Integration of Waste Assessment Model and Lean Automation to Improve Process Cycle Efficiency in the Automotive Industry

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ABSTRACT

Purpose: This study aims to improve Process Cycle Efficiency (PCE) by reducing waste in the assembly production line. This research is a case study conducted in a four-wheel vehicle manufacturing company to create a Lean production system.

Methodology/Approach: This study uses the Waste Assessment Model (WAM) and Lean Automation integration methods carried out by 5 expert judgements in the selected four-wheeled vehicle industry.

Findings: Based on the WAM method, this study found the biggest waste on the assembly line, namely transportation with a percentage of 20.44%. Improvements made with Lean Automation can increase the value of PCE from 56.76% to 63.62%.

Research Limitation/Implication: This research is limited to one model, namely Multi Purpose Vehicle (MPV). This research provides benefits for companies related to waste reduction. For similar companies, this research can be input for manufacturing practitioners in improving manufacturing performance to compete in the global market. This Lean production can reduce manpower which has an impact on saving production costs.

Originality/Value of paper: This paper provides added value related to the application of Lean terminology which aims to improve industrial automation-based manufacturing companies.

Category: Case study

Keywords: assembly line; lean automation; process cycle efficiency; value stream mapping; waste assessment model

1 INTRODUCTION

Indonesia, Thailand, Malaysia and the Philippines are known as the “ASEAN-4 cluster” and are the dominant automotive players in Southeast Asia (Irawati and Charles, 2010). Based on ASEAN Automotive Federation (2020) shows that the total production of four-wheeled vehicles in ASEAN reached 4,158,953 units in 2019. Indonesia is a country that has developed rapidly as an exporter of four-wheeled vehicles and is the world’s leading automotive producer (Syah, 2019). After starting vehicle assembly in the 1920s, for the first time Indonesia has produced more than 1 million vehicles. Thus making Indonesia the 17th largest vehicle producer in the world (Natsuda, Otsuka and Thoburn, 2015). Currently, competition is an ongoing challenge faced by industrial companies, especially four-wheel vehicle manufacturers. Manufacturers of four-wheeled vehicles strive to continuously improve the efficiency of the production system by reducing non-value-added activities (NVA) (Swarnakar and Vinodh, 2016; Garza-reyes et al., 2017; Chaurasia, Garg and Agarwal, 2019). This is one of the best ways to be able to compete in the global market.

The automotive industry is one of the industries most actively involved in efforts to improve quality, productivity, labour efficiency and continuous improvement activities (Habidin et al., 2016; Psomas and Antony, 2019). Several research studies clearly show significant opportunities for efficiency improvements in the automotive industry through the implementation and higher utilization rates of Lean management (Kaneku-Orbegozo et al., 2019; Prabowo and Adesta, 2019).

According to Liker and Meier (2006), waste is one of the biggest problems in the manufacturing industry. One way to identify waste is to use the Waste Assessment Model (WAM) method (Marifa et al., 2018). The advantage of this model is the simplicity of the matrix and questionnaire that covers many things and can contribute to achieving accurate results in identifying the root causes of waste. WAM is often integrated with the Lean method as an improvement method. Lean is a Lean production concept that is suitable for creating an effective and efficient production system (Prayugo and Zhong, 2021). The Lean approach can eliminate waste to improve manufacturing performance (Setiawan and Hasibuan, 2021). Lean is a sustainable strategy to reduce waste.

Several studies related to Lean have a great effect on the manufacturing industry, including reducing manpower, reducing lead time, saving production costs, increasing productivity and increasing customer satisfaction. The purpose of this research is to increase the efficiency of the cycle process by reducing the waste in the assembly production line. This research is a case study in the Automotive Industry. The method used is the Waste Assessment Model (WAM) to determine the greatest waste and Lean Automation as a method of improvement.

2 LITERATURE REVIEW

2.1 Waste Assessment Model (WAM)

WAM is a model developed to simplify the search for waste problems and identify ways to eliminate waste. This model states the relationship between the seven wastes (Henny and Budiman, 2018; Paramawardhani and Amar, 2020). Waste Relation Matrix (WRM) is a matrix used to analyze the measurement criteria (Tannady et al., 2019). Waste Matrix Value (WMV) is the conversion of each symbol into a score in the form of a percentage which serves to simplify the matrix. The Waste Assessment Questionnaire (WAQ) is a tool to identify and allocate waste that occurs in the production line. The waste value on the WAQ is obtained from the WRM that has been done previously and is used for the initial WAQ assessment based on the type of question. WAQ consists of 68 different questions.

