

Applying Lean Tools to Optimize Resource Utilization in a Mechanical Engineering Company

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Abstract

This study applied Lean tools without reducing staff, focusing instead on continuous improvement through enhanced machine efficiency, reduced waiting time, and optimized labor allocation. By using tools such as Value Stream Mapping, Balanced Transfer, Plant Simulation, and the E-Kanban system, the study reduced production time from 122.72 to 88.21 minutes and significantly improved overall productivity. Besides the workstation performance was improved, this study also addressed system-wide impacts, enabling effective reuse of labor when customer demand increases. The results show that a flexible application Lean tools is more effective than a rigid one and offers considerable potential for innovation in other manufacturers environments. However, the limitation of the study is that improvements have so far been implemented only within the production department, without involving other functional areas. In future research, we extend the scope of improvement to the entire enterprise and adapt this human-centered model to other manufacturing firms to promote sustainable growth without workforce reduction.

Keywords

Lean manufacturing, Line balancing, E-Kanban, Plant Simulation, Value Stream Mapping.

Introduction

Currently, lean manufacturing and value stream mapping (VSM) are extensively utilized to help businesses optimize production processes, reduce waste, and enhance efficiency (Tripathi et al., 2021). Lean is defined as a philosophy and management system that aims to maximize customer value by eliminating waste, promoting continuous improvement and integrating people into the production process (Santos et al., 2021; Majava & Ojanperä, 2017). Lean manufacturing focuses on eliminating seven common types of waste: defects, unnecessary transportation, over-processing, excess inventory, underutilization of employee creativity, waiting, and overproduction (Liker & Meier, 2006; Monden, 2012). The goal of

lean is not to reduce the workforce but to improve the efficiency of each employee, ensuring that everyone contributes maximum value to the organization (Wang et al., 2022; Żegleń et al., 2022). The five core principles of lean include defining value, value flow, creating processes, establishing traction, and continuous improvement (Wang et al., 2022). In The Toyota Way, Lean is described as a culture of continuous improvement with the main goal of eliminating waste and creating value for customers (Liker, 2004).

Value stream mapping (VSM) also plays an important role in identifying bottlenecks in a process, helping enterprise improve efficiency (Hellin & Meijer, 2006). VSM is defined as analytical Lean tool, it used to identify wastes, value, value streams, and the flow of materials and information across processes (Araibi et al., 2023). The value chain describes all the activities required for a product or service from formation to delivery to consumers and post-treatment. When a product moves through stages, it will increase its value (Hellin & Meijer, 2006). Governance in the value chain is defined as power and power relationship, which determines the distribution and flow mode of resources in the value chain (Gereffi, 1994).

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Value chain can be used as a tool to divide enterprises into main activities, thus determining the source of competitive advantage. Value, not cost, should be the basis of determining competitive position (Brown, 1997; Van Landeghem & Cottyn, 2022). Creating value beyond the execution cost is the ultimate goal of any strategy (Porter, 1985). Boehlje (1999) proposed six dimensions of the value chain: process, product line, capital flow, information flow, incentive system and management (Boehlje, 1999).

Production improvement does not stop at enhancing labor efficiency, but also requires the optimization of both human resources and machinery (Shah & Ward, 2007). In this study, we applied the Lean tools and flexibly utilized Value Stream Mapping (VSM), line balancing and Plant Simulation tools to optimize both human resources and machinery in a Mechanical Engineering Manufacturing Company. The combination of these tools has been implemented by some research groups such as the study of FikilePoswa et al. who simulated value stream mapping (SVSM) as a lean assessment tool for decision making in the continuous improvement process to bring consistency, minimize errors and non-value-added time in the VSM implementation phase in the truck manufacturing industry (Poswa et al., 2022). Nallusamy & Saravanan (2016) used VSM, line balancing and work standardization to improve the overall productivity of a small scale industry reducing the total waiting time from 5780 seconds to 3946 seconds.

