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Research Article

The Implementation of Lean Automation and Kitting System Integration to Improve Assembly Line Efficiency in the Automotive Industry

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ABSTRACT

The rapid development of the automotive industry in Indonesia has intensified global competition, requiring manufacturers to continuously improve production efficiency and operational performance. However, inefficiencies remain in the final-2 assembly line, where excessive non–value-added activities such as unnecessary operator movement and part searching contribute to a high cycle time and low Process Cycle Efficiency (PCE). This study aims to reduce production inefficiencies by identifying and eliminating waste in the assembly process. The research employs the Value Stream Mapping (VSM) method to analyze the current production flow and determine sources of non–value-added activities. Based on the analysis, improvement initiatives were implemented through the integration of Lean Automation and the Kitting System. Lean Automation reduces manual repetitive tasks and minimizes operational waste, while the Kitting System organizes and supplies components to the assembly line in a structured and timely manner. The implementation results show a significant improvement in production performance, where the cycle time decreased from 160.08 seconds to 88.08 seconds. Consequently, Process Cycle Efficiency increased from 53.03% to 57.89%. These findings demonstrate that integrating VSM with lean automation and structured kitting effectively enhances production efficiency and supports the development of a more competitive automotive manufacturing system.

1. INTRODUCTION

The development of the automotive industry in Indonesia and the ASEAN region has shown a significant growth trend over the past two decades. Indonesia has become one of the largest automotive production bases in Southeast Asia, competing with Thailand and Malaysia in terms of production volume, investment, and innovation capability (Asean Automotive Federation (AFF), 2022; Hanson & Brolin, 2013). Government support through industry policies such as Making Indonesia 4.0 and the development of the electric vehicle ecosystem has driven improvements in national competitiveness. At the ASEAN level, market integration through the ASEAN Economic Community (AEC) has created vast opportunities for the automotive industry to expand its export reach, while also presenting challenges in maintaining production efficiency and tighter cost control (Natsuda et al., 2013, 2015; Tortorella et al., 2021). With rising market demand and increasing competition, automotive companies are required to enhance operational efficiency without compromising product quality (Muhammad & Yadrifil, 2018).

Along with these developments, manufacturing technology in the automotive industry has undergone a major transformation. Automation, production data digitalization, and the implementation of Smart

Manufacturing concepts have become the main focus in creating adaptive and efficient production processes (Kolberg et al., 2017; Malik & Bilberg, 2019; Setiawan et al., 2021). Technologies such as robotic assembly, automated guided vehicles (AGV), and picking lamp systems are increasingly adopted to improve production speed, precision, and consistency (Dosymov et al., 2024). However, technological advancements alone are not sufficient without efficient process flow. Many companies still face issues related to non–value-added activities such as waiting time, excessive material movement, and searching for components on the shop floor. These activities often go unnoticed but contribute significantly to wasted time and energy, thus reducing overall Process Cycle Efficiency (PCE) (Makwana & Patange, 2021; Nallusamy & Adil Ahamed, 2017; Paramawardhani & Amar, 2020).

To overcome these problems, the implementation of Lean Manufacturing principles has become a strategic approach. The lean concept focuses on reducing waste and increasing the value-added portion of every activity within the production process (Azevedo et al., 2019; Singh & Singh, 2020). By identifying and eliminating activities that do not deliver value to customers, companies can achieve higher process efficiency. The main principle of lean is to help organizations identify waste sources and create smoother production flow. However, in the modern industrial era, traditional lean implementation alone is often insufficient to achieve optimal performance levels (Chaurasia et al., 2019; Nallusamy, 2016).
Therefore, the concept of Lean Automation has emerged, representing an advanced level of lean by integrating automation technology into lean manufacturing principles. Lean Automation aims to combine the process efficiency of lean systems with the speed and precision of automation technology (Trstenjak & Cosic, 2019). This integration allows production activities to operate more quickly, consistently, and flexibly, while remaining focused on waste reduction. One of the most effective implementations of Lean Automation in the automotive industry is its integration with the Kitting System (Azevedo et al., 2019; Bucko et al., 2020).