2.2 Lean Concept

Terminology of Lean Manufacturing is a system efficiency approach by reducing waste (Leksic, Stefanic and Veza, 2020; Rifqi et al., 2021). A good production system needs to identify non-value added activities in the production chain. Non-value added activities should be eliminated to reduce production lead time (Siregar et al., 2018; Rizkya et al., 2020). Manufacturing organizations effectively use Lean tools and techniques to identify and eliminate waste through continuous improvement (Zahrotun and Taufiq, 2018). While Lean Automation refers to the incorporation of Lean production with digital automation technology into the operationalization of practice (Dănuţ-Sorin, Opran and Lamanna, 2020; Tortorella, Narayanamurthy and Thurer, 2021; Tortorella et al., 2021). This method is supported by the Value Stream Mapping (VSM) tool, where previously we need to map current conditions and prepare for future conditions (Lacerda et al., 2016; Seth, Seth and Dhariwal, 2017; Narkea and Jayadevab, 2020; Setiawan, Tumanggor and Purba, 2021). The VSM technique serves as a powerful tool in enabling organizations to implement Lean manufacturing models (Romero and Arce, 2017; Nallusamy and Adil Ahamed, 2017; Ikatrinasari, Hasibuan and Kosasih, 2018).

3 METHODOLOGY

This research uses the WAM method and Lean approach. This study uses primary data and secondary data. Primary data was collected through field observations. The data is obtained directly to observe the real conditions in the company such as the four-wheeled vehicle assembly process which is then described on the VSM map. Primary data was also collected through interviews and distributing questionnaires to 5 expert judgement who had at least 5 years of experience in assembling four-wheeled vehicles with a minimum position as manager. Secondary data is obtained through the company's annual report such as production capacity, number of workers and processing time. This study uses systematic steps to get the best results. This research step is divided into 3 stages, namely as follows:

Stage 1: Define the problem phenomenon that occurs in the production line. Determine research objectives based on the phenomenon of the problem. Conducting a literature review on WAM and Lean. The literature review is used to gain an understanding of research methods.

Stage 2: Collecting data and identifying the flow of the four-wheeled vehicle assembly process using VSM. Identifying 7 wastes is done by distributing questionnaires to obtain information from the company regarding waste that occurs in the assembly process using the WAM method. This stage requires accurate data and information so that the results obtained can be properly accounted for. The data used in the calculation of availability time, takt time, calculation of uptime, change over time, value-added (VA) and non-value-added (NVA), total lead time and PCE. To calculate PCE can use formula (1) and calculate efficiency value use formula (2):

$$PCE = \frac{Value\ Added\ Time}{Total\ Process\ Lead\ Time}\ x\ 100\% \tag{1}$$

$$E = \frac{\sum_{i-1}^{n} Wi}{\mathrm{n.Ws}}\ x\ 100\% \tag{2}$$

Stage 3: Make improvements to the largest waste based on WAM results. After the improvement is done then suppress with the future process flow. The implications of the research are discussed to determine the contribution of research to the industry. Finally, conclusions are obtained based on the results of improvements that have been made to the production line. The stages of this research can be seen in Figure 1.