The context for this research arises from a case in which the performance of 150 machine operators in a mechanical manufacturing company improved from 69% to 80.5% through targeted training and performance evaluation methods. Based on this improvement, the following research question was posed: How does increasing the performance of a specific group of employees impact the overall production process and other departments within the company? To address this problem, the team adjusted the number of employees required at each workstation in the product's production process, recalculated the product cost, and subsequently forecasted customer demand based on cost reductions. A new production plan was then developed to accommodate increased demand. The object of the article is to optimize the production process without reducing staff by scaling up the production when customer rises, thereby enabling the efficient reuse of existing human resources.

This study presents a unique approach to optimizing the manufacturing process through the application of modern Lean tools. It aims to optimize resources utilization, enhance production efficiency, and address spillover effects on both the over all manufacturing

system and internal company resources. The approach focuses on the effective reuse of human resources and scaling up production, particularly within the context of small and medium-sized mechanical enterprises.

Research methods

Data Collection

The time data of each workstation is collected through the use of a stopwatch, while the business operating costs come from the ERP (ABsoft) software system. Factors such as business operation waste, workstation overload, or excess inventory have also been identified. Number of required observations (95% confidence level) (Montgomery, 2020):

$$N' = \left(\frac{40 \sqrt{N \sum X^2 - (\sum X)^2}}{\sum X} \right)^2 \quad (1)$$

1. N : additional observation times
2. N : initial observation times
3. X : observed value

Data Analysis

Product cost analysis involves accurately identifying and allocating costs to specific production activities and products using the Activity-Based Costing (ABC) method.

Lean Manufacturing is used to identify and reduce waste in the manufacturing process (El-Namrouty & AbuShaaban, 2013). Value Stream Mapping (VSM) analysis and line balancing are employed to optimize the manufacturing process.

Value chain diagram analysis (VSM) creates a detailed value chain diagram to identify bottlenecks and wasteful activities in the production process. Based on the analysis results, the research team proposed improvement suggestions for each process and specific components to enhance operational efficiency.

Line balancing is used to evenly distribute tasks among workstations, reducing idle time and optimizing the performance of both employees and machines (Mengist, 2019; Otieno et al., 2020). Tasks at stations were adjusted to ensure no station was overloaded, improving the balance of the entire production line.

Additionally, Tecnomatix Plant Simulation 2302 software is used to simulate production plans and validate proposed improvements. This helps develop various production scenarios and evaluate the impact

of proposed changes on production performance. By utilizing plant simulations, the team can validate improvements before actual implementation, thereby reducing risks and strengthening decision-making.

Research results

Number of workers needed

The efficiency increased from 69% to 80.5% ($\uparrow 11.5\%$), the total output increased from 1046 to 1222 and the improvement resulted in an increase of 176 products (assuming).

$$N = \frac{N_0 \times Q_0}{Q_1} = \frac{150 \times 1049}{1222} \approx 129 \text{ Workers} \quad (2)$$

- N : Number of workers needed after adjustment.
- N_0 : Current number of employees.
- Q_0 : Previous output (before adjustment).
- Q_1 : Post-adjustment output (new output) (Montgomery, 2020).

21 mechanical operators and 21 machines will be reduced, and the workshop area will be reduced by 420 square meters (20 m²/person).

Product costing

Product cost estimation is the process of predicting all costs related to product production, including materials, labor, and general production costs (Niazi et al., 2006). One common method is activity-based costing (ABC), which not only allocates general costs but also measures the resources used for product production and distribution activities (Cooper & Kaplan, 1998).

$$C_{\text{total}} = C_{\text{materials}} + C_{\text{labor}} + C_{\text{overhead}} \quad (3)$$

Include:

- C_{total} : Product Cost.
- $C_{\text{materials}}$: Material cost.
- C_{labor} : Labor costs.
- C_{overhead} : General production cost (Cooper & Kaplan, 1998).

However, in this article, direct labor costs will be included in the general production costs because it is difficult to accurately determine the direct labor costs for each product due to large-scale production. Products are subject to Value Added Tax (VAT) 10% (Tab. 1–4).

General production costs = 214,818.23 USD/month (including general office costs, general personnel costs, general raw material costs, general depreciation costs).