The Kitting System is a material management method in which components required for the assembly process are organized and prepared in a single package (kit) according to the work sequence (Hanson & Medbo, 2019; Jainury et al., 2014). This system ensures that operators on the production line receive only the prearranged components, minimizing unnecessary searching and movement (Bevilacqua et al., 2012). The integration of the Kitting System with Lean Automation creates a more efficient working environment, as the entire material flow is systematically controlled and the component retrieval process can be automated using picking lamp system automation (Hanson et al., 2012; Hanson & Medbo, 2019; Jainury et al., 2014; Sali & Sahin, 2016).

By implementing the integration of Lean Automation and the Kitting System, automotive companies can achieve a significant increase in Process Cycle Efficiency (PCE) (Boudella et al., 2018). This improvement occurs as non-productive time is drastically reduced, allowing operators to focus solely on value-added activities, namely product assembly (Hanson & Medbo, 2019). Studies have shown that the implementation of this system can enhance assembly line efficiency while reducing assembly errors and waiting time between processes (Hanson & Medbo, 2019).

Previous studies have widely implemented the kitting system as an effective method for supplying parts to the assembly line. By preparing and grouping components in advance, the kitting system enables operators to receive all required parts in a single kit, thereby reducing part retrieval time and minimizing unnecessary movement during the assembly process. As a result, many studies have reported that the kitting system can successfully reduce cycle time in assembly operations. However, most previous research focuses primarily on improvements within the assembly line, while inefficiencies during the part picking process in the storage area are often not addressed.

This study proposes an integrated approach by combining lean automation through a picking lamp system with the kitting system. The novelty of this research lies in integrating these two approaches to reduce part searching time in storage and minimize non–value-added activities both in the storage area and the assembly line.

2. METHOD

This research was conducted through three main stages: the preliminary stage, analysis stage, and results stage. In the preliminary stage, the researchers identified the phenomena and problems occurring on the assembly line, particularly those related to low process efficiency. The research object was then determined, focusing on efforts to improve assembly line efficiency. A literature review was also carried out to explore recent and based on lean manufacturing and automation approaches.

The next phase was the analysis stage, in which secondary data were collected, including the cycle time of each workstation, waste identification and mapped using Value Stream Mapping (VSM) to illustrate the current process conditions (Permana et al., 2020; Suhardi et al., 2020).

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Once wasteful activities were identified, a root cause analysis was conducted, followed by the design of improvements using the Lean Automation approach combined with the Kitting System. This integration aimed to reduce non–value-added activities and streamline material flow across the production process (Swarnakar & Vinodh, 2016).

In the results stage, researchers measured the outcomes of implementing Lean Automation and the Kitting System in improving assembly line efficiency. A post-improvement Value Stream Mapping (VSM) was then developed to compare the conditions before and after implementation, highlighting the reduction of non–value-added activities and overall process improvement. This comparison provided clear evidence of performance enhancement in cycle time and process flow. The final step involved drawing conclusions based on the study's findings, emphasizing the effectiveness of integrating Lean principles with automation. Detailed information regarding this process can be seen in Fig. 1.

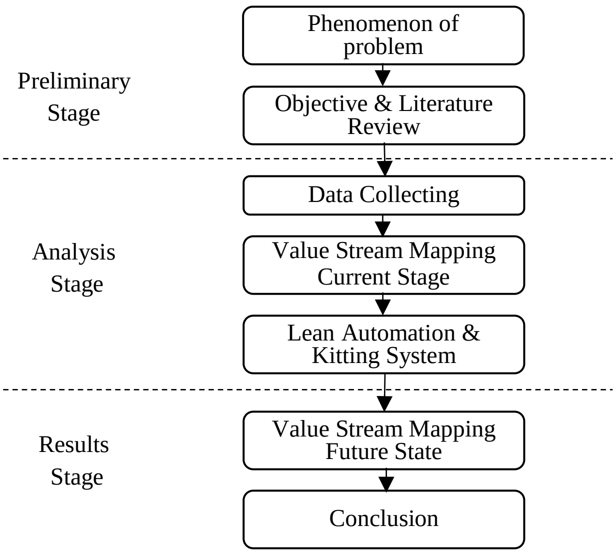

Fig 1. Research Step

The research methodology employs a Lean Automation and Kitting System integration approach as a solution to improve the efficiency of material retrieval processes in the warehouse area. Initially, the process was carried out manually, where operators searched for components one by one using a checksheet to prepare for vehicle assembly. This activity is categorized as a non–value-added activity because it does not directly contribute to the product's value but consumes time and increases the risk of errors. Through the implementation of Lean Automation, the material retrieval process is transformed into an automated system integrated with real-time production requirements. Subsequently, the automatically retrieved components are organized in a special trolley known as the Kitting System.