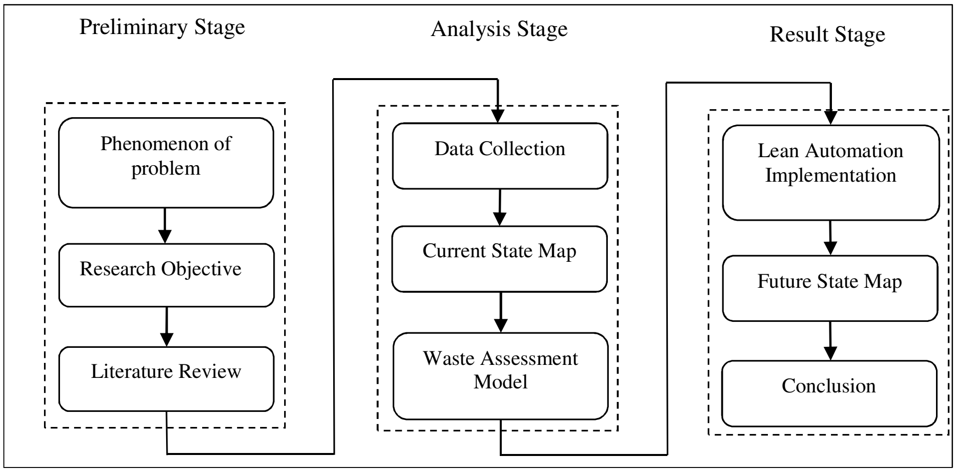


Figure 1 – Study Framework

4 RESULT AND DISCUSSION

4.1 Analysis of WAM

This chapter will discuss problem-solving analysis based on the research steps that have been determined. Then an analysis of the implications of this research is carried out as the value of the research contribution to the industry. The analysis begins by making a VSM based on initial observations in the field. The following VSM current conditions can be seen in Figure 2.

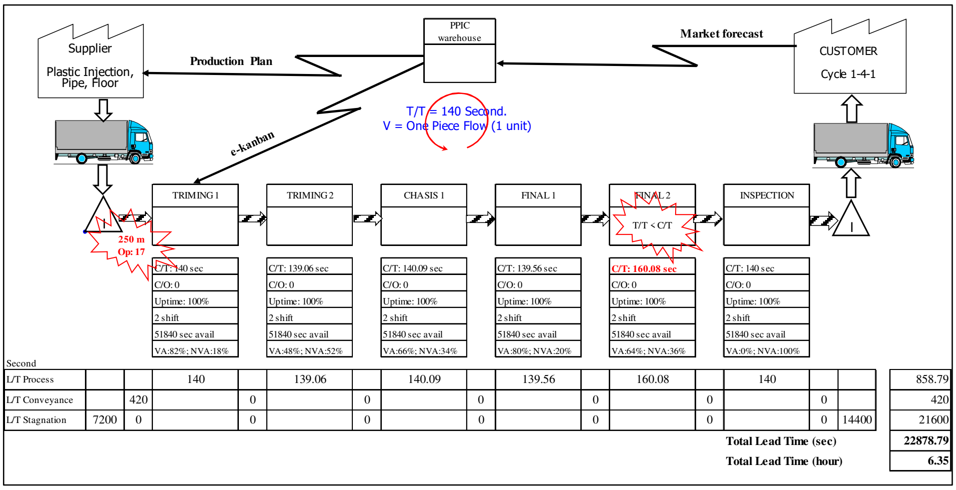


Figure 2 – Current State Map

Based on Figure 2, the Takt Time (T/T) value in the Final 2 process is less than C/T, which means that the final 2 process cannot meet the customer's demand so that improvements need to be made by minimizing activities that do not have added value. This assembly process is a process that has the same work elements, so the classification of work elements is divided into several activities such as the Install, walking, pickup, torque, marking, check, unpack, withdraw process. The following classification of work elements based on VA and NVA can be seen in Table 1.

Table 1 – Classification of NVA and VA Activities

Work Element Classification	Trim 1	Trim 2	Chassis	Final 1	Final 2	Inspection
Install	115	65.64	83.59	112.01	102,08	0
Walking	9	11.28	0	12.85	14	0
Take/put	5	37.06	40.76	14.7	16	0
Torque	0	0	9.16	0	0	0
Marking	0	0	6.58	0	0	0

Work Element Classification	Trim 1	Trim 2	Chassis	Final 1	Final 2	Inspection
Check	11	0	0	0	0	140
Unpack	0	17.45	0	0	28	0
Withdraw	0	7.63	0	0	0	0
Total	140	139.06	140.09	139.56	160.08	140
VA (%)	82.14	47.20	66.20	80.25	63.76	0
NVA (%)	17.85	52.79	33.79	19.74	36.23	100

The amount of production process performance can be determined by calculating PCE, which is using the total value add (VA) divided by the total process lead time. Where the total process lead time consists of the total process lead time from the beginning to the end. To calculate PCE can use formula (1), as $\frac{487.48}{858.79}\ x\ 100\% =\ 56.76\%$.

