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Exploratory approaches for improved cost effectiveness and profitability: Utilizing mathematical analysis and value stream mapping on production floors

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Abstract

This paper focuses on the application of Value Stream Mapping (VSM) within the context of the electronics manufacturing industry, aiming to improve its operational efficiency and financial performance. The study thoroughly analyzes costs, integrating VSM to justify economic benefits. Data was collected directly from the manufacturing floor to create a current state map, enabling the identification of non-value-added activities and sources of waste. Areas for potential improvement were pinpointed to reduce or eliminate these inefficiencies. By implementing these proposed enhancements, the paper outlines a future state map for the electronics manufacturing process and presents the results of applying Value Stream Mapping. Comparing the current and future state maps, the study reveals that embracing Lean principles, in conjunction with Value Stream Mapping, can significantly benefit the electronics manufacturing industry. Specifically, it can reduce production lead times by 67.84% and decrease costs by 8.69%. This research underscores the financial implications of adopting Value Stream Mapping, illustrating that by combining Lean principles with VSM, industries can offer rapid customer responses at lower costs, a crucial factor for improving competitive performance in the existing market landscape.

Keywords: Lead Time; Value stream mapping; TPT Time; Manufacturing cost; Lean Manufacturing

1. Introduction

In today's rapidly evolving landscape of technology and consumer demands, the electronics manufacturing industry faces the constant challenge of staying competitive while maintaining profitability. In this dynamic environment, optimizing operational efficiency becomes paramount. This paper delves into the application of Value Stream Mapping (VSM) as a strategic tool to enhance the performance of electronics manufacturing, emphasizing the economic benefits derived from its implementation. The electronics manufacturing sector operates at the intersection of innovation and mass production, where swift responses to market changes and cost-effective production processes are essential for success. To address these imperatives, the study draws inspiration from the application of VSM in an electronics industry context and adapts its principles and methodologies to the electronics manufacturing arena.

Our research centers on the meticulous analysis of production costs, with a primary focus on the integration of Value Stream Mapping to substantiate the economic justifications for proposed improvements. Data is meticulously collected from the manufacturing floor, allowing us to construct a comprehensive current state map. This map serves as the foundation for a detailed examination of non-value-added activities and the identification of sources of waste within the electronics manufacturing process. Through this systematic approach, we pinpoint areas ripe for improvement, with

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the goal of minimizing or eliminating inefficiencies. Moreover, this paper not only suggests a future state map for the electronics manufacturing process, post-implementation of improvements identified through VSM, but also provides a thorough analysis of the results achieved. Our comparative analysis of the current and future state maps underscores the transformative potential of embracing Lean principles alongside Value Stream Mapping. The findings reveal the prospect of reducing production lead times by a staggering 67.84 % and simultaneously lowering costs by 8.69%.

In an era where speed to market and cost-efficiency are pivotal to success, the synthesis of Lean principles and Value Stream Mapping emerges as a catalyst for change within the electronics manufacturing industry. This research highlights the significant financial implications of adopting VSM, demonstrating that its synergy with Lean principles can empower industries to deliver rapid customer responses while concurrently driving down costs—a strategic imperative for enhancing competitive performance in today's fiercely competitive market landscape. In the pages that follow, we delve into the intricacies of this transformative journey towards heightened efficiency and financial sustainability within the electronics manufacturing sector. In this research paper, we employed the Value Stream Mapping (VSM) tool in the upholstery section of a furniture industry located in Bangladesh. This section is responsible for providing furniture products with foam, padding, springs, and other necessary components. The application of VSM in the furniture industry is relatively rare, particularly in developing countries like Bangladesh, where the furniture sector often lacks specialized production lines for specific product categories. Our study is based on a real-life case study conducted within an electronics industry undergoing a transition from traditional carpentry to more industrialized processes. This industry faces challenges in remaining competitive in the middle-class market due to high production costs, hindering its ability to offer competitive prices. Additionally, the company aspires to enter the global market by exporting its products, necessitating improved competitive performance. Consequently, the company is motivated to implement Lean tools to achieve its objectives more efficiently, with Value Stream Mapping being a novel approach in this industry. Our research focuses on initiating Value Stream Mapping within the upholstery section of the electronics industry to reduce lead times, minimize waste, and subsequently lower production costs. While there is substantial prior research on the application of Value Stream Mapping in various sectors such as manufacturing, healthcare, and construction, traditional Value Stream Mapping approaches often do not consider costing systems. There is also limited work that evaluates and justifies the cost and financial outcomes of Lean and Value Stream Mapping specifically in the furniture manufacturing sector. Therefore, our research aims to bridge this gap in existing literature.