Table 1
Allocation of general production costs

Type of Cost	Amount (USD)	Type of Cost	Amount (USD)
Office rent cost (6480 m ²)	4.050	Basic salary	105,375.00
Utility costs	125	Allowances	7,025.00
Office supplies costs	20.83	Social insurance and welfare costs	4,683.33
Office equipment costs	83.33	Training costs	1,250.00
Administrative costs	20.83	Recruitment costs	208.33
Marketing costs	12,500.00	Support costs for human resources	416.67
It costs	2,500.00	Management costs for human resources	833.33
Maintenance and Repair costs	83.33	Safety and Labor protection costs	2,083.33
Miscellaneous costs (anniversaries, gifts, etc.)	416.67	Reward costs	1,666.7
Total office costs	19,591.67	Total human resource costs	122,625.00
Support material costs	416.67	Depreciation of machines and equipment	31,041.67
Repair material costs	166.67	Depreciation of transportation vehicles	3,580.73
Packaging support costs	333.33	Depreciation of office equipment	3,958.33
Experimental material costs	208.33	Depreciation of tools	645.83
Management support materials	500		
Accessory materials	30,833.33		
Total material costs	32,458.33	Total depreciation costs	39,226.56

Table 2
 Materials Constituting the Products

Product Name	Production Quantity	Raw Material	Weight (kg)	Unit Cost (USD)
Jig (SP1)	32	Stainless steel	10	25.00
Automotive stamping die (SP2)	680	Tool steel	200	583.33
Plastic mold for printer parts (SP3)	520	Polyethylene	8	16.67
Automotive and motorcycle parts (SP4)	480	Alloy steel	5	12.50
		ABS plastic	1	02.08
		Rubber	0.3	1.00

 Table 3
 Production Cost and Time

Product Name	Direct Cost	Production Time (hours)	Machine Hours	Service Allocation Cost	Total Cost
SP1	25	2.05	65440	5.94	31.31
SP2	583.33	9.42	6405.6	27.35	612.42
SP3	16.67	3.11	1617.2	9.03	26.27
SP4	15.58	1.09	523.2	3.16	18.95
Total		73986			

Currency unit: USD

 Table 4
 Channel Allocation and Selling Price

Product Name	Channel %	VAT %	Standard Selling Price (Post-Improvement)	Standard Selling Price (Pre-Improvement)
SP1	30%	10%	44.24	44.78
SP2	30%	10%	873.28	875.76
SP3	40%	10%	39.57	40.46
SP4	40%	10%	28.87	29.18

Currency unit: USD

Rental costs decreased by 262.5 USD/month; basic salary costs, allowances, insurance and social benefits decreased by 8,750 USD/month; depreciation costs of machinery, equipment, tools and instruments decreased by 4,424 USD/month.

$$A = \frac{T_0}{T_1} \times M \quad (4)$$

- A : Allocated overhead cost per product.
- T_0 : Total overhead cos.
- T_1 : Total machine running hours.
- M : Machine running hours.

Forecasting customer demand

The average product cost decreases by 1.2%. Elasticity levels based on studies in the manufacturing industry, typically range from 1 to 2 (Ebrahimi et al., 2021; Kianfar, 2019).

$$\% \text{ Change in quantity demanded} = \text{PED} \times \% \text{ Change in price} \quad (5)$$

Customer demand is expected to increase by 1.2% to 2.4%. The slight reduction in product cost indicates that scaling up production does not rely solely on the production department but also requires the

collective effort of the entire organization. Competitive advantage cannot be understood merely by looking at the company as a whole; it stems from individual activities within the value chain, including design, manufacturing, marketing, distribution, and product support. Each of these activities plays a crucial role in shaping the company's relative cost structure while creating differentiation to enhance its competitive advantage (Porter, 1985).

Production system

The five main production areas are divided into 26 workstations, including (Fig. 1):

$$\text{VAT} = \text{WT} - \text{NVT} \quad (6)$$

- VAT: Value-Added Time
- WT: Working Time
- NV: Non-Value-Added (Conversion) Time

The total value-added time is 52.89 minutes, while the production time of the product is 122.72 minutes, indicating that the production process need to improve. The line balancing method and plant simulation will be used to model and accurately identify issues in the production process.