WAM is used to identify waste in each process. To get accurate data, respondents consisting of expert judgement must answer the questions in the waste assessment questionnaire that occurs in the production line and about the waste that may occur due to other waste. The results of the questionnaire were then assessed and ranked using WAM. Based on this assessment, it was found that transportation is the largest waste in the four-wheeled vehicle assembly process, which is 20.44%. This waste is the biggest waste that affects the entire production process. The summary of the percentage of waste that appears in the production process can be seen in Table 2.

Table 2 – Recapitulation Result of WAM

Remark	O	I	D	M	T	P	W
Score (Yj)	0.1416	0.1291	0.1274	0.0665	**0.1424**	0.0347	0.0765
Pj Factor	171.19	204.38	222.73	183.42	**215.74**	110.05	321.43
Final Result (Yj final)	24.24	26.39	28.37	12.20	**30.73**	3.82	24.59
Final Result (%)	16.13	17.55	18.87	8.12	**20.44**	2.54	16.35
Rank	5	3	2	6	**1**	7	4

Based on transportation activities from the warehouse to the assembly line, currently supplying materials uses the line stocking concept where materials are supplied to each assembly work station in packaging containers such as poly boxes, carton boxes, or pallets and the layout of materials in storage is arranged based on each supplier. The following process details can be seen in Figure 3.

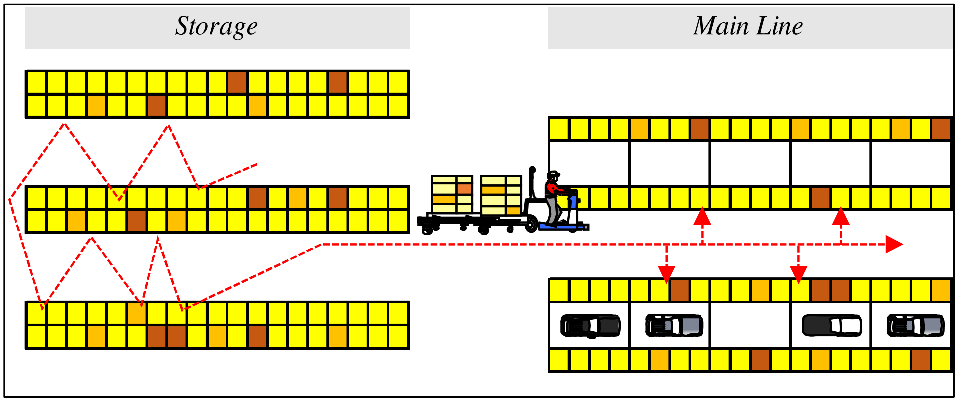


Figure 3 – Line Stocking Concept (Current Condition)

Based on the analysis, the weakness of this system is that sometimes operator errors occur in taking materials due to high material variations. The distance between the 1st, 2nd and so on material collection is very far and the process of finding material takes a lot of time, due to the large variety of vehicle models and stock parts are generated at each work station. The lead time (L/T) of the process of taking materials and supplying materials to the mainline needs to be calculated as the value of the efficiency line in terms of time and the use of labour in this transportation process. Based on the existing data, the average lead time of transportation in supplying materials is shown in Figure 4. (T/T is obtained from 140 seconds multiplied by the minimum material in the box = 3 materials so that 140 x 3 = 420 seconds). The overall efficiency value in the assembly process can be seen in Figure 4.