This system functions to prepare and group components according to the assembly sequence, allowing production operators to perform assembly activities without searching or sorting components. The research stages include identifying the existing process, conducting a value stream mapping, designing the automation system, testing the kitting implementation, and evaluating process efficiency. By combining Lean Automation and Kitting System, it is expected that material retrieval time will be significantly reduced, human errors minimized, and production flow efficiency substantially improved.

3. RESULT AND DISCUSSION

The results of this study began with developing a current state value stream mapping for the four-wheeled vehicle assembly line, which consists of six main workstations: Trimming 1, Trimming 2, Chassis, Final 1, Final 2, and Inspection. The collected data from each workstation are presented in Fig. 2. The analysis revealed variations in cycle times and waiting times across the stations, indicating the presence of non–value-added activities that contribute to material accumulation and process delays. These findings highlight inefficiencies within the current production flow. Therefore, the value stream mapping serves as a foundation for proposing process improvements aimed at reducing waste, streamlining workflow, and minimizing total lead time to enhance overall production efficiency.

As illustrated in Figure 2, the cycle time (C/T) observed in the Final 2 workstation is longer than the takt time (T/T), indicating that this stage of the assembly process is unable to meet the production rate required by the subsequent process, namely the Inspection station. This condition creates a bottleneck that can potentially delay the overall production flow. To address this issue, a detailed analysis of the work elements in the Final 2 process was carried out to identify and classify the activities into two main categories: value-added (VA) and non–value-added (NVA) activities. Since the assembly operations consist of standardized and repetitive tasks, these elements were grouped into several types of actions, including installing, walking, picking up components, tightening bolts (torque), marking, checking, unpacking, and pulling or withdrawing parts. The classification process aimed to distinguish activities that directly contribute to product value from those that do not. The results of this analysis provided the VA and NVA ratios, which are summarized in Table 1.

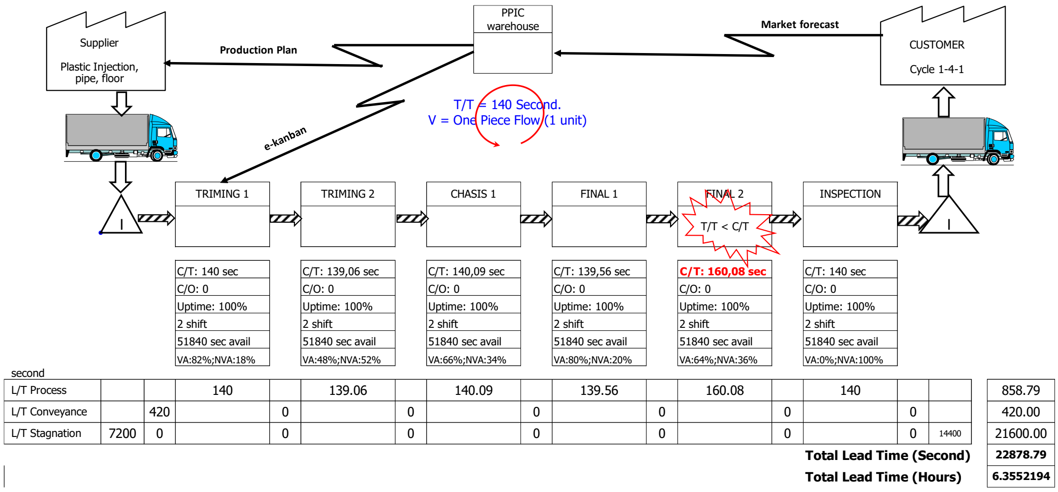

Fig. 2. Value Stream Mapping (Current Condition)

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	70.08	0
Walking	9	11.28	0	12.85	25.00	0
Take/put	5	37.06	40.76	14.7	30.00	0
Torque	0	0	9.16	0	0.00	0
Marking	0	0	6.58	0	0,00	0
Check	11	0	0	0	0.00	140
Unpack	0	17.45	0	0	35.00	0
Withdraw	0	7.63	0	0	0	0
	140	**139.06**	**140.09**	**139.56**	**160.08**	**140**
VA	82.14%	47.20%	66.21%	80.26%	43.78%	0.00%
NVA	17.86%	52.80%	33.79%	19.74%	56.22%	100.00%