The primary objective of this paper is to introduce Lean principles to the electronics industry by applying Value Stream Mapping, with a focus on a cost-based approach. This approach is intended to assist the organization in optimizing production processes to deliver high-quality products with minimal waste, improved inventory management, and financial justification. To achieve this objective, we selected a specific product family and collected the necessary data to create a current state map of the existing production process. This map was then meticulously analyzed to identify shortcomings and areas of waste, leading to the proposal of recommendations for their mitigation. Subsequently, we developed a future state map based on these suggestions. We also discussed the anticipated outcomes of the proposed future state map, acknowledging the limitations of our research and outlining avenues for future exploration.

2. Related Works

Value Stream Mapping (VSM) has found its way into various sectors, including construction and intricate operational settings, intending to optimize efficiency within their respective domains of use. This industry faces challenges in remaining competitive in the middle-class market due to high production costs, hindering its ability to offer competitive prices. Additionally, the company aspires to enter the global market by exporting its products, necessitating improved competitive performance. Consequently, the company is motivated to implement Lean tools to achieve its objectives more efficiently, with Value Stream Mapping being a novel approach in this industry.

Various sectors, including construction and intricate settings, have embraced VSM to enhance operational efficiency within their respective domains. In Lugert's 2018 study, an evaluation was conducted on the existing state of value stream mapping, considering users' viewpoints, the imperative nature of the method, and exploring potential avenues for its ongoing enhancement to ensure resilience in the context of digitalization [1]. In 2018, Kumar and colleagues employed the Lean-Kaizen methodology, characterized by the ongoing elimination of process inefficiencies through incremental modifications. This approach led to substantial decreases in setup time, manpower requirements, production lead time, and value-added time. The analysis involved the use of value stream mapping to assess the current state and integrate suggested improvements into both the present and future states [2]. In 2018, Garza-Reyes and colleagues introduced a sequential methodology based on the PDCA (Plan-Do-Check-Act) cycle for the efficient application of environmental value stream mapping. This approach aims to facilitate the achievement of sustainable and environmentally friendly operational performance [3]. Arce and colleagues (2017) considered ergonomic conditions and aimed to improve productive performance using a novel tool called Ergonomic Value Stream Mapping.