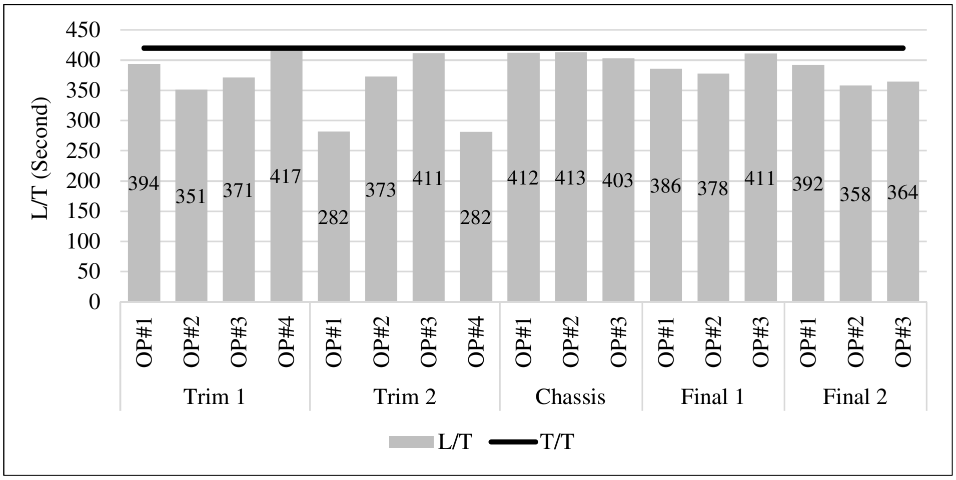


Figure 4 – Job Balancing Transfer Man Power

The efficiency value can be calculated by the formula (2) as $\frac{394+351+371+417+282+373+411+282+412+413+403+\cdots+364}{17\ x\ 417} x\ 100\% = \ 90.28\%.$

4.2 Improvement with Lean Automation

4.2.1Kitting System

Based on the FGD by expert judgment, the supply system will be changed from line stocking to kitting system, namely the delivery of materials to the mainline in a set and ready to be assembled. In this system, each material is collected, transported, and stored in a specific container which will be sent to the mainline. Where the layout in the material warehouse is arranged according to the order of material requirements on the mainline. The concept of kitting system can be seen in Figure 5.

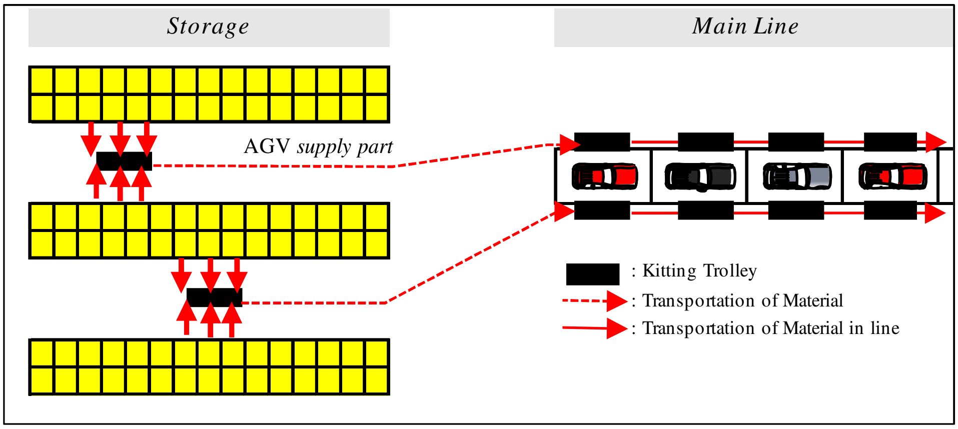


Figure 5 – Kitting System Concept (Future Condition)

The way this kitting system works is that the operator takes the material using a trolley that has been designed according to the shape of the material. This trolley contains materials that are arranged in sets for the needs of operators on the mainline. An example of a trolley kit can be seen in Figure 6.

Figure 6 – Trolley Kit

4.2.2Picking Lamp System

To reduce the time in the process of finding materials in the warehouse, we can combine it with an automation system that is integrated with the e-kanban system, where the operator will work based on the e-kanban command and the system will give a signal to the material warehouse in the form of a live light. This means that only materials with a live indicator light must be picked up by the operator to be set into the Trolley Kit so that the operator does not have to search for materials to be picked up. How the picking lamp system works can be seen in Figure 7.

Figure 7 – Picking Lamp Working System

4.2.3 Automatic Guided Vehicle (AGV)

Another improvement in transportation waste is implementing AGV. AGV is a vehicle that is guided automatically with computer technology. The way the AGV system works is a vehicle that can be programmed like a multi-purpose robot that is guided by a magnetic track attached to the floor. This fix is aimed at processes that do not add value. Improvement was made to replace human labour when supplying materials from the warehouse to the mainline using AGV. This AGV is part of an automated tool with low-cost automation so that it can reduce direct labour costs in this NVA activity. The way AGV works is bringing the Trolley Kit to the mainline so that it can replace human labour in supplying materials to the mainline as shown in Figure 8.