Data collection for Value Added (VA) and Non–Value Added (NVA) activities was conducted through a cycle time study using a work sampling approach. A total of 50 subgroup observations were recorded using video-based analysis to capture detailed work elements. The recordings were subsequently analyzed through elemental work analysis to accurately classify and quantify VA and NVA activities within the process. Based on the results of time measurement in the classification table of NVA and value-added portion has also surpassed 50%. This indicates a strong potential for improvement to reduce the NVA percentage. The parameter used to evaluate the performance of the four-wheeled vehicle assembly process is the Process Cycle Efficiency (PCE), which is defined as the ratio of the total value-added time to the total lead time, where the lead time represents the total working time of all processes, as shown in the formula below:

$$PCE = \frac{Value\ Added\ Time}{Total\ process\ Lead\ Time}\ x\ 100\%$$

$$= \frac{455.48}{858{,}79}\ x\ 100\%$$

$$= 53{,}03\ \%$$

VA activities. Inspection activities are categorized as 0% Value Added (VA) because they do not directly add value from the customer's perspective. Although inspection is necessary to ensure product quality and detect defects, it does not transform the product or enhance its functional value. Therefore, inspection activities are classified as Non–Value Added (NVA) in the value stream analysis. And if it can be seen that at the Final 2 workstation, in addition to the cycle time exceeding the takt time, the non

Non Value-add Analysis

A deeper analysis of the assembly process at the Final 2 workstation indicates that a significant portion of the activities performed by operators are still classified as Non Value-Added (NVA) tasks. The dominant cause of this issue lies in the high frequency of operator movements required to retrieve parts and components from the storage area. These actions, while necessary for completing assembly operations, do not directly contribute to the product's value creation. Instead, they consume time and physical energy, ultimately leading to inefficiencies within the production line. The distance between the unit and the line stocking area is approximately 1.8 meters, requiring the operator to take around two steps to retrieve the parts and two steps to

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return to the workstation. This repetitive movement contributes to motion waste and increases non–value-added activities, which ultimately affects the overall cycle time of the assembly process. Moreover, the storage area's placement outside the assembly conveyor, as shown in Fig. 3, further extends the operator's movement distance. This condition not only increases the total cycle time but also contributes to operator fatigue and a decline in Process Cycle Efficiency (PCE). To address these challenges, layout optimization and the introduction of an improved material handling system are essential. Implementing a more compact and strategically positioned storage arrangement, such as point-of-use storage or kitting systems, can significantly reduce operator travel distances. Consequently, these improvements would streamline the workflow, enhance productivity, and support the overall objective of achieving a leaner and more efficient assembly process.

The main issue with the line stocking concept is that placing parts beside the assembly line generates a high level of Non Value-Added (NVA) activities (Hanson & Brolin, 2013; Sali & Sahin, 2016). Operators are required to search for the necessary components, unwrap each part individually, and return empty boxes to the back of the chute. These activities do not add value to the product but instead increase cycle time and operator workload, ultimately reducing the overall efficiency of the assembly process.

Fig. 3. Final 2 Work Stasiun Condition

Implementation Kitting System

To overcome the weaknesses found in the line stocking concept, a literature review was conducted regarding the implementation of the kitting system as a more efficient material supply method (Caputo et al., 2015; Hanson & Brolin, 2013). Based on the findings, it can be concluded that shifting from a line stocking system to a kitting system offers significant stages in improving material flow efficiency and reducing non–value-added (NVA) activities in the assembly line (Sali & Sahin, 2016). In the kitting concept, all materials required for one product unit are collected and arranged in a special container or *kit* within the storage area. Each *kit* contains components organized according to the assembly sequence, eliminating the need for operators to search for parts, open packaging, or return empty boxes as in the line stocking system. Once prepared, the *kit* is delivered directly to the required workstation using a trolley or internal transport system. Additionally, the warehouse layout is modified so that materials are arranged based on the order of assembly requirements, enabling faster and standardized retrieval. By implementing this system, material handling time can be reduced, errors in component delivery minimized, and operator efficiency significantly improved. The kitting system concept in this study is illustrated in Fig. 4, which shows a more structured material flow that supports the implementation of lean manufacturing principles within the assembly area.

