Implementation of Lean Manufacturing to Reduce Production Cycle Times and CO2 Emission in Gate-to-Gate Life Cycle Assessment in the Biodegradable Plastic Industry

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Abstract

The main focus of the industry in the 21st century is sustainability and customers. On a world scale, plastic produces a large carbon footprint during the process of producing to become plastic pellets. Biodegradable plastic is a sustainable solution to this environmental problem. Unfortunately, sustainable products tend to have high production costs. Lean manufacturing has been proven to provide advantages for manufacturing companies in the form of eliminating waste to increase product value and customer satisfaction. Value stream mapping (VSM) is an important tool of the lean approach and is used to identify and reduce activities that do not add value. Life Cycle Assessment (LCA) is a systematic method for evaluating the environmental burden associated with a product, process, or activity, by identifying and measuring the energy and materials consumed and the waste released into the environment. This study aims to implement the concepts of lean manufacturing and life cycle assessment at the gate-to-gate stage in the biodegradable plastics industry to reduce cycle time and environmental impact to cut production costs therefore products can be sold at lower prices. In this paper, various aspects closely related to lean manufacturing are analyzed and reviewed, such as business process reengineering (BPR), layout optimization, machine automation, line balancing, and increased capacity. The results showed that the combination of VSM and LCA with simulation is a good alternative in making decisions to reduce cycle time and environmental impact on the Biodegradable Plastics Industry.

Keywords
Lean Manufacturing, Life Cycle Assessment, Value Stream Mapping, Business Process Reengineering, Plastic Biodegradable

1. Introduction
Based on Indonesian Marine Debris Monitoring document published by the Ministry of Environment and Forestry (KLHK) (2017), shows that marine debris in Indonesia is dominated by plastic waste by 41% of the total composition of marine waste in Indonesia. This can be shown in Figure 1. As reported by ScienceMag, the increase in the amount of plastic waste from 1950 to 2015 has increased by 190 times, with an average increase of 5.8 tons per year. According to the World Economic Forum in The New Plastic Economy, Rethinking the Future of Plastic, the ratio of fish in the ocean to plastic will be 1:3 in 2025.

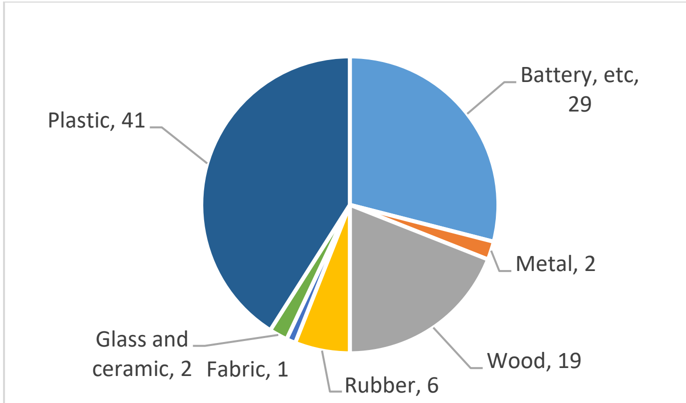

Figure 1. The composition of waste in the Indonesian seas in 2017

Apart from the upstream impact, the downstream impact of plastic is also dangerous. Plastic contributes to greenhouse gases that cause the climate crisis from the extraction and production process. Ninety-nine percent of the main raw materials for plastic in the world are oil and natural gas extracted or taken from the non-renewable bowels of the earth. The process of extraction and refining to become plastic pellets requires a lot of energy. This results in large carbon emissions. On a world scale, plastic produces a carbon footprint of 1,781 million Metric Tonnes of CO2. Sixty percent of these emissions are generated during the process of producing and transporting petroleum into plastic pellets (Zheng and Suh 2019). This can be shown in Figure 2.

