Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 6, 7750-7763
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i6.3681

A lean manufacturing approach to waste minimization: a case of industrial rack plant

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Abstract: The concept of Lean Manufacturing is a methodology focused on eliminating waste in various activities through the application of five key principles: defining value, mapping the value stream, ensuring flow, establishing pull, and pursuing perfection. Starting with the identification of value based on product sales, it was determined that industrial rack product is the top-selling product. A Current Value Stream Map (Current VSM) was created to illustrate value-adding activities within the production process and highlight sources of waste. The analysis identified inefficiencies in the production processes of side frames, beams, and packaging, which hindered the ability to meet the target takt time of 60 seconds per unit. Once the processes requiring improvement were identified, strategies for optimization were developed, leading to the creation of an Improved Value Stream Map (Improve VSM). The implementation of waste reduction measures resulted in a significant decrease in production cycle time, from 104 seconds per unit to 60 seconds per unit—a reduction of 42.31%, enabling compliance with the target takt time. Ultimately, the complete elimination of waste led to the creation of an Ideal Value Stream Map (Ideal VSM). This was achieved by incorporating pull system and continuous u-shaped line principles and consolidating workstations to minimize non-value-adding activities. These improvements not only enhanced production efficiency but also maximized the ability to meet customer demands and contributed to building a competitive advantage.
Keywords: *Cycle time reduction, Industrial rack, Lean manufacturing, Line balancing, Value stream mapping.*

1. Introduction

In response to the escalating competition within manufacturers, organizations must enhance their production processes to minimize costs and improve competitiveness [1]. One widely adopted approach to achieve these objectives is "Lean Manufacturing," a recognized production system that establishes high-efficiency standards by eliminating waste in production. This methodology enables the production of high-quality products, delivered on time and at reduced costs, thereby increasing organizational competitiveness. Beyond addressing cost and quality factors, Lean Manufacturing emphasizes waste elimination across various activities, ensuring the efficient transformation of raw materials into valuable products for customers. Moreover, time has emerged as a critical factor in maintaining competitiveness, compelling manufacturing companies to uphold production standards for business continuity.

Lean Manufacturing is grounded in five core principles [2-3]: defining value, mapping the value stream, ensuring flow, implementing pull systems (just-in-time production), and striving for perfection. Among these principles, value stream mapping (VSM) is a widely used tool for process analysis and improvement. VSM provides a comprehensive understanding of the overall production process, focusing on resource flow and supply chain information. It helps identify value-adding activities (Value-Added Activities) and non-value-adding activities (Non-Value-Added Activities), enabling the reduction of lead times, elimination of waste, and enhancement of customer satisfaction.

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However, VSM can be challenging for individuals unfamiliar with production processes, as it may obscure the flow of resources and information.

In the context of a case study factory that manufactures 25 product types categorized into seven groups, analysis of sales data over the last three months reveals that industrial racks represent the highest-selling product. Consequently, improving the production efficiency of this product is a strategic priority for enhancing profitability and competitiveness for the whole company. This research aims to apply Lean Manufacturing principles to achieve the following objectives: reducing cycle time to meet target cycle times (Takt Time), minimizing inventory during production (Work in Process), and decreasing lead time for industrial rack production. Additionally, the study seeks to create value stream maps for both the current and ideal states of the production process in a rack manufacturing plant.

The anticipated outcomes include the identification of waste throughout the production process using VSM, facilitating continuous workflow improvements across each production stage. Ultimately, the research aspires to establish a production line characterized by short lead-time, cost-effectiveness, and enhanced competitiveness.

2. Literature Review

2.1. Lean Manufacturing

Lean Manufacturing is a systematic approach that focuses on waste reduction and optimizing the conversion of raw materials into finished products [4]. It combines tools, techniques, and practices to enhance organizational performance by streamlining operations [5]. Viewed as both a mindset and a methodology, Lean leverages various strategies to minimize waste, improve departmental efficiency, and align business processes into a continuous flow. This process-driven approach aims to eliminate non-value-adding (NVA) activities and enhance resource utilization while bolstering an organization's capacity to address unforeseen challenges [6].

The primary goal of lean is to reduce production costs by identifying and systematically eliminating waste. It fosters a culture of continuous improvement through strategic implementation, employing scientific methods to minimize NVA activities and boost overall efficiency [7]. By focusing on streamlining workflows and eradicating inefficiencies, Lean Manufacturing significantly enhances operational performance [8].

At the core of Lean manufacturing are five fundamental principles [2-3]:

1. Identifying Value: Understanding business goals and customer needs to define and deliver value, which serves as the foundation for waste reduction.
2. Mapping the Value Stream: Planning workflows by outlining steps, resources, and responsibilities, while identifying and removing waste using concepts like "Muda."
3. Creating Flow: Establishing a seamless, bottleneck-free workflow by addressing operational challenges and refining task execution.
4. Implementing a Pull System: Aligning production with demand to avoid overproduction and excessive inventory, ensuring resources are utilized as needed.
5. Pursuing Perfection: Encouraging continuous improvement through feedback and iterative refinement to achieve operational excellence.

Through these principles, Lean Manufacturing provides a structured framework for achieving long-term efficiency, adaptability, and enhanced productivity in organizations.

2.2. Application of Lean Manufacturing

One of the fundamental applications of lean in industry involves streamlining production processes through tools such as value stream mapping (VSM), which identifies inefficiencies and opportunities for improvement [9-11]. For instance, industries use VSM to pinpoint bottlenecks and improve material flow, ensuring smoother operations and reduced lead times.