Figure 8 – Transport Parts with AGV System

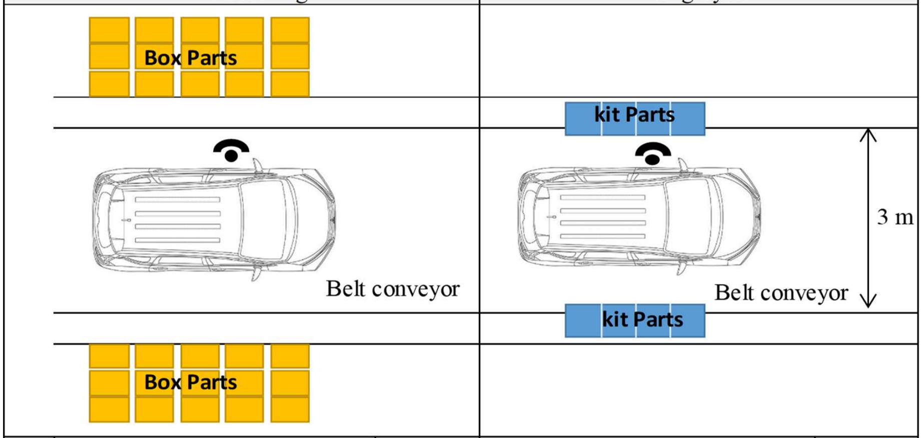
Based on improvements with Lean Automation, it can eliminate waste such as activities to find materials, supply materials and place materials beside the mainline as in the previous condition (line stocking concept). The results of this improvement can reduce operators for transportation activities as much as 6 people which has an impact on increasing the efficiency value on the transportation line to 98.72%. The following comparison between the number of manpower before and after the repair can be seen in Table 3.

Table 3 – Comparison between the Number of Man Power

Process	Trim 1	Trim 2	Chassis	Final 1	Final 2	Inspection	Total
Before	4	4	3	3	3	0	**17**
After	2	2	3	2	2	0	**11**

Improvements with this Kitting System automatically provide convenience to operators in the mainline process. The operator only needs to take the material and install it. This improvement can eliminate activities that do not have added value such as walking to pick up materials, sorting materials, unpacking materials and moving boxes. Based on the Final-2 process, it is known that T/T: 140 seconds < C/T: 160.08 seconds, meaning that the product completion time is longer than the customer's request or the delivery is late. With this Kitting System, we can eliminate work elements that are NVA, resulting in a decrease in cycle time from 160.08 seconds to 113.08 seconds. Improvements to the Kitting System can be seen in Figure 9.

Line Stocking			Kitting System	



No	Work Element	Time (s)	Work Element	Time (s)
1	Walk to the shelf	2	Walk to the shelf	1
2	Take a logo	2	Take a logo	2
3	Walk to the unit	2	Walk to the unit	1
4	Open logo in plastic	2	Open logo in plastic	0
5	Install logo	4	Install logo	4
6	Walk to the shelf	2	Walk to the shelf	1
7	Take rear lamp A	1	Take rear lamp A	1
8	Unwrap the rear lamp	18	Unwrap the rear lamp	0
9	Put the pack into the box	4	Put the pack into the box	0
10	Walk to the unit	2	Walk to the unit	1
11	Install rear lamp A	32.06	Install rear lamp A	32.06
12	Walk to the shelf	2	Walk to the shelf	1
13	Take rear lamp B	1	Take rear lamp B	1
14	Unwrap the rear lamp	8	Unwrap the rear lamp	0
15	Put the pack into the box	5	Put the pack into the box	0
16	Walk to the unit	2	Walk to the unit	1
17	Install rear lamp A	32.02	Install rear lamp A	32.02
18	Take the fuel cap and fuel label	2	Take the fuel cap and fuel label	1
20	Move box	3	Move box	0
21	Install cap fuel	14	Install cap fuel	14
22	Install fuel label	14	Install fuel label	14
23	Close the cap fuel and fuel lid	6	Close the cap fuel and fuel lid	6
Total		160.08	Total	113.08

Figure 9 – Comparison of Line Stocking and Kitting System

Based on the system replacement from Line Stocking to Kitting System as a whole, it can eliminate operator time in walking to pick up material on the outside of the assembly line, open boxes and move empty boxes to be returned to the bottom of the rack.