Fig. 4. Kitting System

Implementation Lean Automation

Lean automation is implemented to minimize non–value-added (NVA) activities in the material picking process within the warehouse. To shorten the operator's time in searching for and verifying materials to be retrieved, this study integrates an automation system through the implementation of a picking lamp system. In this system, the operator's work instructions are displayed via illuminated light signals at the locations of the required materials. This means that operators no longer need to search for materials manually; they simply pick the items from the positions where the indicator lights are on. The retrieved materials are then collected into a kit trolley according to the requirements of each workstation along the assembly line. With this system, the material picking process becomes faster, more accurate, and more efficient, as the risk of picking errors is minimized. Moreover, non-productive time caused by searching activities can be completely eliminated, thereby improving the overall Process Cycle Efficiency (PCE). The picking lamp system plays a crucial role in the implementation of lean automation, as it combines the efficiency of both information and material flows into one integrated system. The information system flow of this picking lamp system is illustrated in Fig. 5, which visually shows the light signal sequence as a guide for operators during material picking. The picking lamp system operates by using an e-kanban as the production order input, signaling the warehouse that a four-wheeled vehicle model X will be produced. The Bill of Material (BOM) data then identifies model X and sends signals to the corresponding component locations on the parts rack. As a result, the indicator lights for all components required for model X illuminate as output. This automation is supported by Warehouse Management System (WMS) and Internet of Things (IoT) technologies, fully integrated with the company's ERP system to ensure real-time synchronization and accurate information flow across production and logistics operations.

With the implementation of the picking lamp system, operators no longer need to spend time searching for materials manually. Instead, they simply pick the components indicated by the illuminated lights on the parts rack. This system effectively guides the operator to the correct material location, minimizing the risk of errors and reducing non–value-added activities in the picking process. As a result, material handling becomes faster, more accurate, and more efficient, supporting overall production flow improvement. The detailed operation and configuration of this system can be seen in

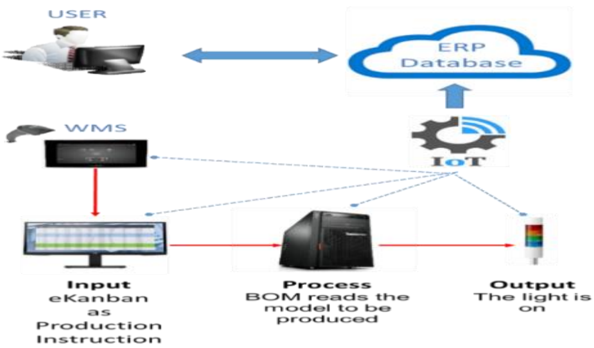


Fig. 5. The information system flow of picking lamp system

Fig. 6, which illustrates how the indicator lights guide the material picking process.

Fig. 6. Picking Lamp Working System

Implementation of kitting system in assembly line

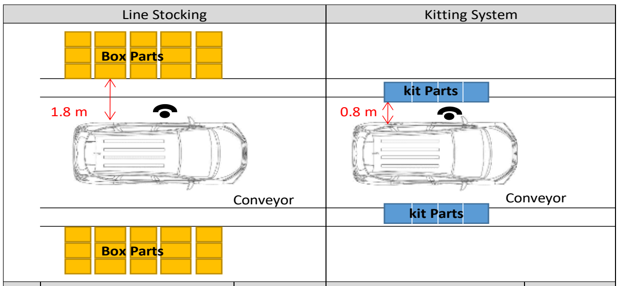
The kitting system ensures that parts already assembled into a kit are delivered from the warehouse directly to the assembly line. The components placed in the kit trolley are positioned beside the vehicle being assembled, with each trolley containing only the specific parts required for that vehicle model. As the assembly process progresses, the kit trolley moves in sync with the vehicle along the conveyor line. By implementing this system, operators are no longer required to perform non–value-added (NVA) activities such as sorting parts, unwrapping packaging, or placing empty boxes back on the storage rack. Instead, the operator simply picks the necessary parts from the trolley and installs them directly onto the vehicle. Additionally, walking activities are significantly reduced, as the distance between the kit trolley and the vehicle is approximately 0.8 meters, allowing operators to work more efficiently within their immediate workspace. This setup not only shortens cycle time but also improves ergonomics and productivity in the assembly process. The overall condition of the assembly line after the implementation of this improvement can be seen in Fig. 7, which illustrates the synchronized movement between the kit trolley and the vehicle along the production line.