A scaled-down production model with a total of 26 workstations, each machine representing a workstation will be simulated using Plant Simulation software as follows (Fig. 2).

Before starting work, workers will have to go to the warehouse to get the tools and equipment and sign for confirmation. After finishing the work, they have to put the tools and equipment back in the warehouse and also sign for confirmation. This causes a waste of time due to moving, waiting and management. From actual observations at some large enterprises such as Honda and Hyundai, the group proposed to improve the process by placing tool cabinets with hooks right at each processing machine and assigning workers to manage tools themselves. A surveillance camera system will be installed to ensure the effective use and preservation of tools and equipment. Before leaving, workers will check the quantity, arrange them neatly and update the information to the management system. This solution not only reduces waste of time but also increases workers' self-awareness and responsibility in managing tools and equipment.

The product completing area where processes such as surface treatment, spray painting and electroplating occur, which generate dust and chemical fumes. Therefore, this area will be separated from other areas and

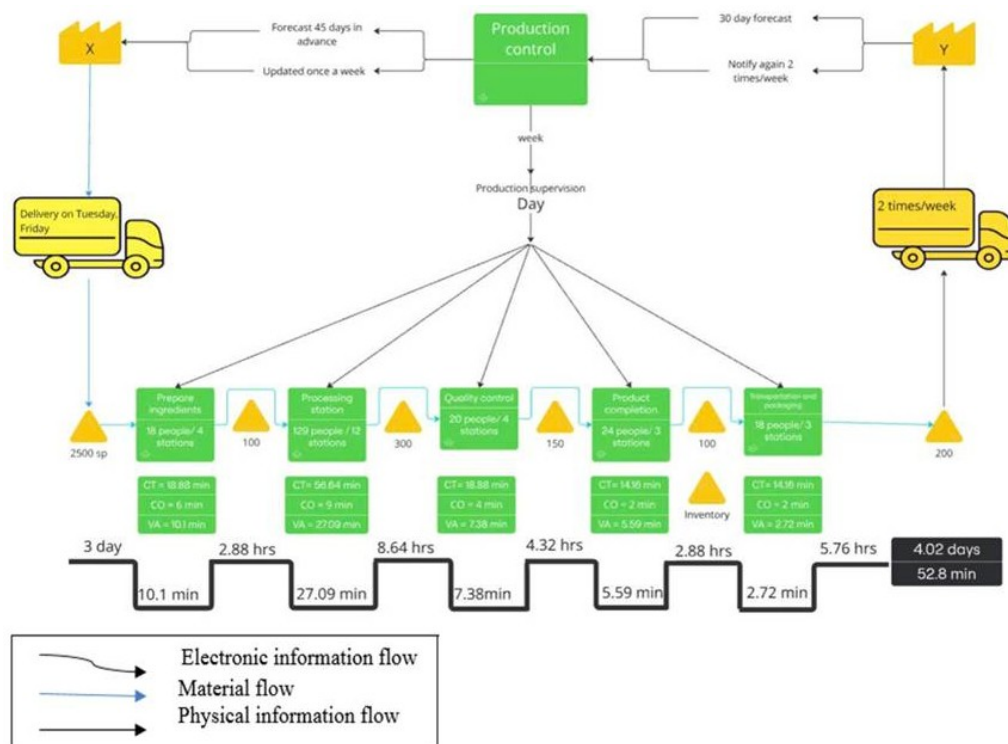


Fig. 1. Current Value Stream Map

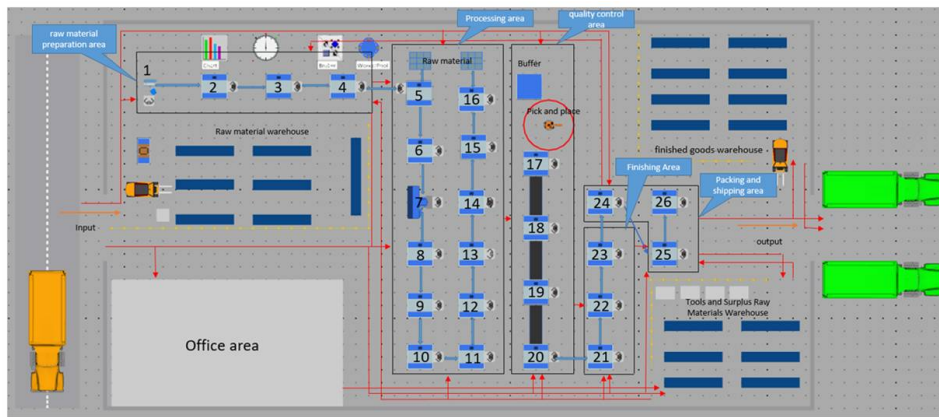


Fig. 2. Factory layout before renovation

a dedicated ventilation system will be installed to minimize pollution and protect the health of employees. A separate maintenance area will be built, which will help to quickly handle technical problems, minimizing machine downtime and production interruptions.