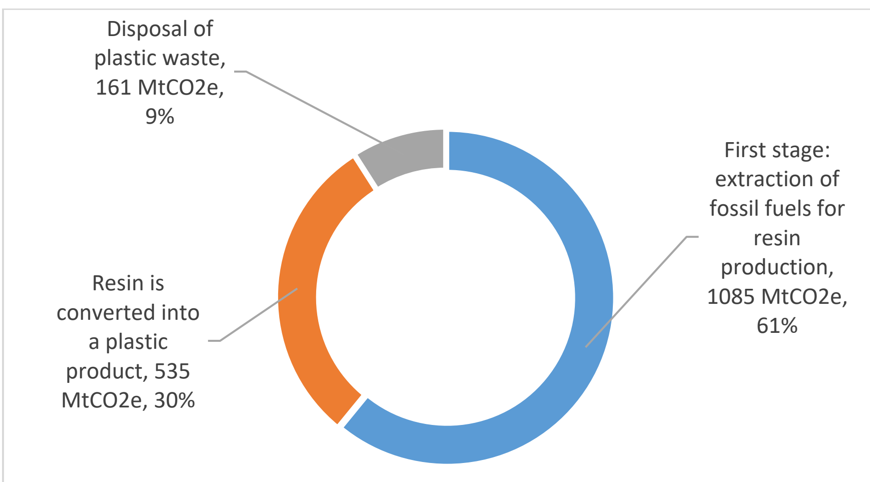

Figure 2. Life Cycle Emissions from plastic-based fossil fuels

One of the sustainable plastic industries that produces non-fossil energy-based products is the biodegradable plastic industry. Biodegradable plastics are defined according to standard ASTM D6866 as materials that determine the carbon/bio-based biogenic carbon content of solid, liquid, and gaseous samples using radiocarbon analysis. This product can also be reused or recycled. When the quality of plastic has decreased, plastic can be disposed of into biomass which can later be reused as raw material for biodegradable plastic. In addition to reducing waste in the environment, this life cycle can reduce carbon dioxide emissions. But on the other hand, this biodegradable plastic has not been widely accepted by the public because of its high price. According to SWA (2014), the price of biodegradable plastic is 2-2.5 times more expensive than conventional plastic. Table 1 below is a comparison of the prices of biodegradable plastic and conventional plastic sold in the market in 2022.

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Table 1. Price comparison of biodegradable and conventional plastics

Size	Biodegradable Plastic	Conventional Plastic
32/21 cm x 35 cm 20 mic	Rp 46.500, -/pack	Rp 9.000, -/pack
43/24 cm x 46 cm x 20 mic	Rp 57.500, -/pack	Rp 11.000, -/pack
40/28 cm x 45 cm x 25 mic	Rp 63.000, -/pack	Rp 17.000, -/pack

Therefore, to answer the challenge of lowering plastic prices, the biodegradable plastic industry must reduce production costs, by reducing the production cycle time. This can be done with lean manufacturing. The lean principle originates from the Japanese manufacturing industry. Lean manufacturing is an integrated system consisting of many interrelated elements whose main objective is to eliminate waste by reducing or minimizing the variability associated with supply, processing time, and demand (Shah and Ward 2003). Lean is a management philosophy that mainly stems from Taiichi Ohno's Toyota Production System (TPS) and was recognized as Lean in the 1990s. TPS is known for its focus on reducing waste seven to increase overall customer value (Yamamoto et al. 2019).

In the biodegradable plastic industry, there are many inefficient and non-value-added (waste) production processes, including no planning or forecasting, small capacity hot mix machines, the distance between hot mix machines and extruders far apart, the existence of a weighing process manual, and non-inline vacuum process. Therefore, to overcome this problem, the implementation of lean manufacturing was carried out in the aspects of business process reengineering, increasing production capacity, layout optimization, automated machines, and line balancing.

In practice, adopting sustainability into manufacturing processes is a challenging task. Lean manufacturing focuses on reducing costs by eliminating waste and non-value-added activities, while sustainability aims at protecting the environment. Researchers are currently working on the relationship between lean manufacturing and sustainability in the industry (Kowang et al. 2016). The study by Caldera et al. (2017) study the role of lean thinking in sustainable business practices and provide a new strategy called 'regenerative development' with nine main characteristics related to small and medium enterprises (SMEs) in Australia. Garza-Reyes et al. (2018) and Dieste et al. (2019) establish a positive relationship between lean methods and environmental performance. Logesh and Balaji (2021) conducted an experimental investigation to implement green manufacturing by reducing waste using lean tools in an electrical components manufacturing company.

Research on the combination of lean manufacturing and life cycle assessment (LCA) to reduce cycle times and environmental impacts is interesting research to do. LCA is a systematic method for evaluating the environmental burden associated with a product, process, or, activity, by identifying and measuring the energy and materials consumed and the waste released into the environment. The LCA system will evaluate environmental impacts based on input data from manufacturing processes such as energy requirements, time intervals, and materials for a product. The implementation reported in this study is to apply LCA techniques at the gate-to-gate level and revise existing manufacturing flows with Lean tools (Figure 3).