Lean principles have also been instrumental in implementing just-in-time (JIT) inventory systems, minimizing overproduction, and aligning inventory levels with actual customer demand. This application is particularly prevalent in the automotive and electronics sectors [12-14], where overstocking can lead to significant cost burdens.

Moreover, lean tools such as 5S—Sort, Set in Order, Shine, Standardize, and Sustain—play a critical role in organizing workplaces, reducing clutter, and enhancing operational efficiency [15]. By fostering a clean and orderly environment, industries can achieve better safety standards and employee morale.

Industries have also applied lean concepts to improve quality management through error-proofing mechanisms like poka-yoke in the work of Soliman and Saurin [16]. This has proven especially valuable in sectors such as aerospace and pharmaceuticals, where product quality and safety are paramount.

In addition to manufacturing, lean principles are increasingly applied in service-oriented sectors and healthcare, demonstrating their versatility. For example, hospitals leverage lean to optimize patient flow and reduce wait times, borrowing methodologies developed in industrial applications.

The integration of lean with emerging technologies, such as automation and Industry 4.0, represents a contemporary evolution [17-19]. Smart factories leverage lean principles alongside digital tools like IoT and predictive analytics to create highly adaptive and waste-efficient systems.

Through its focus on continuous improvement and waste elimination, lean manufacturing continues to serve as a cornerstone of industrial advancement, enabling companies to remain competitive in dynamic markets [20].

3. A Case Study Company

The case study focuses on an industrial rack manufacturing company that produces 25 primary product types, categorized into seven groups: A, B, C, D, E, F, G, and industrial racks. To identify a representative product for analysis, the authors conducted a Product Quantity (PQ) Analysis by examining the sales data of all product types over the past three months. This analysis compared sales volumes to determine the product with the highest demand.

A bar chart (Figure 1) was created to visualize the sales performance of each product type, ranking them from highest to lowest. Based on this analysis, the product with the highest sales volume was selected for further study and to serve as the basis for creating the value stream analysis.

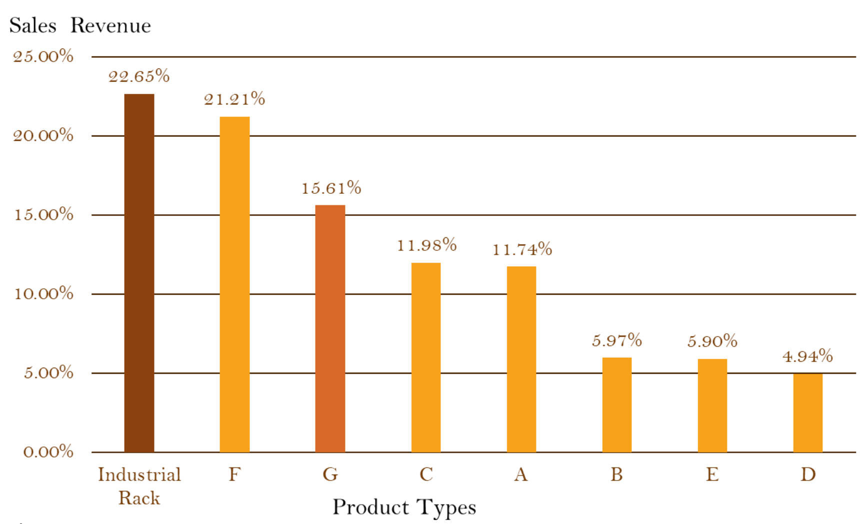

Figure 1.
Product quantity analysis.

The results of the PQ analysis revealed that industrial racks had the highest sales volume during the period under review. Consequently, industrial racks were chosen as the focal product for developing the value stream mapping (VSM).

ISSN: 2576-8484
Vol. 8, No. 6: 7750-7763, 2024
DOI: 10.55214/25768484.v8i6.3681

3.1. Outline Process Chart

A set of industrial racks comprises two primary components—side frames and beams—which are manufactured within the factory. Additional components, including wire decks, double hooks, and tie supports, are short cycle time or procured externally to complete the finished product, which is then packaged into boxes. The Outline Process Chart for the industrial rack production process is presented in Figure 2.

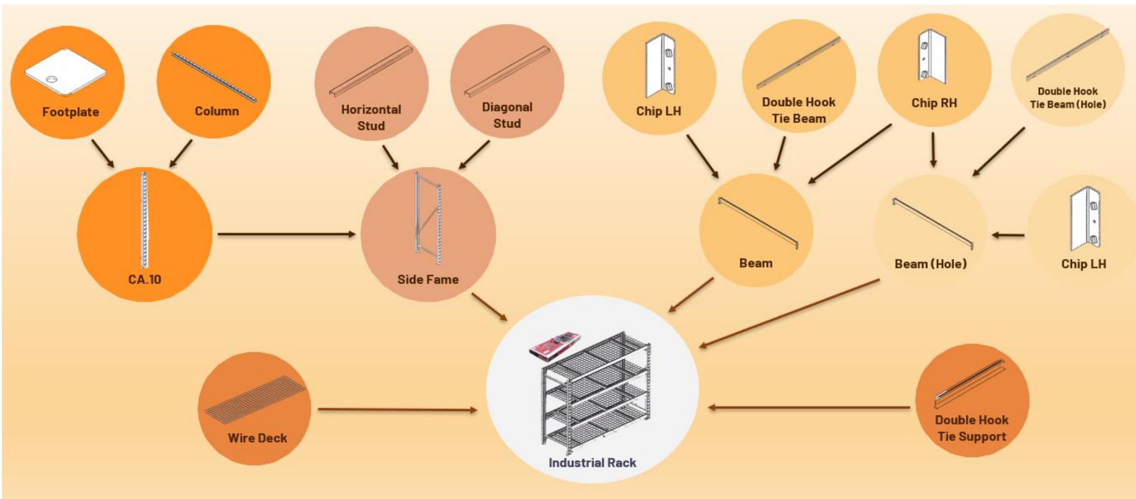

Figure 2.
Outline process chart of industrial rack.