Fig. 7. Kit trolley at assembly line

Comparison between line stocking and kitting system

When comparing the line stocking system with the kitting system, a significant reduction in cycle time can be observed at the Final 2 workstation. Through the implementation of the kitting system, various non–value-added (NVA) activities have been completely eliminated, such as unwrapping vehicle logos and lamps before assembly, as well as moving empty boxes back to storage areas. These improvements contribute directly to shorter process times and smoother material flow along the assembly line. Moreover, operator walking activities have been reduced from an average of 4 seconds to just 1 second, as the distance between the parts in the kit trolley and the vehicle being assembled is now very close. This proximity minimizes unnecessary motion and supports a more ergonomic working environment. Overall, the kitting system not only improves efficiency but also enhances productivity and operator focus by simplifying the material handling process. The difference in workflow and efficiency between the line stocking method and the kitting system is clearly illustrated in Fig. 8, which shows how the implementation of the kitting approach leads to a more organized, leaner, and faster assembly process compared to the conventional line stocking setup

If we observe the results of implementing the line stocking



No	Work Element	Time (Second)	Elemen Kerja	Time (Second)
1	Walk to the shelf	3	Walk to the shelf	1
2	Take the logo	2	Take the logo	2
3	Walk to the unit	3	Walk to the unit	1
4	Unwrap the logo	2	Unwrap the logo	0
5	Install the logo	4	Install the logo	4
6	Walk to the shelf	4	Walk to the shelf	1
7	Take rear lamp A	2	Take rear lamp A	1
8	Unwrap the rear lamp	20	Unwrap the rear lamp	0
9	Place the package in the box	4	Place the package in the box	0
10	Walk to the unit	4	Walk to the unit	1
11	Install rear lamp A	24.04	Install rear lamp A	24.04
12	Walk to the shelf	4	Walk to the shelf	1
13	Take rear lamp B	2	Take rear lamp B	1
14	Unwrap the rear lamp	13	Unwrap the rear lamp	0
15	Place the package in the box	5	Place the package in the box	0
16	Walk to the unit	4	Walk to the unit	1
17	Install rear lamp B	24.04	Install rear lamp B	24.04
18	Walk to the unit	3	Walk to the unit	1
19	Move the box	8	Move the box	0
20	Install the fuel cap	9	Install the fuel cap	9
21	Install the fuel label	9	Install the fuel label	9
22	Close the fuel cap and fuel lid	7	Close the fuel cap and fuel lid	7
		160.08		88.08

Fig. 8. Line Stocking vs Kitting System

and kitting system, there is a clear reduction in cycle time—from 160.08 seconds to 88.08 seconds. This significant improvement indicates that several non–value-added (NVA) work elements have been successfully eliminated from the process. By reducing unnecessary activities such as searching for parts, unwrapping components, and moving empty containers, the overall workflow becomes more efficient and streamlined. Consequently, this optimization leads to an increase in Process Cycle Efficiency (PCE), as the proportion of value-added time within the total lead time becomes higher. The improvement demonstrates that the kitting system not only shortens cycle time but also enhances productivity, reduces operator fatigue, and supports lean manufacturing principles by eliminating waste in motion, waiting, and over-processing.

$$PCE = \frac{Value\ Added\ Time}{Total\ process\ Lead\ Time}\ x\ 100\%$$

$$= \frac{455.48}{786.79}\ x\ 100\%$$

$$= 57{,}89\ \%$$

Value Stream Mapping (After Improvement)

Based on the improvement results, it can be clearly observed that the reduction of non–value-added (NVA) activities has brought a significant positive impact on the Final-2 assembly process. The cycle time successfully decreased from 160.8 seconds to 88.08 seconds, marking an impressive improvement of nearly 45%. This substantial reduction indicates that various unnecessary work elements, such as excessive motion, waiting time, and redundant handling, have been effectively eliminated. Consequently, the process flow has become more streamlined, enabling operators to perform their tasks more efficiently with less fatigue and wasted effort. The improvement also ensures that the Final-2 workstation can now meet the needs of the subsequent inspection process, as its cycle time is well below the takt time of 140 seconds. This alignment reflects a balanced workflow between stations, preventing delays or accumulation of work-in-progress (WIP) items. Furthermore, the application of lean manufacturing principles in this stage has proven effective, as the systematic elimination of waste (muda) directly contributes to higher productivity and smoother process synchronization. The shorter cycle time allows better coordination between workstations, reduces idle time, and enhances the overall production rhythm. In addition, the improvement has positively influenced both material and information flow across the line, creating a more continuous and responsive system. These advancements are visually represented in the Value Stream Mapping (VSM) shown in Fig. 9, which highlights the improved performance of each process step after the implementation of corrective actions. Overall, the results demonstrate that targeted lean interventions not only enhance operational efficiency but also strengthen the entire value stream, ensuring a more stable, flexible, and sustainable assembly process for future production demands.