The problem of assigning tasks to stations is solved by using line balancing technique to distribute work evenly among the workstations (Mengist, 2019). This helps to minimize idle time of both human and machine, thereby optimizing production efficiency (Mengist, 2019). In addition, when there is a change in task execution time due to training and skill improvement of employees, line balancing technique will help to adjust tasks among stations so that no station is overloaded, while making the most of available resources (Li & Boucher, 2017).

$$T_{\text{avg}} = \frac{T_{\text{total}}}{N_{\text{sta}}} = \frac{75.045}{26} = 2.886 \text{ minutes.} \quad (7)$$

- T_{avg} : Average time at stations
- T_{total} : Totaltime at stations
- N_{sta} : Number of stations (Goyal et al., 2022)

$$IT = CT - ST \quad (8)$$

- IT: Idle time
- CT: Cycle time
- ST: Station time

Since the machines at the stations operate in parallel, the stations operate in series, and the time at the stations is not balanced, the cycle time of the entire system will be determined by the bottleneck station, because it is the station that limits the speed of the system. Station 3 is the bottleneck with 4,720 minutes and a total cycle time of 4,720 minutes. About the current takt time, the team is currently not using it as customer demands will change with production improvements and product cost reductions (Fig. 3).

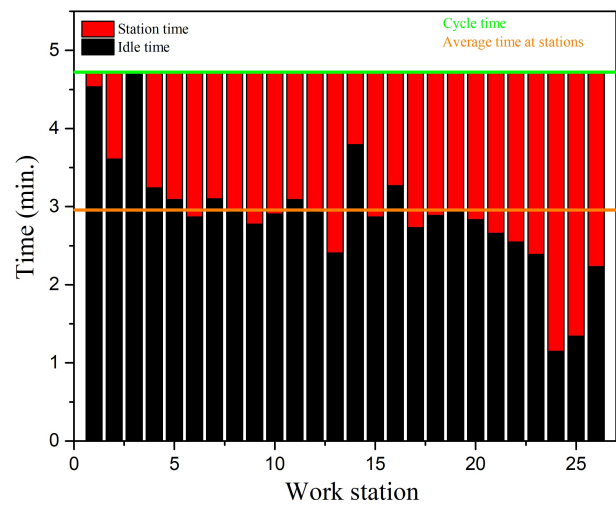


Fig. 3. Processing time chart of workstations

In the material preparation area, the working time is higher than the average time at other stations, resulting in personnel in the packaging and transportation areas having to regularly go to support to ensure production progress. This will lead to imbalances between stations and waste of movement time, while reducing the overall efficiency of the production process (Tab. 5).

To solve this problem, we proposed to separate stations 1 and 3, and combine stations 24 and 25 to reduce the load on stations with high cycle times. Reduce 1 employee at station 13, retain 2 previous employees at station 14, and transfer 1 previous machine operator to station 2.