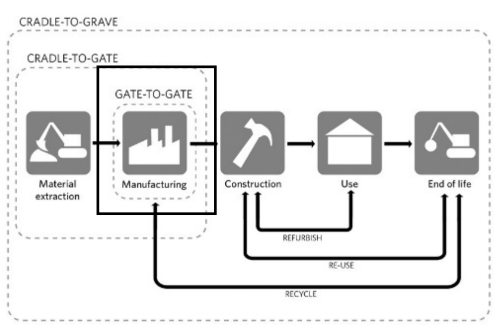

Figure 3. Stage of Life Cycle Assessment

In the biodegradable plastic industry, the manufacturing level has the largest carbon emission value compared to the stages of making flour by farmers, changing resin into bags, recycling, landfilling, and composting. Therefore, this is in line with the implementation of lean manufacturing to reduce carbon emissions at the manufacturing level.

Value stream mapping (VSM) is an important tool of the lean approach and is used to identify and mitigate non-value-added activities with the end goal of redirecting production practices to align with Lean thinking and establishing plans for future improvement. Mapping the current state aims to identify waste in the production line. Future states are suggested with improvements to eliminate waste, reduce cycle time, and environmental impact

1.1. Objectives

This study aims to carry out improvement and re-engineering of the production process by applying the concept of lean manufacturing and life cycle assessment in the biodegradable plastics industry to reduce production cycle time and environmental impact.

2. Literature Review

The main focus of the industry in the 21st century is sustainability and customers. Organizations that focus on cycle time as a measure of productivity can reduce delivery times and improve quality, thereby increasing customer satisfaction. Currently, companies are required to have a sustainable competitive advantage strategy to achieve company goals, namely company performance that generates relatively high profits. Many companies use lean manufacturing principles to reduce TAKT time, cycle time, and waiting time to increase productivity and speed of delivery.

Identifying non-value-adding activities, such as unbalanced workloads, setup time, idle time, and improper layouts is also key to reducing costs. Any activity that a customer may be willing to pay for is a value-added activity, whereas any activity that does not contribute to the physical completion of a product or service is non-value-added. To determine the percentage added value, it is necessary to calculate the processing time, namely the sum of the cycle times of all operations in a production process. Following is a further explanation of lean manufacturing and its aspects, and a life cycle analysis.

2.1. Lean Manufacturing (LM)

Lean can be defined as a systematic approach to identify and eliminate waste, or non-value-adding activities through continuous improvement by flowing products (materials, work-in-process, output) and information using a pull system from internal and external to pursue excellence and perfection (Mutiara 2018).

Lean manufacturing is a process management philosophy that uses less labor, manufacturing space, tool investment, and engineering time to develop new products. LM aims to reduce operating costs and eliminate waste on the shop floor. In developing countries, the concept of lean has been introduced recently, for example in India, to be the most solutive problem-solving. Since lean manufacturing is a multi-dimensional construct, the results show that about 80% of the respondents have implemented multiple dimensions of Lean, especially focusing on customer requirements, recall systems, reduced setup time, increased production, supplier performance, statistical process control, and cross-cutting issues (Jadhav et al. 2014). Rekha et al. (2017) uses the concept of lean manufacturing, namely Line Balancing and Conveyor line efficiency to reduce cycle time. Chan and Tay (2018) use line balance, standardized work, and standardized layout in implementing lean manufacturing. Meanwhile, Sordan et al. (2021) in implementing lean manufacturing use line balancing which involves semi-automatic production lines assisted by industrial robots. In this study 5 aspects of systematic lean improvement, namely business process reengineering, layout optimization, automated machinery, line balancing, and increased capacity. Lean manufacturing is applied in this research to reduce cycle time significantly.

2.2. Value Stream Mapping (VSM)

Value Stream Mapping is a lean technique used to analyze the flow of materials and information currently required to bring a product or service to consumers. VSM is used to identify areas for improvement and to eliminate waste. By reducing waste, the proportion of value-added time increases throughout the process and the speed of process output can also be increased. This makes the redesigned process more effective and efficient (Nallusamy & Adil Ahamed 2017). Dinesh and A. Prabhukarthi (2013) explained value stream mapping in the pomp manufacturing industry. Florin

Buruiana and AMGoncalves Coelho (2009) have mapped out the current state of affairs in the shaft manufacturing industry. On the future state map, researchers can change supermarket pull systems and one work cell and reduce waiting times. Sawjiani and Shiralkar (2022) explain that VSM can reduce the storage time for the "Deutz Head 8047" section in inventory so that it can reduce storage costs and avoid unnecessary inventory with the VSM method. And many other studies apply the Lean Manufacturing concept with the VSM method in many industries. However, there has been no research that applies the Lean Manufacturing concept to the biodegradable plastic industry.

