dryer to reduce the moisture content	-	48		X					VA
31	Kernel	Processing the kernel	-	1224	0	X					VA
32	Storage	Filling CPO into storage tanks.	*storage tank*	0	1				X		NNVA
33	Storage	Waiting for pure CPO to be loaded into delivery tanks	-	0	0				X		NNVA
34	Storage	Filling pure CPO into delivery tanks	truk	0	1			X			NNVA
Total lead time process CPO				**17893**	**40**	**15**	**2**	**10**	**4**	**3**	

Data analysis was based on the total lead time calculations, and the total production time was reduced to 298.21 minutes. These results demonstrate that the proposed improvements have had a positive impact. The future state mapping of the production section at PT XYZ Plantation Unit POM, reflecting these improvements, is shown in Figure 3, highlighting the reduction of waste in CPO production.

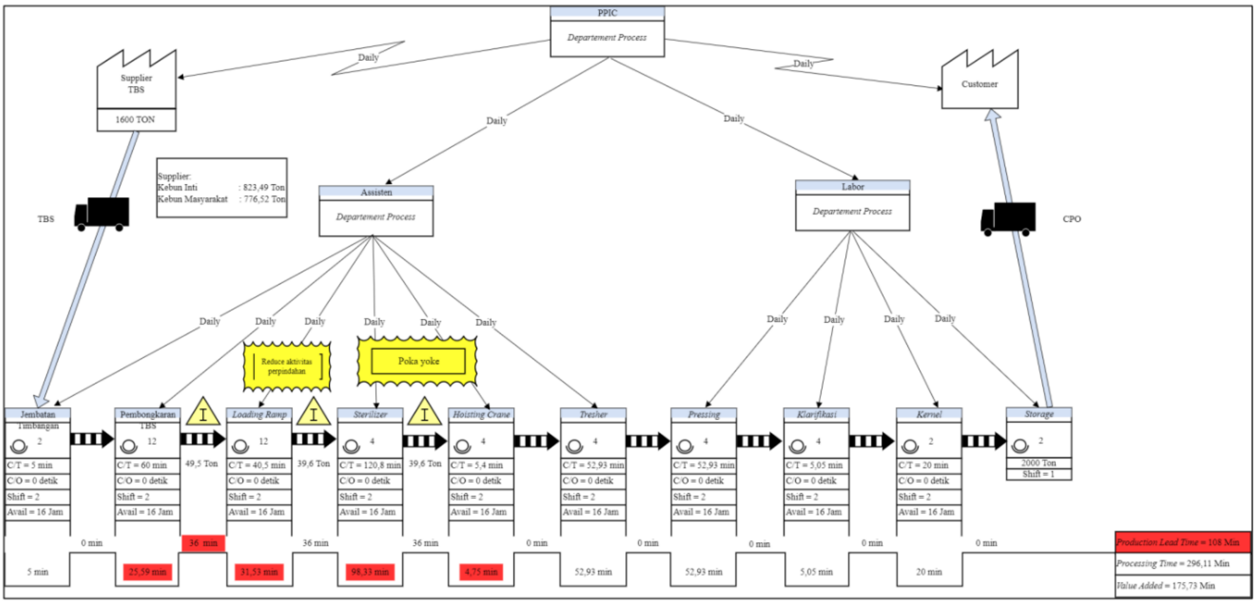

Figure 3. Future VSM

4. Conclusion

Waste in the FFB processing at PT XYZ, as identified through Value Stream Mapping (VSM), includes waiting, delay, motion, and overproduction. The results from waste identification using the WRM and WAQ show the following order of waste in the CPO production: motion (19.39%), waiting (14.91%), transportation (14.57%), overproduction (14.23%), defects (14.21%), inventory (14.17%), and overprocessing (8.52%). The PAM analysis revealed 34 activities, with 50% value-added (VA) activities, 8.82% non-value-added (NVA) activities, and 41.18% necessary but non-value-added (NNVA) activities. The Process Cycle Efficiency (PCE) before improvements was 55%, and after implementing improvements through future state mapping, the PCE increased to 68%, showing a 13% improvement.

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