- Station 14 has 10 employees, the cycle time at the station is 3.752 minutes, reduced to 3.002 minutes after the change.
- Station 13 has 11 employees, the cycle time at the station is 2.379 minutes, increased to 2.929 minutes.
- Station 2 has 5 employees, the cycle time at the station is 3.569 minutes, reduced to 3.12 minutes.

Table 5
Number of employees and time at the station

Area	Station	Processing Time (minutes)	Number of Workers
Raw Material Preparation Area	1. Receive raw materials	4.535	4
	2. Inspect and classify	3.609	5
	3. Laser cutting	4.720	6
	4. Prepare materials	3.239	3
	5. Rough machining	3.091	10
	6. Lathe	2.869	11
	7. Milling	3.100	12
	8. Drilling	2.962	10
Machining Area	9. Deburring	2.777	12
	10. Polish surface	2.906	11
	11. Cut angles	3.091	10
	12. Weld components	2.962	10
	13. Grind edges	2.406	11
	14. Machine precise holes	3.795	10
	15. Inspect dimensions after machining	2.869	11
	16. Assemble roughly	3.267	11
	17. Inspect rough dimensions	2.730	6
Quality Inspection Area	18. Inspect surface quality	2.888	4
	19. Inspect thread accuracy	2.934	5
	20. Inspect hardness and durability	2.832	5
Finishing Area	21. Polish and clean	2.656	9
	22. Paint	2.545	7
	23. Finish assembly	2.388	8
Packaging and Shipping Area	24. Pack products	1.148	8
	25. Label and inspect	1.342	5
	26. Transport to warehouse	2.230	5

After adjustment, production time on a product has been reduced from 122.72 minutes reduced to 88 minutes, a reduction of 34.72 minutes. This shortening of cycle time helps to improve production efficiency, and at the same time reduces the situation of employees moving between regions, thus optimizing labor productivity and using machines more reasonably (Tab. 6).

$$H = \frac{T_{\text{avg}}}{\text{CT}} \times 100 = 61.84\% \quad (9)$$

- H : Transmission efficiency
- T_{avg} : Average time at stations
- CT: Cycle time

The average time at the stations is used as the benchmark for achieving the optimal performance of the production line. As a result, line balancing will only reach a relative level, and further efforts to achieve perfect balance will yield diminishing returns. According to the Pareto principle, 80% of the results can be achieved with 20% of the effort. This means that after reaching a reasonable balance, using additional resources for small-scale improvements may no longer bring significant benefits while costs rise (Lestyánszka Škúrková et al., 2023) (Fig. 4).

Table 6
 Output after improvement

Status	Cycle time (minutes)	Available time per day (minutes)	Number of cycles per day	Number of products per cycle	Daily output	Efficiency
Before	4.72	480	102	10.3	1049	61.84%
After	3.267	480	147	10.3	1499	84.40%

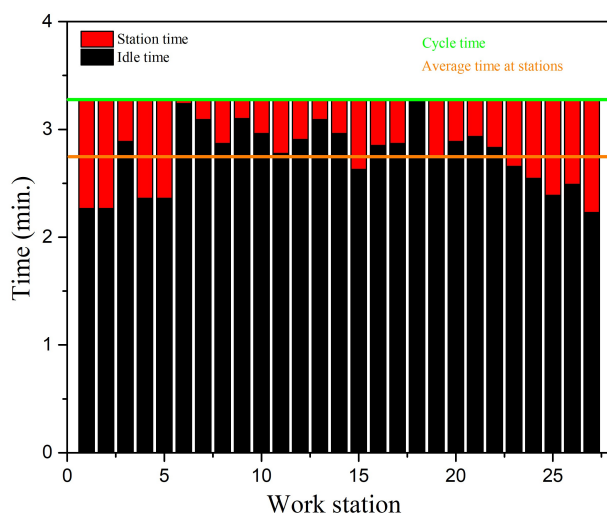


Fig. 4. Processing time chart after line balancing

$$T_{\text{avg}} = \frac{T_{\text{total}}}{N_{\text{sta}}}$$

$$\begin{aligned} \text{Average time at stations} &= \frac{73.8}{27} \\ &= 2.733 \text{ minutes} \end{aligned} \quad (10)$$