2.3. Life Cycle Analysis (LCA)

Life Cycle Assessment (LCA) is one of the environmental management techniques used to evaluate environmental sustainability, energy used, environmental audits, and environmental impact assessments. LCA is a method for analyzing the entire cycle from the production process to waste treatment by looking at costs, energy used, and environmental damage, starting from taking raw materials to making products. The use of LCA method has four main options for determining the boundaries of the system used based on the ISO 14044 standard in an LCA study, namely cradle to grave, cradle to gate, gate to grave, and gate to gate. The main focus of this research is at the gate-to-gate stage, namely by comparing the LCA values of conventional plastics, the biodegradable plastic industry before implementing lean manufacturing, and the biodegradable plastic industry after implementing lean manufacturing.

2.4. Business Process Reengineering

BPR is defined as “Radically redesigning processes to achieve significant improvements in cost, quality, and service” (Davenport and Short 1990). BPR can be applied in various conditions, for example, conditions where the company is in big trouble and there are no alternative solutions, conditions where the company is in trouble as a result of changes in the surrounding environment, and conditions where the company has a lot of pressure so there is no solution. Business activities must be seen as groups of people or even total tasks that must be partitioned into processes that can be designed more effectively in both manufacturing and service environments. For the successful implementation of this process, a fundamental change is needed by ensuring that this change is conceptualized correctly, the quality of the company's workforce is good and its implementation culture is established within the organization (Isakhani and Mir-Ghaderi 2011). The BPR that was carried out in this study was to change make to order to forecasting.

2.5. Layout

Facility layout issues have a significant impact on the productivity and efficiency of a manufacturing system. Generally, layout problems relate to the optimization of facility space and location (e.g., machines, departments) and are orientation optimizing system performance within the facility space (Al-Zubaidi et al. 2021). Inadequate layout is also a possible cause of the problem, as it relates to non-value-added handling and transport (Forno et al. 2014). In China, since space is mostly not a constraint, each operation is usually allocated a dedicated area separate from each other. As a result, the distance between operating processes becomes long. The most common objective in implementing facility layouts is to minimize material handling costs between facilities (Reisinger et al. 2022).

2.6. Line Balancing

Generally, line balancing relates to the level of productivity. Line balancing is affected by the standard time and the number of workers, which in turn affects the company's productivity. A higher level of balancing indicates better performance. Therefore, to increase productivity further, it is necessary to optimize line balancing. Ongkunaruk and Wongsatit (2014) stated that initially the line balancing problem was developed for efficient mass production of standardized products. The line balancing tool tries to allocate the same amount of time for workers in each process so that the production flow can be smooth and without long waiting times. However, in the real situation of labor-intensive production processes, the task time is uncertain as it depends on other factors including worker skills, work environment, fatigue, etc. As a result, task times often vary within the workforce. (Chan & Tay 2018).

There are still many other studies that apply the concept of Lean Manufacturing in many industries. However, there is still little research that applies the concept of Lean Manufacturing and Life Cycle Assessment simultaneously, especially in the biodegradable plastic industry. In this study, 5 aspects of lean were systematically improved, namely business process reengineering, layout optimization, automated machinery, line balancing, and capacity building. Lean manufacturing is applied in this research to reduce cycle time significantly. While the life cycle assessment is to reduce environmental impact.

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3. Methods

A well-known method for visualizing time wastage in manufacturing systems is value stream mapping (VSM). The current state of VSM captures all value-added and non-value-added activities involved in the set of processes required to manufacture a part/product (Black and Phillips, 2010). The methodology proposed in this study is based on the lean concept with a case study strategy. Data is collected and structured to understand the problem effectively. The stages of VSM are shown in Figure 4.