3.2. Current Value Stream Mapping (Current VSM)

Data was collected on each step of the rack production process in the case study factory, following the outlined operational methods, and used to create the Current State Value Stream Mapping (Current VSM), as shown in Figure 3. The details are summarized as follows:

1. Working Time Data: The available working time is 630 minutes per day.
2. Customer Order Data: Captures demand information from customers.
3. Raw Material Delivery Data: Details of the delivery schedules and quantities from suppliers.
4. Production Planning and Control: Responsible for forecasting customer demand, developing production plans, and communicating material requirements to suppliers.
5. Storage: Manages raw material inventory received from suppliers, ensuring storage and maintenance until production begins.
6. Inventory or Work-in-Process (WIP) Data: Tracks intermediate inventory during the production process.
7. Side Frame Component Production Process: Starts with the Foot Plate stamping, Column rolling, Diagonal Stud and Horizontal Stud cutting, and concludes with black sandblasting.
8. Beam Component Production Process: Includes Tie Beam rolling and stamping, Chip RH and Chip LH stamping, and black sandblasting.
9. Tie Support Component Production Process: Involves rolling and stamping Tie Support components followed by black sandblasting.
10. Wire Deck Component Production Process: Starts with outsourcing the ordering process and concludes with silver spraying.
11. Packing Process: Involves packaging all four components—Side Frame, Beam, Tie Support, and Wire Deck—into product boxes, which are then stored for transfer to the Finished Goods Storage area.
12. Shipping: Manages the movement of finished products from storage to customers.

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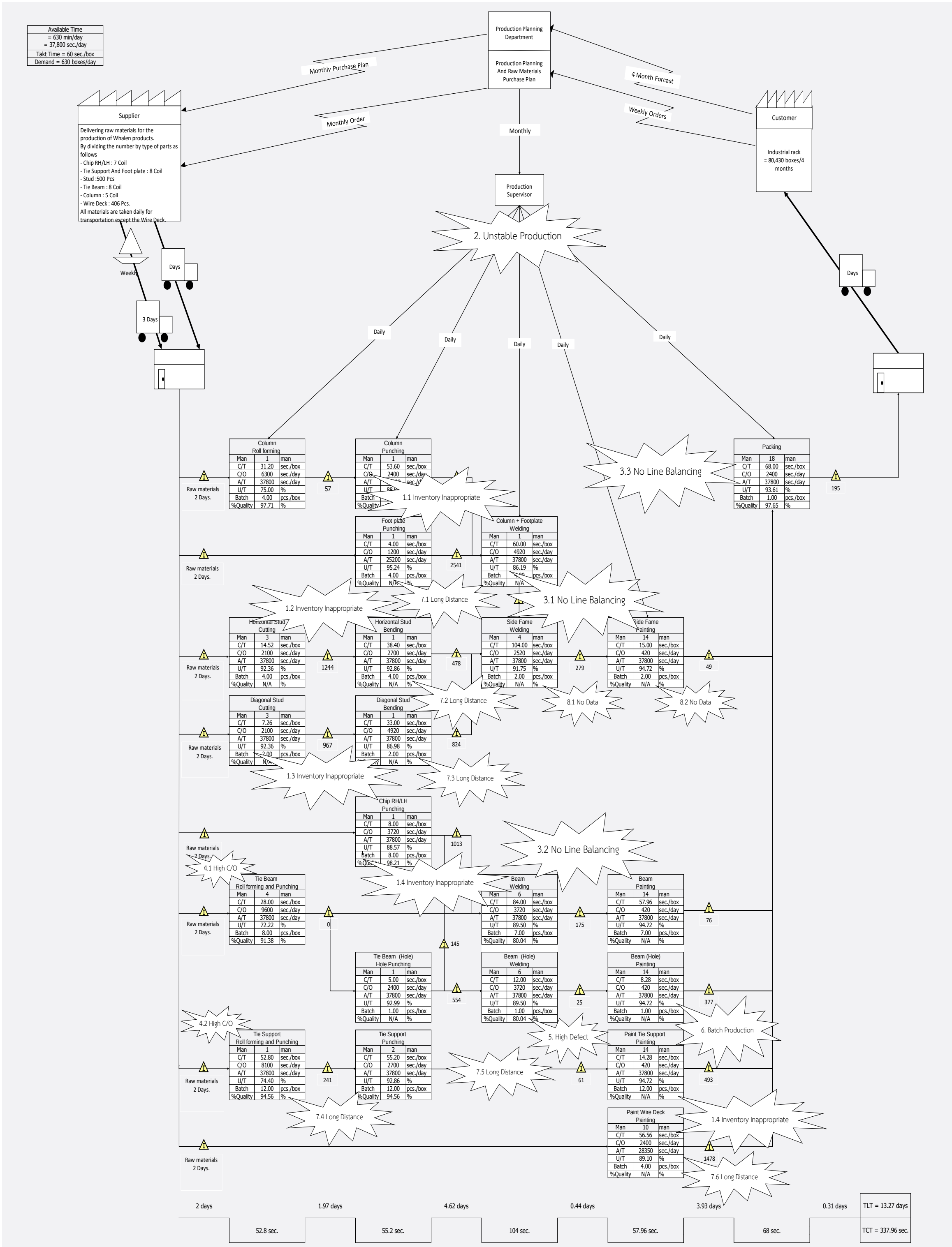

Figure 3.
Current value stream mapping of industrial rack.