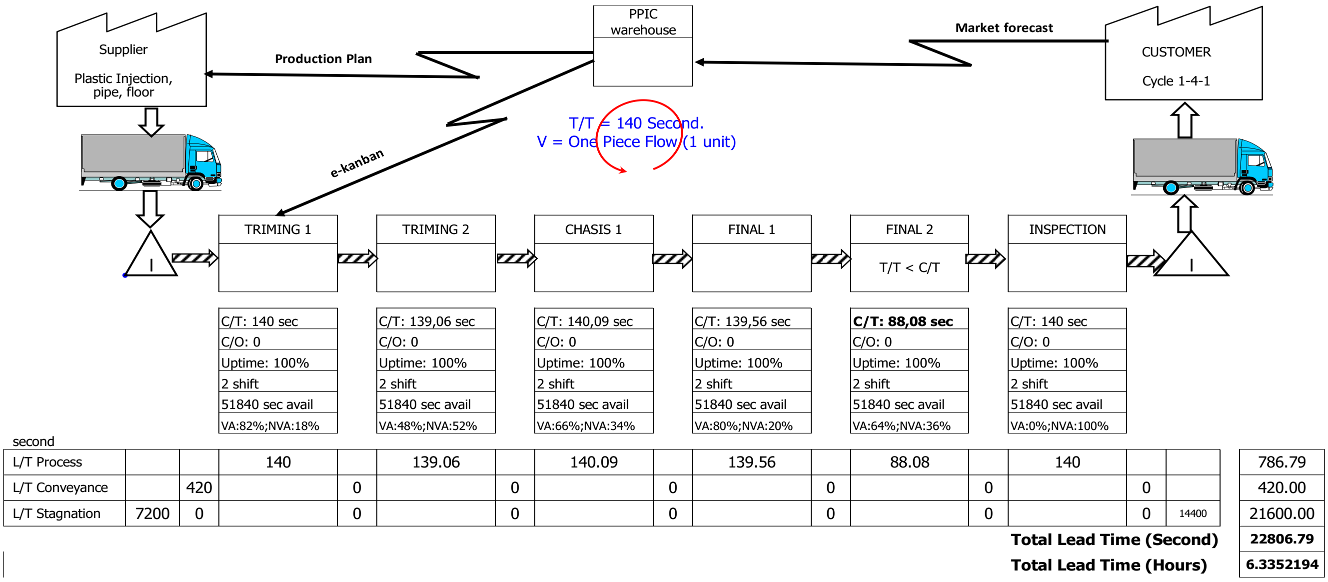


Fig. 9. Value Stream Mapping (After Improvement)

4. CONCLUSION

This study aims to evaluate the effectiveness of integrating the kitting system and lean automation in improving assembly line efficiency. The research was initiated by identifying operational issues in the four-wheeled vehicle assembly line, particularly at the Final-2 workstation, where the cycle time exceeded the takt time required by the subsequent process. Detailed analysis revealed several non–value-added (NVA) activities, including unwrapping plastic packaging, walking to retrieve parts, and handling empty boxes, which contributed to inefficiencies and reduced Process Cycle Efficiency (PCE).

To address these issues, an improvement strategy was implemented through the integration of a kitting system supported by lean automation using a picking lamp system. This integrated approach streamlined the material supply process, minimized operator movement, and reduced part searching time. As a result, the cycle time decreased significantly from 160.08 seconds to 88.08 seconds, while PCE increased from 53.03% to 57.89%.

The contribution of this research lies in demonstrating that the integration of kitting systems with lean automation can simultaneously optimize material preparation and assembly operations. However, this study is limited to a single workstation and production line environment. Future research is recommended to apply similar approaches to multiple workstations and evaluate the long-term impact on overall production system performance.

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