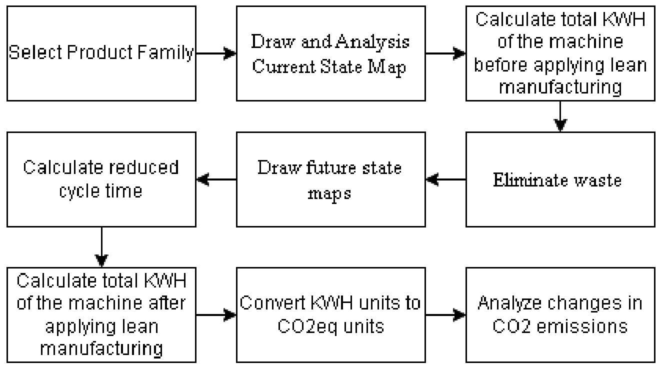

Figure 4. Stage of VSM

All processes are not mapped in value stream analysis. A particular product family is chosen for mapping. A family is a group of products that undergo similar processing steps which are performed by the same set of machinery. After selecting a proper product family, the current state or as-is state of the plant is mapped. Cycle time, changeover time, and delivery time at each stage are needed to calculate the total KWH. Data adequacy tests on cycle time, changeover time, and delivery time at each stage were carried out to find out whether the amount of observed data was sufficient to conduct research. The number of observations that must be made in work sampling will be influenced by two factors, namely the level of accuracy and the level of confidence. The data adequacy test formula is shown below.

$$N' = \left(\frac{\frac{C}{\alpha} \cdot \sqrt{N \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i \right)^2}}{\sum_{i=1}^{N} x_i} \right)^2$$

N : Totalobservational data
N' : Total theoretical data
C : Confidence level
α : Degree of accuracy

If the resulting value is N > N' then the data is sufficient. After that, analyze the current state map to determine waste, process bottlenecks, and bottleneck points. Current condition maps are analyzed for all wastes and priority is set for any wastes found. The seven wastes listed in the TPS are overproduction, waiting, transportation, improper processing, unnecessary inventory, unnecessary movement, and defects. Waste found in the current state map is eliminated based on its priority. The production flow process is made more continuous and pull is prioritized over push.

The next step is to calculate the total KWH of the machine before implementing lean manufacturing. After that, eliminate waste and draw a map of the future state. The five identified lean aspects are implemented. The five lean aspects are shown in Figure 5.

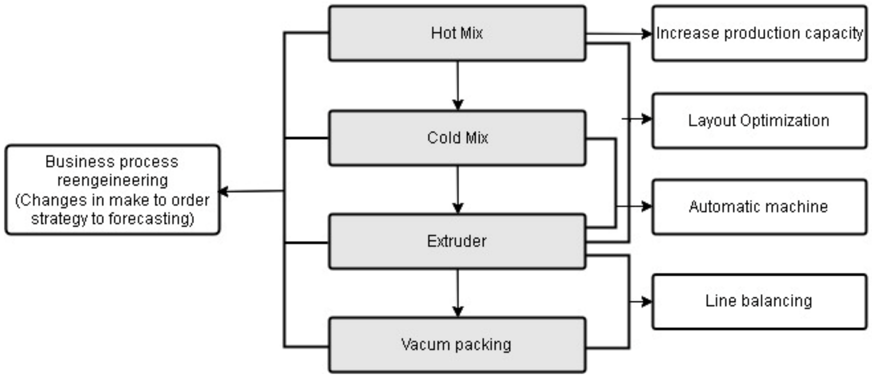

Figure 5. Five lean aspects to implemented

After implementing the five lean aspects above, the next step is to calculate the reduced cycle time, total KWH of the machine before and after implementing Lean Manufacturing, and change the calculation unit to kgCO2eq to determine changes in CO2 emissions.

4. Data Collection

The calculation of cycle time, changeover time, and delivery time in each stage was divided into 6 subgroups based on observation days with 6 replications with a 99% confidence level and 0.01 degree of accuracy. Calculation results show that the value of N' is smaller than the value of N. Therefore, sampling data is sufficient to represent production data. The result adequacy test is shown in Table 2.

Table 2. Result in adequacy test

Machine	Time	Data collected per day	Total days	N	N'	Information
Hot Mix	Cycle Time	6	6	36	2.240344	N > N'. Enough data.
	Changeover Time	6	6	36	21.16024	N > N'. Enough data.
	Delivery Time	-	-	-	-	Distance to the next stage is close. Therefore, is no delivery time.
Cold Mix	Cycle Time	6	6	36	1.454405	N > N'. Enough data.
	Changeover Time	6	6	36	31.75356	N > N'. Enough data.
	Delivery Time	6	6	36	25.46338	N > N'. Enough data.
Extrusion	Cycle Time	6	6	36	0.065426	N > N'. Enough data.
	Changeover Time	-	-	-	-	Using a continuous system
	Delivery Time	-	-	-	-	Distance to the next stage is close. Therefore, is no delivery time.
Extrusion	Cycle Time	6	6	36	35.8837	N > N'. Enough data.
	Changeover Time	6	6	36	32.98067	N > N'. Enough data.
	Delivery Time	-	-	-	-	Distance to the next stage is close. Therefore, is no delivery time.