Figure 3 illustrates the Current VSM, while wastes identified in each process area are summarized in Table 1.

Table 1.
Type of waste and process location.

No	Process location	Type of waste
1.1	Footplate-rolling &press	High inventory, WIP
1.2	Horizontal stud-C	
1.3	Diagonal stud-C	
1.4	Chip RH/LH-Press	
1.5	Paint Wire deck	
2	Production Supervisor	High production variation
3.1	Side Frame-Welding	No line balancing
3.2	Beam-Welding	
3.3	Packing	
4.1	Tie beam-rolling &press	Long change over time
4.2	Tie support-rolling &press	
5	Beam-welding	High defect rate
6	Tie support-painting	Batch production
7.1	Footplate from rolling &press to welding	Long distant transfer
7.2	Horizontal stud from press to welding	
7.3	Diagonal stud from press to welding	
7.4	Tie support from rolling &press to paint	
7.5	Tie support from press to paint	
7.6	Wire deck from paint to pack	
8.1	Side frame welding	No quality inspection data
8.2	Side frame paint	

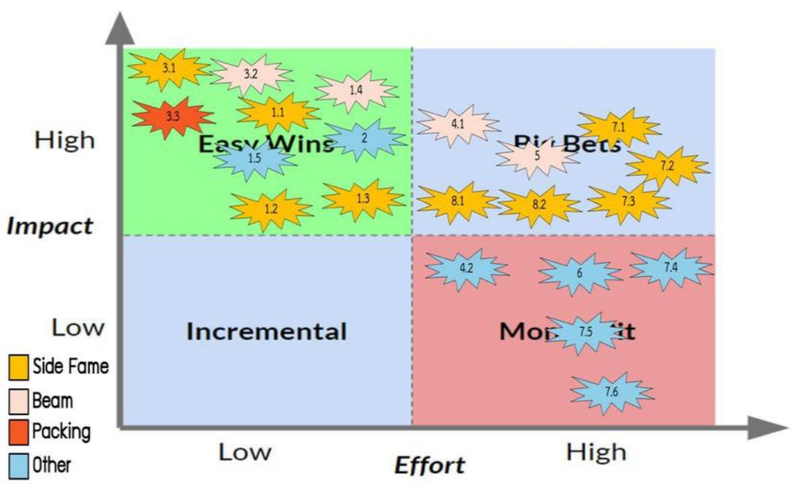

Figure 4.
Impact-effort matrix of waste.

The Impact-Effort Matrix (Figure 4) was employed to prioritize the identified wastes. This tool highlights the most significant issues (highest impact) and those that are easiest to address (lowest effort), enabling the development of strategies to enhance production efficiency and meet customer expectations.

The work identifies three primary waste categories for elimination: Waste no. 3.1, no. 3.2, and no. 3.3. All three involve unbalanced production cycle times across processes, specifically in the Side Frame production, Beam production, and packaging areas. Addressing these wastes aims to improve process efficiency, enhance customer satisfaction, increase value-added time (Value Added Time), and

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reduce non-value-added time. These improvements are reflected in the updated value stream map.

4. Data Analysis and Discussion

A key source of inefficiency in the current production process is the lack of line balancing in the Side Frame, Beam, and Packing processes. As shown in Figure 5, the cycle times for these processes are 104, 84, and 68 seconds, respectively, all exceeding the takt time of 60 seconds.

To address these issues, significant improvements were implemented to reduce the cycle times of these three production processes, as detailed in subsequent sections.

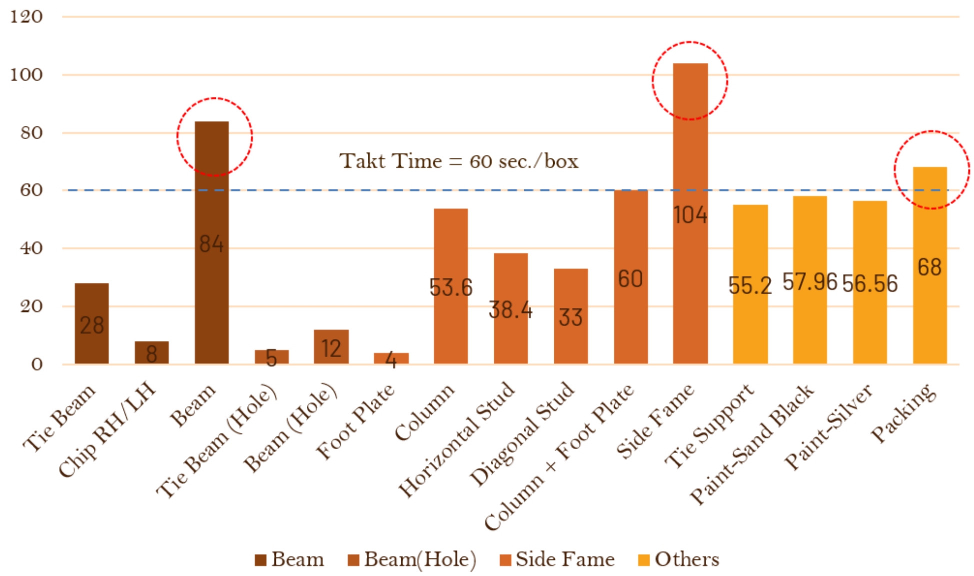

Figure 5.
Process time chart.