They conducted a dual assessment, evaluating both conventional productive performance and subjective mental workload [4]. In 2017, Chen proposed a method to improve the effectiveness of food traceability systems. The approach involved integrating value stream mapping and cyber-physical systems through a fog computing network. Additionally, the suggestion was made to include the use of artificial neural networks for additional validation [5]. In 2017, Dadashnejad and Valmohammadi conducted a study to evaluate how enhancements recommended through the analysis of value stream mapping impact the overall equipment effectiveness (OEE) [6]. In Meudt et al.'s 2017 study, they applied established Lean production techniques to develop a six-step value stream mapping 4.0 approach. This was done to capitalize on efficiency-enhancing opportunities in the ongoing process of digitalizing production methods [7]. In 2017, Shou et al. conducted a comprehensive analysis across multiple sectors, encompassing manufacturing, health care, construction, product development, and services. Their aim was to examine the evolution of value stream mapping methodologies in diverse sectors, with the goal of distinguishing approaches. This was undertaken to enhance comprehension and facilitate the more effective application and development of value stream mapping in different sectors [8]. In their 2017 research, Seth et al. implemented Lean principles within a intricate production setting, employing certain simplifications in their application of value stream mapping. They found that the overarching messages of Lean methodologies remained unaffected by the complexities inherent in the environment. The study further offers recommendations for incorporating Lean practices in engineer-to-order (ETO) and high-mix low-volume (HMLV) environments [9]. In their 2017 work, Gunduz and Naser adopted a cost-centric methodology, integrating it with the Line of Balance technique, to implement value stream mapping in an underground pipeline construction project. The objective was to enhance sustainability and minimize costs associated with the value stream [10]. Rodriguez et al. (2016) employed a simulation-based experimental design to integrate Lean production with human resource practices. This integration led to increased job autonomy, job satisfaction, and operational performance. The findings also indicated a positive correlation between job autonomy and job satisfaction, as well as between job satisfaction and operational performance [11]. In their 2017 research, Ramadan et al. employed a real-time manufacturing cost tracking system to address limitations observed in traditional value stream mapping costing systems. They integrated Lean Manufacturing with Radio Frequency Identification (RFID) to enhance the methodology [12]. In 2016, Kumar endeavored to create a comprehensive approach for integrating Lean Manufacturing techniques into the garment industry. His focus involved the reorganization of sewing rooms through the utilization of value stream mapping analysis. Additionally, he applied cellular manufacturing to enhance flexibility within the production process [13]. Rahman et. al (2023) considers the cryptocurrency system which is the most important factor for electronics sector for choosing mapping and materials for smooth production [22]. Sifat et al (2023) implements big data tool for MapReduce and Apace spark which is the future plane for this electronics production in floor. Specifically, when the data size is more this research is very important. They use Multimode clusters with data compression methods and try to compare them which is significant for the expansion of our research when we select huge data [33]. Fayshal et. al (2023) considers the environmental factors and safety risk assessment factor for the human and environment and this study has significantly depended on these factors [26,27]. Kamal et. al (2019) gives empirical evidence by using RFID technology for warehouse management by android application which has great impact on worker motivation to work in an electronics industry that reduce the non-value-added time [28]. Parvez et. al (2022) gives a Great discussion on ergonomics factor of students from which we consider the human working posture for the efficiency measurement of worker in the electronics plant because ergonomics factors are one of the most crucial matters for the productivity improvement changeover time for the SKU is important to reduce the lead time [29,30]. Ullah et al. (2023) describes very gently in his three different papers regarding manufacturing excellence, scheduling operation and equipment efficiency from which we can consider for the overall equipment selections and job shop scheduling purpose. [34,36,37]. Shakil et. al (2013) interprets the process flow chart for a jute mill which is very informative for our industry data and cycle time minimization research [36]. Hossain et al. (2023) also discusses the electricity generation from moving vehicles that can be used for land sensing when we have done my research [40].

In 2016, Ciarapica and colleagues endeavored to narrow the disconnect between contemporary approaches to new product development and the success of projects. Their focus involved examining the distinctions between existing practices and optimal methodologies. They delved into the root causes of these variances and proposed specific measures to address them. Their approach centered on the application of value stream mapping within the context of a new product development project [14]. In 2016, Vinodh and colleagues introduced a comprehensive methodology that combined value stream mapping and life cycle assessment to evaluate the societal, economic, and environmental repercussions of a process or system [15]. Henrique and colleagues (2016) introduced a novel method for value stream mapping designed to eliminate process inefficiencies and bottlenecks within hospital settings, addressing challenges not addressed by existing mapping tools [16]. In the study conducted by Ali et al. in 2015, they integrated value stream mapping with simulation modeling to enhance decision-making regarding the adoption of VSM. This approach proved more effective than relying on prediction tools for assessing the potential impact of improvement initiatives [17]. In 2015, Helleno and colleagues employed a combined approach involving value stream mapping and discrete event simulation to arrive at an optimal decision when faced with the choice between two improvement suggestions [18]. In