Electricity usage per hour, electricity usage when heating, heating time, cleaning time, waste cleaning per heating, machine capacity, input, output, number of operators, working time per shift, rest time per shift, and the distance to the next machine are identified. The results of data collection obtained total added value and non-value-added value.

Table 3. shows data before implementing lean manufacturing (business process reengineering, layout optimization, automated machines, line balancing, and production capacity increase), and Table 4. shows data after implementing lean manufacturing (business process reengineering, layout optimization, machine automation, line balancing, and increased production capacity).

Table 3. VA and NVA before implementing Lean Manufacturing

	Hot Mix	Cold Mix	Extrusion	Packing	Total
CT (hours)	256.31	94.62	132.00	54.45	537.38
CO (hours)	21.94	12.28	0.00	110.55	144.78
DT (hours)	0.00	9.22	0.00	0.00	9.22
VA (days)	12.21	4.51	5.50	2.59	24.80
NVA (days)	1.38	0.92	0.58	5.26	8.14

Table 4. VA and NVA after implementing Lean Manufacturing

	Hot Mix	Extrusion	Packing	Total
CT (hours)	14.028	132.00	54.45	200.478
CO (hours)	6.216	0.00	54.45	60.66
DT (hours)	1.596	0.00	0.00	1.596
VA (days)	0.668	5.50	2.59	8.76
NVA (days)	0.344	0.083	2.59	3.02

Apart from time, electricity reduction before and after lean manufacturing is also calculated. This electricity data is used to determine changes in CO2 emission values. Table 5. shows data before implementing lean manufacturing (business process reengineering, layout optimization, automated machines, line balancing, and production capacity increase), and Table 6. shows data after implementing lean manufacturing (business process reengineering, layout optimization, machine automation, line balancing, and increased production capacity).

Table 5. Data on electricity and emission CO2 before implementing lean manufacturing

Machine	Total hours	Electricity (KW)	Emission CO2 (kg CO2/kWh)
Hot Mix	285.25	9630.69	7887.54
Cold Mix	123.12	3428.08	2807.60
Extrusion	146.00	12159.84	9958.91
Packing	165.00	125.24	102.57
Total	719.37	25343.85	20756.61

Table 6. Data on electricity and emission CO2 after implementing lean manufacturing

Machine	Total Hours	Electricity (KW)	Emission CO2 (kg CO2/kWh)
Hot Mix	22.84	782.54	640.90
Extrusion	134.00	11613.36	9511.34
Packing	108.90	125.24	102.57
Total	265.74	12521.14	10254.81

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5. Result and Discussion

Data collection in this study was carried out by identifying non-value-added and value-added activities at all stages of the process. Furthermore, the type of waste is identified. According to Taiichi Ohno, there are 7 (seven) types of waste commonly found in a company. The seven types of waste are transportation, inventories, motion, waiting/delay, overproduction, over-processing, and defects. The current state is mapped using VSM to analyze the waste in each process. In mapping current business processes, the marketing department provides purchase order information to the production control department. The production control department will manage the order, calculate material requirements, and schedule production. After that material is ordered. The time of purchase until the goods arrive at the warehouse is approximately 7 working days. Then the manufacturing process begins. Starting from the hot mix process, which is a process of mixing tapioca flour and other ingredients with a certain composition and temperature. The cold mix process is a process of mixing materials without heating with a certain composition. The extruder process is the process of melting material and changing material shape to resin. The last, packing process, is the process of wrapping goods using a vacuum machine. VSM before applying lean manufacturing is shown in Figure 6.