$$H = \frac{T_{\text{avg}}}{CT} \times 100 = 84.40\% \quad (11)$$

After line balancing, the cycle time was 3,231 minutes (down from 4.720 minutes previously), which increased line efficiency by 22.55% ↑ and reduced waiting time between stations. Daily output increased from 1,049 pieces to 1,499 pieces with the retention of 7 employees and the addition of 7 machines. Therefore, the output increased by 42.86%, while the total production resources only increased by 3.52%. The balance of workstations minimizes station overload and reduces idle time to the greatest extent possible. This improves the stability of the production line, thereby enhancing the ability to meet production demands when customer demand increases.

By analyzing the value chain graph, we can determine that initial non-value-added time is 4.02 days. This includes activities such as waiting, moving, and

storing between production stages. In order to minimize the time that does not add value, the team suggests placing larger reserve rollers at stations where processing time exceeds the standard cycle time. This helps reduce waiting states and optimize workflows between stations.

Another key solution is the E-Kanban system, which aims to manage the usage of raw materials more effectively. The system is based on the principle of controlling raw material flow through E-Kanban card. When the raw material quantity reaches the minimum inventory, it can send a signal to the production control department. As a result, instead of ordering raw materials twice a week as before, the production control department can order daily from suppliers based on the signal from the E-Kanban card system. After adopting E-Kanban system, the non-value-added time is reduced from 4.02 days to 1.43 days, which is a significant improvement. This adjustment minimizes the waste of material waiting time to the greatest extent possible and enhances the continuity of the production process.

Material flow within the factory has been significantly reduced by assigning tools and equipment directly to employees for self-management at each machine. Packaging and transportation staff no longer need to move to the material preparation area to maintain production schedules, optimizing time and improving work efficiency.

The raw material warehouse has also been reduced in size by the E-Kanban system, granting raw material to be imported daily instead of only twice a week as before. This has created convenient conditions for the expansion of raw material preparation area from 4 stations to 6 stations, and improved the ability to prepare and meet production needs.

In addition, by transferring most equipment to each processing machine tool, the amount of equipment in the warehouse is greatly reduced, which is helpful to optimize the space and manage it more effectively. The product improvement area has also been moved to a separate area with better ventilation system to reduce pollution and improve the working environment (Fig. 5, 6).