4.1. Reducing Cycle Time of the Side Frame Process and Improvement

Observations identified several sources of waste in the Side Frame production process, including delays caused by parts waiting for flipping during the welding process, the lack of line balancing, and prolonged changeover times, as illustrated in Figure 6. To address these inefficiencies, the Side Frame production process was enhanced through the application of Line Balancing, the Single-Minute Exchange of Dies (SMED) technique, and the ECRS methodology, as shown in Figure 7.

The improvements involved integrating the Column and Footplate welding process (CA.10) with the Side Frame welding process, maintaining the same number of personnel and machines. Additionally, the machinery was modified to eliminate downtime during welding. Specifically, the machines were redesigned to allow for continuous operation during the welding of the Side Frame and its subsequent reversal, enabling seamless progression to the next welding stage.

This approach effectively eliminated unnecessary steps in the process, reducing the production cycle time of Side Frame components from 104 seconds per box to 60 seconds per box. This represents a reduction of 44 seconds per box or 42.31%.

DOI: 10.55214/25768484.v8i6.3681

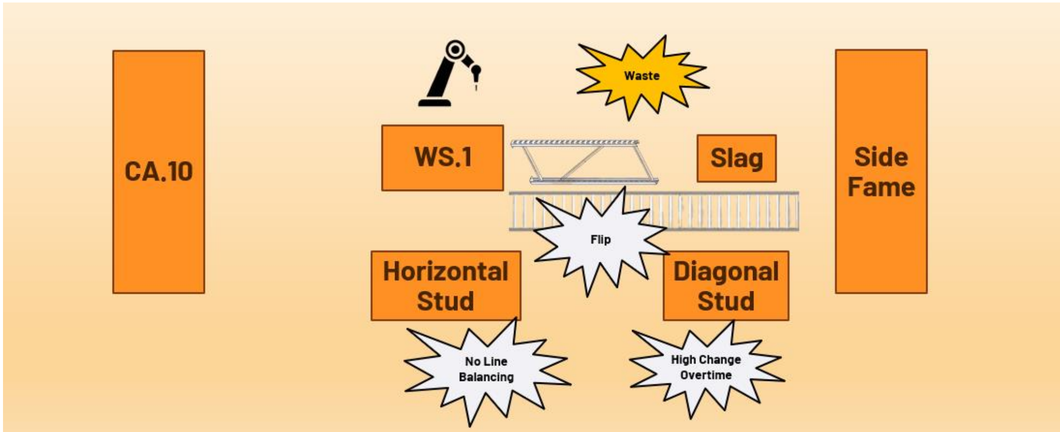

Figure 6.
Current side frame production process.

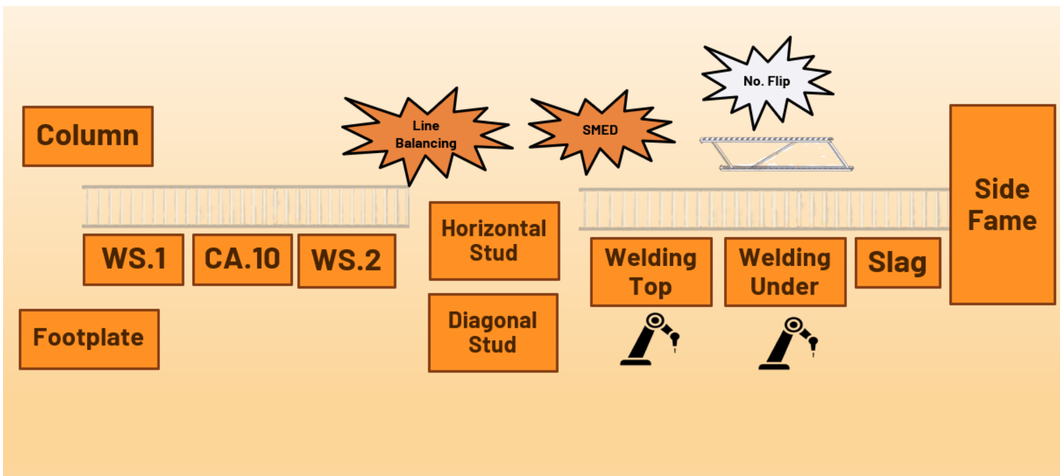

Figure 7.
New side frame process layout without delays for the flipping step.

4.2. Reducing Cycle Time of the Beam Production Process

In the Beam production process, high cycle times were primarily attributed to batch production during the welding process, as depicted in Figure 8. To address this issue, lean manufacturing techniques were employed, including the implementation of a continuous production system based on the One-Piece Flow methodology.

Following the introduction of the One-Piece Flow production system, as illustrated in Figure 9, the production cycle time for Beam components was reduced from 84 seconds per box to 40 seconds per box. This improvement resulted in a cycle time reduction of 44 seconds per box or 52.38%.

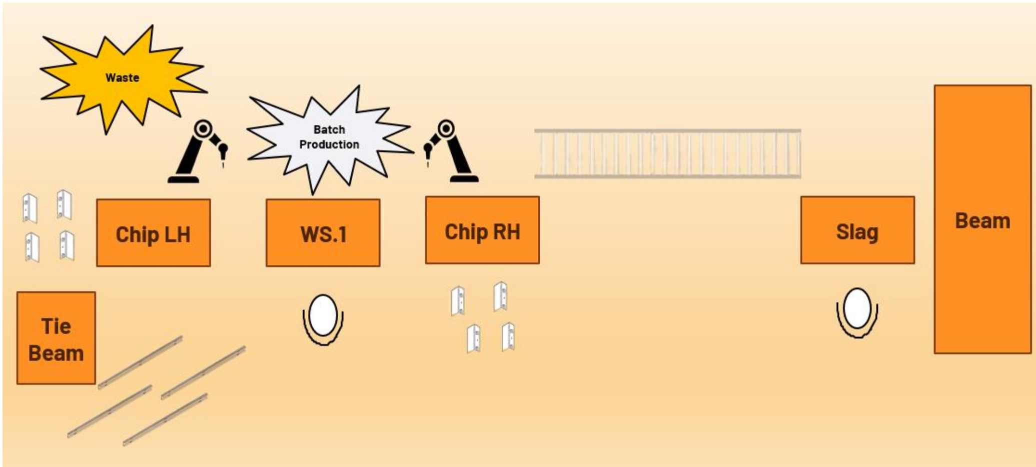

Figure 8.
Current batch production of beam process.