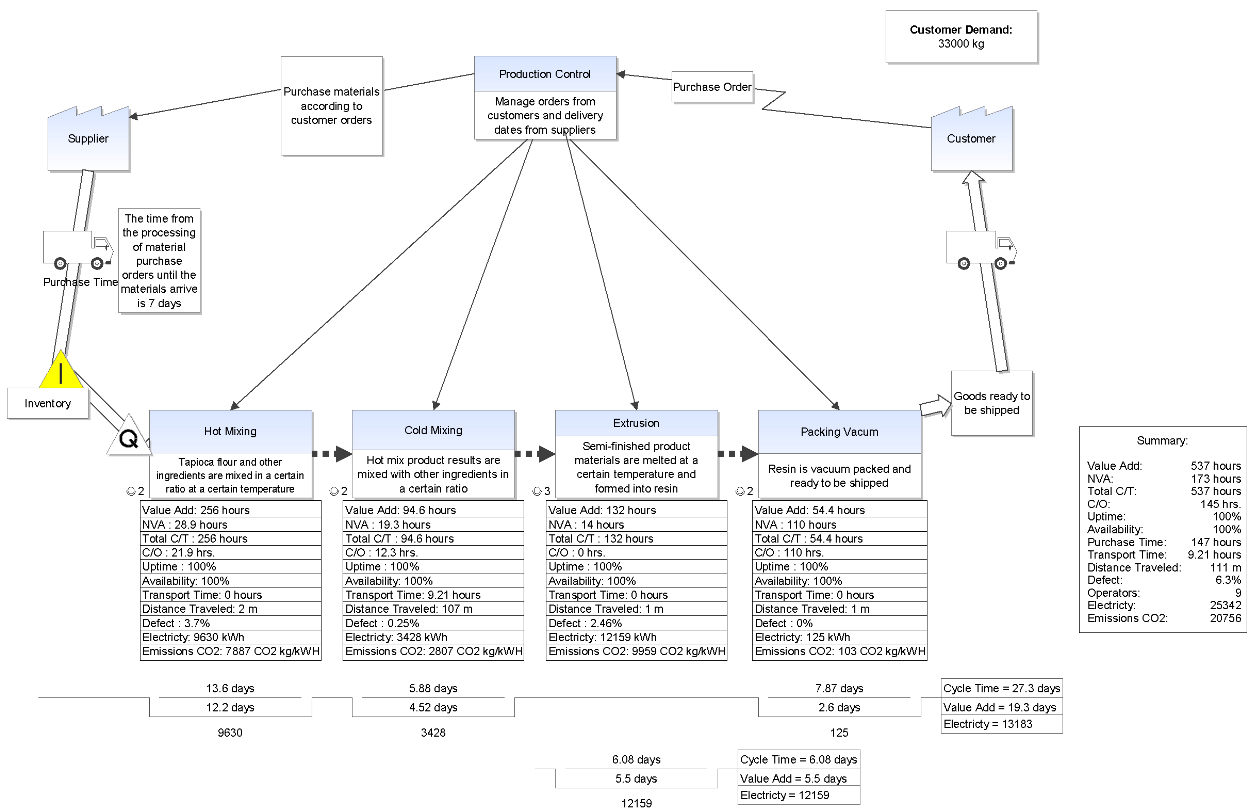

Figure 6. VSM before implementing lean manufacturing

In the marketing department found waste in fulfilling sales orders. Marketing provides information to PPIC by providing a sales order form every time a purchase order comes in from a customer. The production process is carried out after the delivery of this sales order. The high frequency of providing sales orders to PPIC every month causes waste in the setup and clean-up stages of the machine. The types of waste at this stage of the process are motion, over-processing, and defect. This can be avoided by implementing a strategy of Business Process Reengineering, namely changing the make-to-order strategy to forecasting, therefore that the frequency of machine setup and clean-up per month is reduced. Based on history, the forecast needed to execute an order within 1 month is 33,000 kg. In the hot mix process, there are many non-value-added activities, such as the material preparation process, mixed material weighing process, material input process, packaging preparation process to accommodate the WIP material, WIP material removal process, WIP weighing process, and WIP stacking process. The types of waste at this stage of the process are motion, over-processing, and defect. This non-value-added activities frequency can be reduced by increasing the capacity of the hot mix tank. The same thing happened in the cold mix process. However, because the cold mix process does not use heat, this process can be eliminated by installing an automatic mixer and weighing machine, namely the dosing unit on the extrusion feeder. In addition, the distance from the cold mix process to the extruder process is very far. This can result in high delivery times. This type of waste is classified as transport waste. This wastage can be reduced by layout optimization. In addition, by improving the hot mix process, the delivery process which was originally 600 kg per pallet can be increased to 1 ton per pallet. In the vacuum packing process, there is a type of waiting waste. The vacuum output is smaller than the extruder output. This is due to the manual vibrator process in the vacuum packing process. Therefore, it is necessary to apply line balancing, namely balancing the line between the extruder process and the vacuum process. The material coming out of the extrusion is immediately packed using a vacuum mall and vibrated with an automatic vibrator. The future state is mapped using VSM. Figure 7 is showing VSM after implementing lean manufacturing.