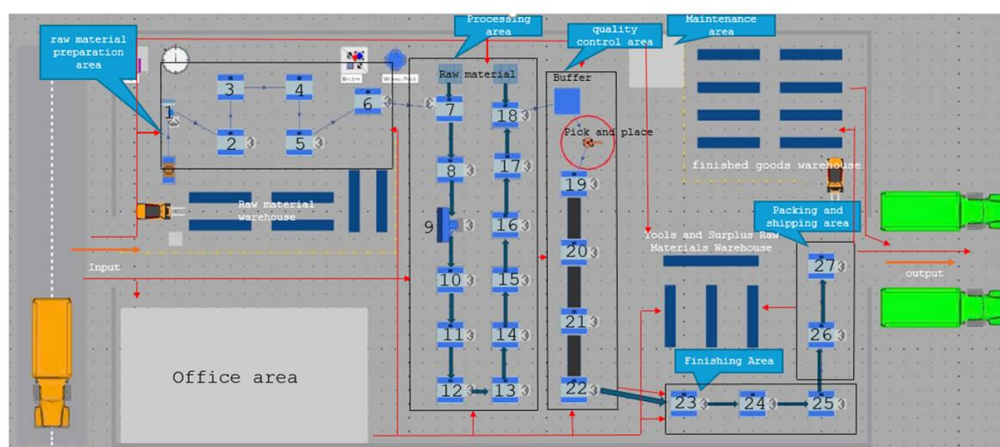


Fig. 5. Factory layout after renovation

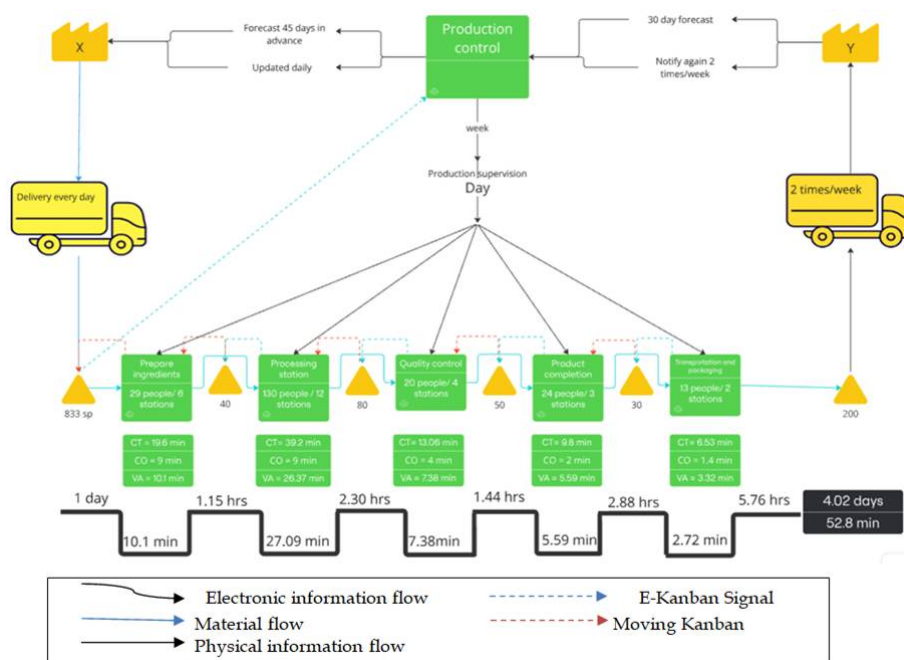


Fig. 6. Value Stream Map after improvement

These improvements not only help reduce unnecessary turnover, but also stabilize productivity and assist employees in keeping up with new schedules without facing workloads. Improving the working environment is also beneficial to the health and performance of employees.

Conclusion

This study stands out for its creative integration of Value Stream Mapping (VSM) and line balancing with tools such as Plant Simulation and the E-Kanban

system. These tools enable the testing and validation of improvements before application, thereby expanding optimization efforts, reducing waste, and enhancing the utilization of human resources.

Key achievements of the study include mapping the current value stream, simulating factory layouts, balancing the production line, identifying sources of waste, and reducing cycle time from 122.72 to 88.21 minutes. These improvement resulted in a 22.55% increase in line efficiency and an increase in daily output from 1049 to 1499 products. Additionally, the enhancements improved also the working environment and helped employees adapt to a new production rhythm.

Although customer demand increased by only 1.2–2.4%, the team successfully optimized the entire process without reducing staff. Challenges such as scaling up operations and retaining labor require company-wide solutions that go beyond production improvements, including reducing material costs and enhancing sales and marketing efforts..

The research team will continue to investigate the remaining issues and expand the scope of the study to encompass the entire enterprise. In future research, we aim to develop and implement this human-centered improvement model in other manufacturing companies, with the goal of achieving sustainable growth without workforce reductions.

These solutions not only help the business maintain flexibility amid market fluctuations but also ensure that the effective utilization of all resources, from human labor to machinery. This represents an important lesson, offering valuable insights for other businesses seeking to implement comprehensive improvement initiatives. Companies can learn from both our successes and limitations, particularly in the context of changing market conditions, to ensure that improvement strategies are implemented sustainably and effectively over the long term.

From this research, the team recognized that in order to support sustainable business development and create significant value, managers must gain deep insights from the perspectives of leaders, employees, and customers.

It is essential to maintain a comprehensive perspective, identify root causes, and apply improvement solutions with flexibility. Since each business has its own unique characteristics, rigidly applying a single solution may offer only temporary results. Issues can only be effectively resolved when addressed at their root.

Finally, managers must adopt the mindset of a business owner to make informed decisions that not only solve short-term problems but also support sustainable growth and continuous improvement. Rather seeking immediate profits by reducing staff, the focus should be on creating long-term value through process optimization and human resource development.

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