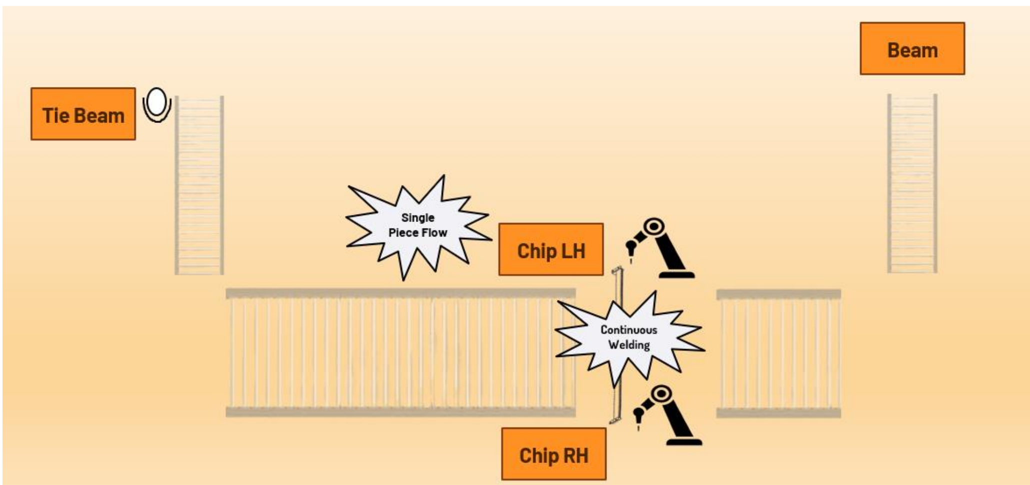

Figure 9.
New continuous welding process for beam components.

4.3. Reducing Cycle Time of Packing Process

The high cycle time in the packing process is attributed to four key issues: inefficient part layouts, reliance on cranes for moving parts, manual wrapping methods, and the absence of line balancing, as illustrated in Figure 10. The improvement of the packing process involved the application of lean production techniques and tools, including process improvement methodologies (ECRS), enhancements to the Karakuri Kaizen mechanism, and the integration of innovative technologies. These measures resulted in notable reductions in cycle time for each step of the packing process, as detailed below.

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Vol. 8, No. 6: 7750-7763, 2024
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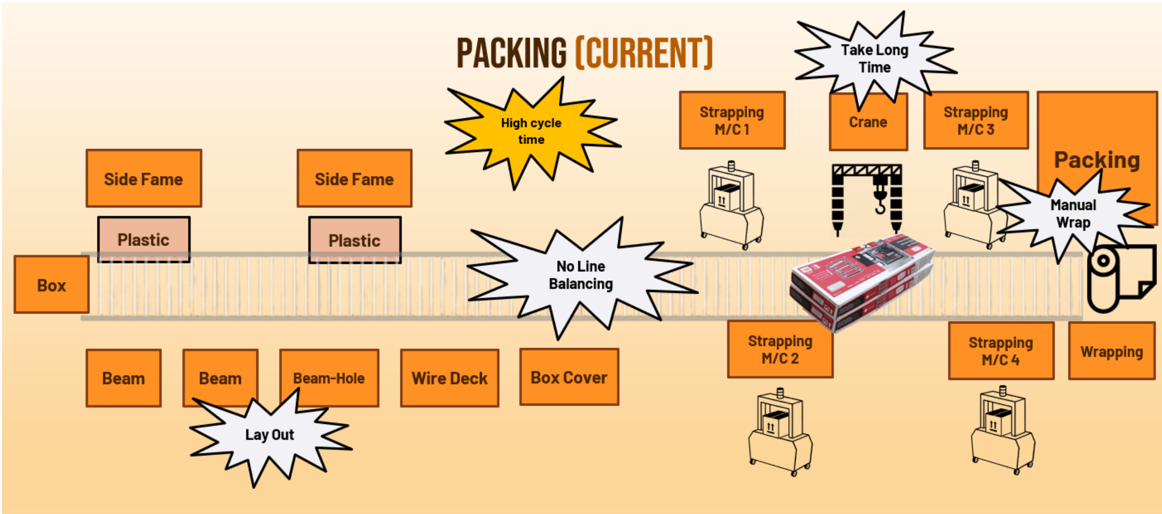


Figure 10.
Waste in the current packing process.

Figure 11 presents a redesigned layout for the supply of parts, which reduced the cycle time from 33 seconds to 27 seconds. Additionally, the adoption of a Karakuri device eliminated the need for cranes, significantly reducing process time. The use of an automated wrapping machine further decreased the cycle time from 68 seconds to 40 seconds, as shown in Figure 12.