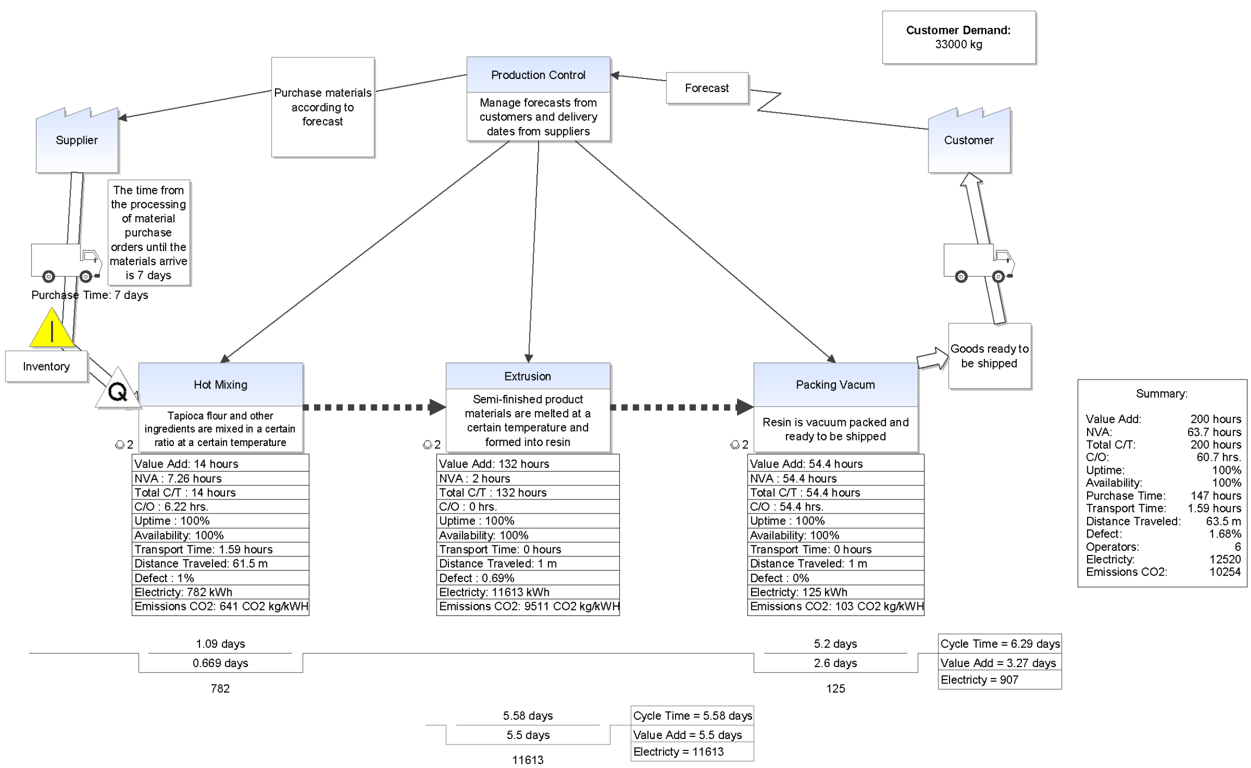

Figure 7. VSM after implementing lean manufacturing

The difference in the total cycle time can be shown in the hot mix process which previously required 285.25 hours, reduced to 22.84 hours. In the cold mix process, from the previous process which required 123.12 hours it was reduced to 0 hours. In the extruder process, the previous process which required 146 hours, was reduced to 134 hours. The packing process, which previously process which required 165 hours, was reduced to 108.9 hours. This reduction in cycle time is directly proportional to the reduction in electricity usage. Before applying lean manufacturing, the electricity used to fulfill a sales order of 33,000 kg was 25,343 kWh, whereas after implementing lean manufacturing it was reduced to 12,521 kWh. It is also directly proportional to the amount of CO2 emissions. Before implementing lean manufacturing, the CO2 emissions generated to fulfill a 33,000 kg order were 20,756 kg CO2/kWh, whereas after implementing lean manufacturing it was reduced to 10,254 kg CO2/kWh.

6. Conclusion

The environmental impact caused by the manufacturing industry has started forcing organizations to expand their performance metrics from economic to environmental aspects. Thus, sustainability and lean become benchmarks for the manufacturing sector. Changing stakeholder requirements, global competition, and pressure to integrate

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sustainability practices are challenges for the manufacturing industry. Lean manufacturing focuses on reducing costs by eliminating waste and non-value-added activities, while sustainability aims at protecting the environment. In this study, calculations of changes in CO2 emission values were carried out before and after the implementation of lean manufacturing. VSM is used to map current and future conditions. The combination of lean manufacturing and LCA in this study is proven to reduce cycle times from previously 719.37 hours to 265.74 hours, and reduce CO2 emission values from previously 20756.61 hours to 10,254 kg CO2/kWh.

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