Based on these improvements, a new PCE was obtained, namely as follows (formula 1): $\frac{487.48}{766.21}\ x\ 100\% = 63.62\%$.

After improvement, the process lead time is reduced due to the elimination of processes that are considered unnecessary. The total lead time of the assembly process decreased from 22,878.79 seconds to 22,666.21 seconds. Based on the improvements that have been made to the assembly process flow, the company can find out a map of the future production process flow. Processes of the future become Leaner and more efficient. The following mapping of the future production flow can be seen in Figure 10.

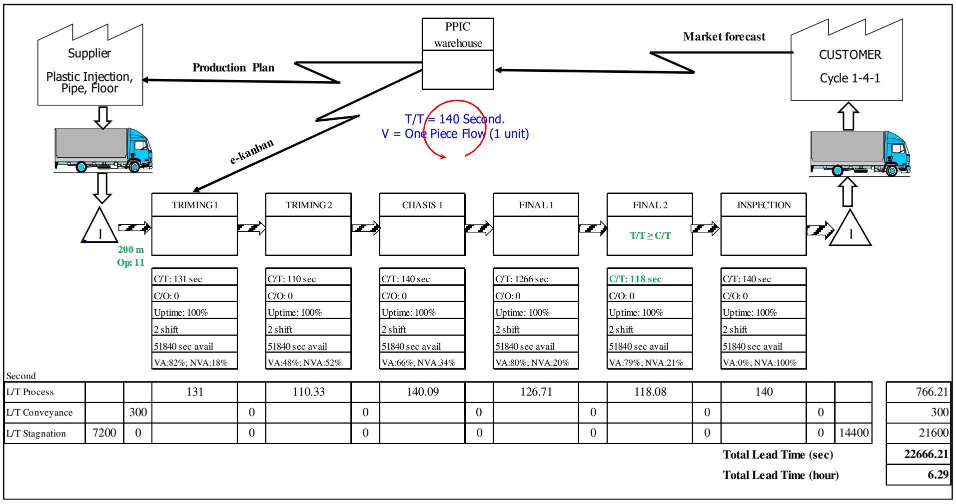


Figure 10 – Future State Map

These results indicate that lean production has a significant effect on the original production process. The comparison before and after the improvement can be seen in Table 4.

Table 4 – Comparison Before and After Improvement

Type of Activity	Before	After
Lead time (second)	22,878.79	22,666.21
Process Cycle Efficiency (%)	56.76	63.62

4.3 Research Contribution

This research provides benefits for companies related to waste reduction. For similar companies, this research can be input for manufacturing practitioners in improving manufacturing performance to compete in the global market. With this Lean production, it can improve manufacturing performance by saving production costs, reducing manpower, increasing productivity and increasing customer satisfaction. The improvements made in this study can be a good example to be applied, developed especially in the four-wheeled vehicle manufacturing process. Finally, improvement can support the company's sustainable business to become a world leader in manufacturing.

4.4 Comparison with Previous Research

Production line improvement using the WAM method can identify the biggest waste that must be repaired immediately to create an effective and efficient production system. This is in line with previous research (Henny and Budiman, 2018) that the WAM method can determine the largest waste. Most of the research with WAM is integrated with the Lean concept. This is in line to create a Lean production system. There are differences in the analysis of improvements in this study, namely making improvements with Lean Automation. The improvements made direct to modern industrial automation. This is a novelty in this study which shows the improvement of industry 4.0.

5 CONCLUSION

The results of identification using the WAM method obtained the largest waste in the four-wheeled vehicle assembly line for the MPV model. The biggest waste occurred is Transportation (20.44%), Defect (18.87%), Inventory (17.55%), Waiting (16.35%), Over Production (16.13%), Motion (8.12%), Process (2.54%).

Improvements in transportation waste are carried out using a Lean automation approach, where transportation activities or material transfer from the warehouse to the assembly line which were originally manual using human labour are replaced with AGV, so as to reduce human labour in the transportation or material handling section from 17 people to 11 people. This study also increased the value of PCE, which before improvement was 56.76% and after improvement increased to 63.62%. Future research can apply Lean concepts to all elements of the production process by integrating all production lines based on industrial automation.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.