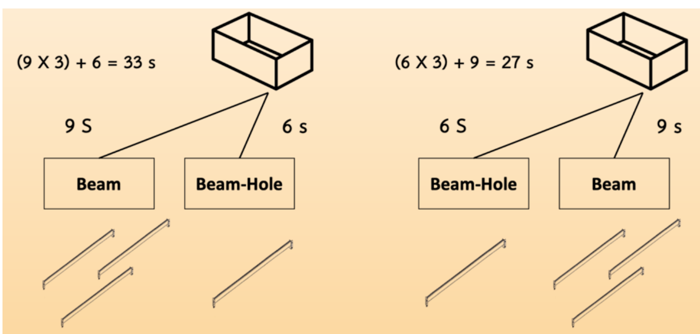
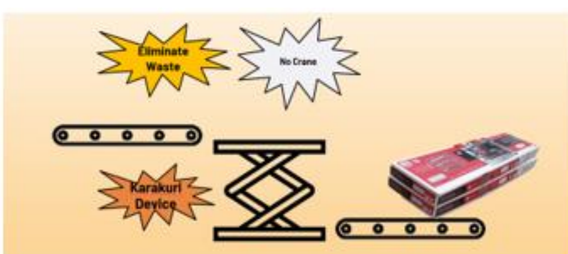
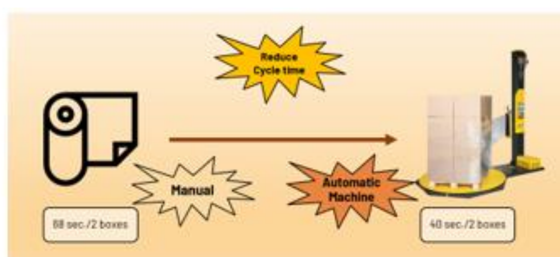


Figure 11.
Re-layout of supply boxes of beam components.



(a)



(b)

Figure 12.
(a) Karakuri device (b) Automatic wrapping machine.

Finally, the application of line balancing techniques ensured that the overall cycle time of the packing process met the target takt time of 60 seconds. These improvements collectively optimized the packing process and enhanced its efficiency. non-value-added time. These improvements are reflected in the updated value stream map.

5. Results and Ideal VSM

Prior to the development of the after the improvement state of Value Stream Mapping (Improved VSM), it was necessary to address and eliminate the waste present in the industrial rack production process of the case study factory. This step was critical to enhancing production efficiency and ensuring the initial focus was on wastes that could be addressed most effectively, in alignment with the Impact and Effect Matrix methodology. Currently, the case study factory produces only 363.46 boxes of racks per day, which falls significantly short of the customer demand of 630 boxes per day.

To address this gap, the decision was made to prioritize the elimination of waste classified as Waste no. 1, Waste no. 2, and Waste no. 3. These wastes were identified and mapped in the current state value stream (Figure 3), with details as follows:

Waste no. 1: This waste pertains to an imbalance in the production cycle time of individual processes. The Side Frame production process, for example, exhibited a cycle time (C/T) of 104 seconds per box.

Waste no. 2: This waste similarly reflects cycle time imbalances exceeding the takt time, particularly in the Beam component production process, which has a cycle time (C/T) of 84 seconds per box.

Waste no. 3: The Packing process also exhibited cycle time imbalances, with a cycle time (C/T) of 68 seconds per box.

The creation of the Improved State Value Stream Map revealed significant improvements in the time required to add value to the production process. The value-added time was reduced from 337.96 seconds to 234 seconds, representing a decrease of 103.96 seconds or 30.76%. This improvement was achieved through the targeted elimination of wastes within the Side Frame, Beam, and Packing component production processes as outlined.

Details of the production process times are presented in Table 2, illustrating the substantial efficiency gains achieved through the implementation of these measures.

Table 2.
Cycle time of components in production process.

Process	Component parts	Cycle time (sec.)
Rolling and press	Tie support and column	44.0
	Horizontal stud and diagonal stud	56.0 (max)
	Tie Beam, Tie Beam (hole), Chip RH/LH	40.0
	Tie support	50.0
Welding	Side frame, beam	60.0 (max)
	Beam	40.0
Painting	Side frame, beam, beam (hole), Tie support, and wire deck	58.0 (max)
	Wire deck	56.0
Packing	Side frame, beam, beam (hole), Tie support, and wire deck	60.0 (max)
Total		234.0

The development of the Improved state value stream map (Improved VSM) for the industrial rack production process revealed a significant reduction in non-value-added time. Specifically, the lead time decreased from 13.27 days to 6.7 days, representing a reduction of 49.51% compared to the current state value stream map. This improvement was achieved through uninterrupted production flow, waste elimination within the production process, mitigation of uncertainties in raw material delivery from suppliers, reduction of WIP and advanced knowledge of customer demand variability for finished products. Following the implementation of the Improved VSM, the proportion of value-added time (VA) significantly increased relative to non-value-added time (NVA). This adjustment enabled continuous value addition to the product and enhanced the production system's capacity to meet the

ISSN: 2576-8484
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customer's target of 630 boxes per day, compared to the previous capacity of 363.46 boxes per day (73.33% improvement). However, the VSM still revealed inefficiencies, such as an inability to achieve continuous piece-by-piece production in alignment with lean manufacturing principles and excessive inventory. To address these challenges, further process improvements were implemented to enhance efficiency, sustain continuous value addition, and ultimately meet customer satisfaction.

5.1. Ideal Value Stream Mapping

The aim was to establish an ideal state value stream map (Ideal VSM), reflecting the optimal future scenario in accordance with lean manufacturing concepts. The Ideal VSM, depicted in Figure 13, incorporates the following features:

1. Pull Production of Raw Material: Integration of supplier delivery volume data with the material requirements planning (MRP) system and the Kanban system to streamline raw material flow.
2. One-Piece Flow Production: Transition from the traditional Supermarket and Kanban production systems to a one-piece flow production system for industrial rack manufacturing across the case study factory. However, the Supermarket and Kanban systems were retained for raw material and product delivery processes to ensure immediate availability in response to customer demand. Then, Cellular Manufacturing is employed as implementation of a U-shaped production layout with Cellular Manufacturing management to optimize the production workflow and enhance process efficiency.