2014, Faulkner and Badurdeen endeavored to create an environmentally and socially conscious value stream mapping method. They accomplished this by incorporating supplementary metrics to assess the ecological and societal impact, and they substantiated this approach through its application in a manufacturing line [19]. In 2014, Forno and colleagues undertook a study involving the analysis of 57 papers. Their research aimed to identify challenges impeding the effective implementation of Value Stream Mapping, delve into the root causes of these issues, and offer guidelines for current state planning and construction [31]. Nazma et. al (2014) and Rahman (2015) interpret how supplier selection may affect the Electronics sectors for an industry that plays significant role for Lean Production Management and cost minimization when we go for VSM, and data driven environment. [20,21]. Rahman et. al (2023) uses the machine learning algorithm which is very useful for this study specifically for the performance prediction of the production at electronics sector when there will be big data. In our future research we will integrate a large amount of data set for which this research will be helpful for expansion [25,24,23]. In their 2023 study, Syed and colleagues provide a comprehensive description of their approach to brain tumor classification using transfer learning across multiple classes, with a specific focus on its applications in healthcare. Their methodology employs Deep Learning, a powerful technique that involves multistage neural network analysis. This approach has the potential to serve as a highly promising model for future developments in the electronics sector, and it underscores the significance of careful raw material selection in this context, as highlighted in reference [32]. Molla et al. (2024) describes in a significant way regarding the covid data in the United States and global side from which we can follow the covid protocol and use this for maintain rules and regulation in the production floor [42].

3. Methodology

The process flow chart of our proposed research methodology given below:

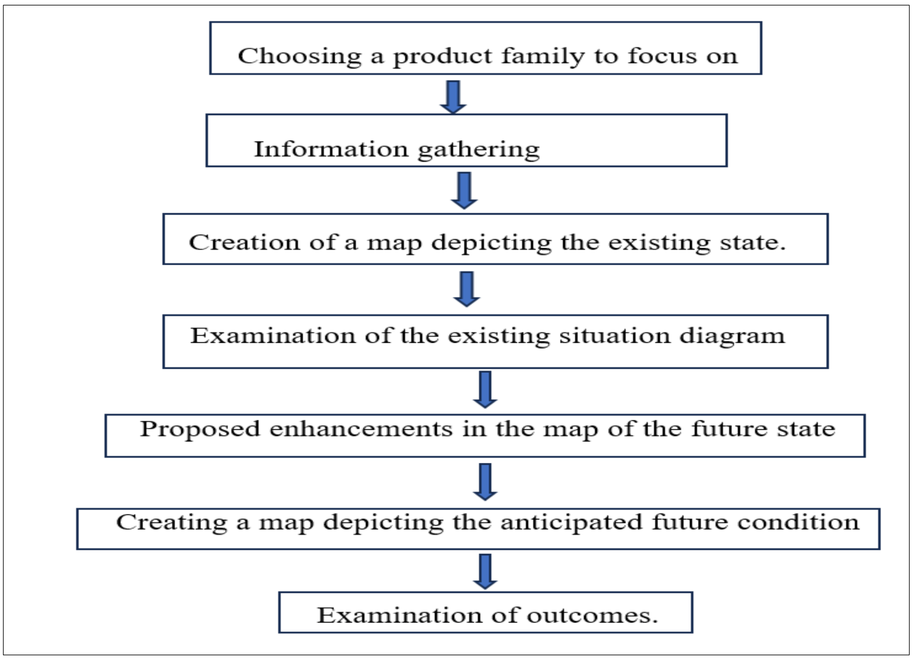

Figure 1 Process flow chart of this research

The electronics industry under consideration primarily manufactures various electronic devices such as smartphones, laptops, tablets, televisions, and home appliances. This industry is organized into six distinct sections, each involving multiple operations. Product lines are diverse and determined by the production planning department based on orders and demand forecasts. Unlike continuous product lines, there may not always be a seamless transition between two consecutive sections. Working with the entire industry and its six products might not be practical. Among the products, smartphones, being both time-consuming and costly, were chosen for focus. Adopting Lean principles, it is crucial to approach Value Stream Mapping (VSM) by moving backward from the customer to upstream, as recommended by Rother and Shook (1999). For smartphones, the next section upstream from the customer is assembly. Thus, the initiative begins with the assembly section. In assembly, multiple production lines run in parallel each day. Evaluating the volume, cost, and lead times of all product families in this section revealed comparable processing times. Consequently, the research proceeds based on the data of a representative smartphone model (e.g., TechMaster), which can be extrapolated to generalize insights for all product families in the assembly section.