These measures collectively aimed to create a lean, efficient production system capable of sustaining continuous improvement and achieving the ideal state.

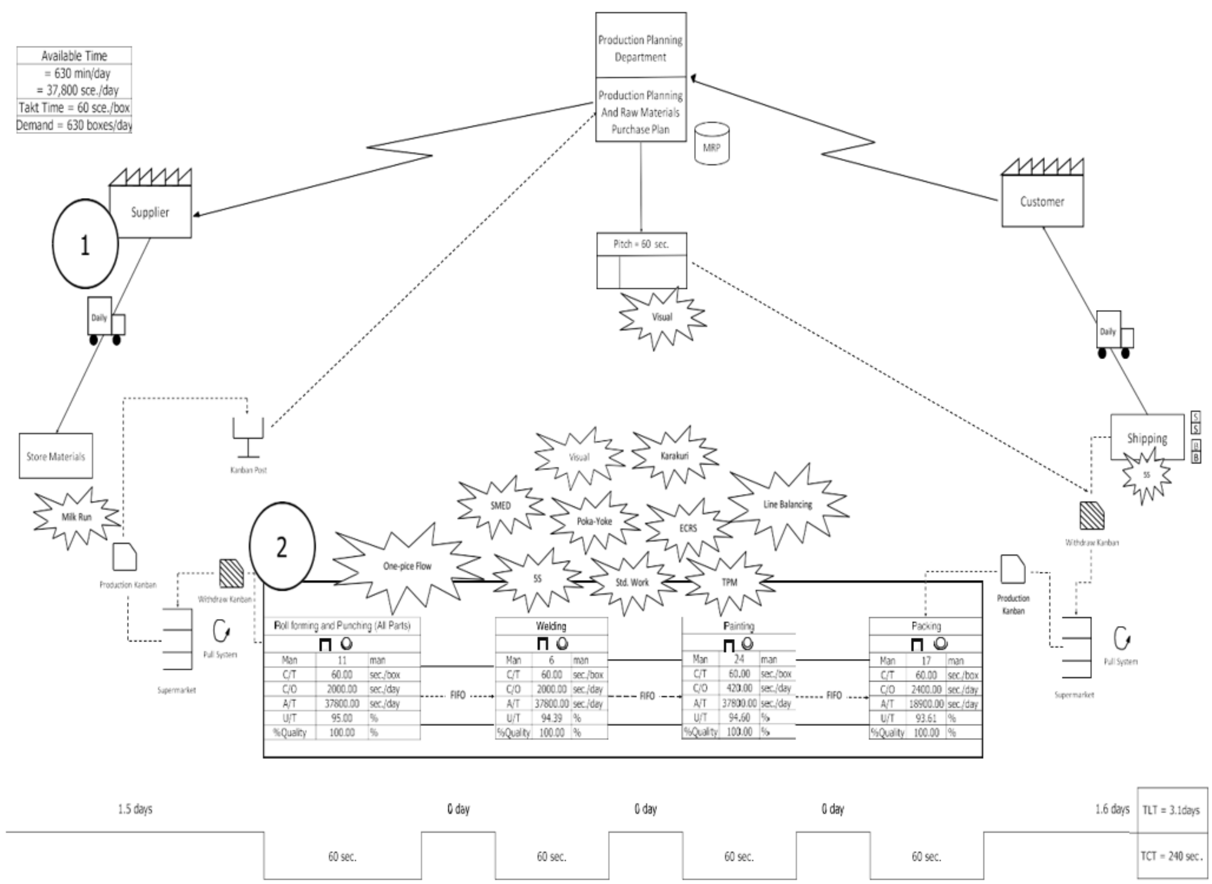

Figure 13.
Ideal VSM for industrial rack.

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Vol. 8, No. 6: 7750-7763, 2024
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6. Conclusions

This work aims to apply the principles of Lean Thinking to enhance the production process of industrial racks. The primary objective is to optimize the cycle time to align with the target cycle time, or Takt Time, set at 60 seconds per box. Analysis of the current state value stream mapping (Current VSM) of the production process revealed a production cycle time of 104 seconds per box and identified 21 sources of waste. Following this, the waste elements were assessed using the Impact-Effort Matrix to prioritize their elimination from the production process.

Subsequent improvements focused on standardizing the workflows for the Side Frame, Beam, and Packing production processes, culminating in the development of an improved value stream map (Improved VSM). This improved configuration reduced the production cycle time to 60 seconds per box, thereby meeting the takt time for industrial rack production. The outcomes of these improvements are summarized in Table 3.

Table 3.
Comparison of production performance.

Production performance	Current VSM	Improved VSM	Ideal VSM
Cycle time (sec./box)	104	60	60
Daily production (box/day)	363.46	630.00	630.00
Total lead time (day)	13.27	6.70	3.10

To ensure sustainable competitive advantage for the industrial rack manufacturing facility, an ideal state value stream map (Ideal VSM) was developed. This design incorporates the pull system an u-shaped line approach within the production process and combines workstations, along with a newly designed workflow. These measures successfully reduced non-value-added time in the production process from 6.7 days to 3.1 days, representing a 53.73% reduction.

Funding:

This study received partly financial support from School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Thailand.

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ISSN: 2576-8484
Vol. 8, No. 6: 7750-7763, 2024
DOI: 10.55214/25768484.v8i6.3681