3.1. Data Collection

Once a product family has been selected, and the required data has been gathered, the subsequent step involves creating a current state map of the existing production process. Initially, this map was manually sketched on paper using a variety of value stream icons to depict the flow of information and materials within the production line. Upon finalization, the map was digitally rendered using Smart Draw software. The data boxes within the map contain essential metrics such as cycle time, changeover time, available time, uptime, distance, and the number of operators involved. Furthermore, the map illustrates material and information flows, establishing connections between different parties and processes using directional arrows. To obtain these metrics, the research team conducted observations and recorded process durations using a stopwatch, repeating each measurement five times and subsequently calculating the mean value. Following a methodology inspired by Rother and Shook (1999) [6], data collection commenced from the shipping stage and proceeded in reverse order through the manufacturing processes, tracing the path of a working unit from its final state to its raw materials or suppliers.

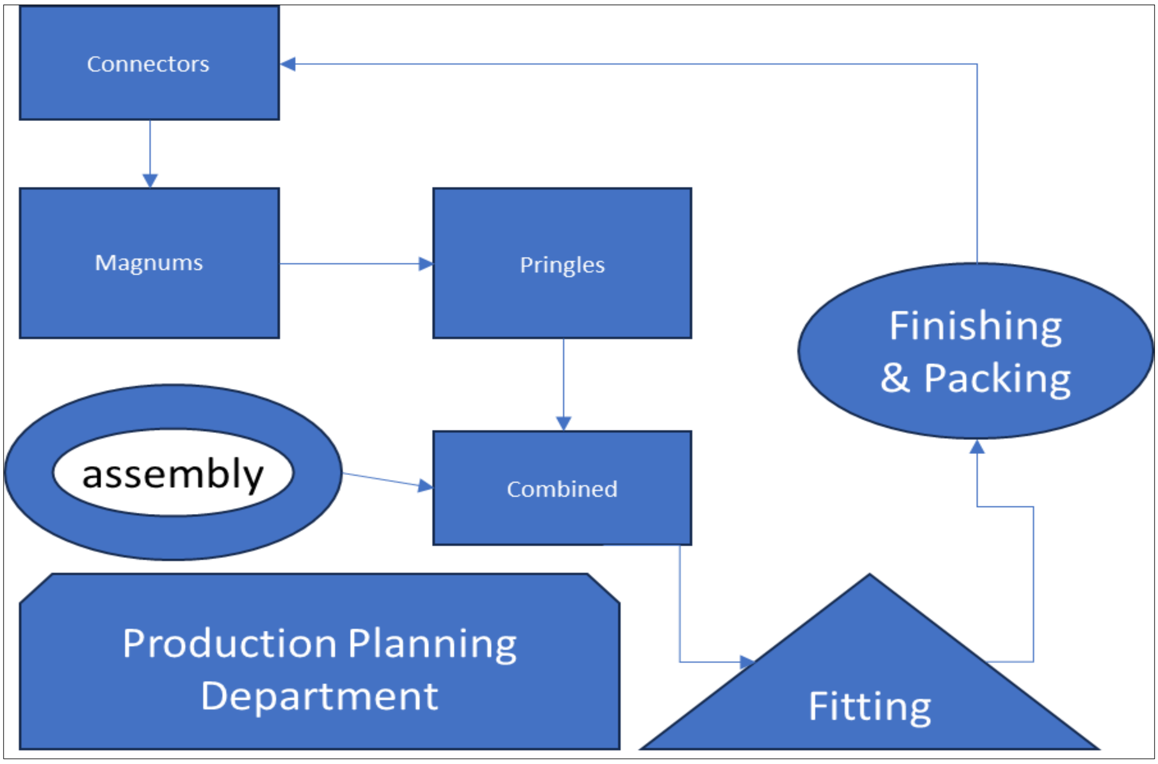

Figure 2 Current Process flow diagram

This data collection approach, often referred to as "snapshot" data, involved documenting inventory levels, as outlined by McDonald et al. (2002) [5]. The summarized process factor values obtained from the production floor are presented in Table 2, with all-time measurements expressed in minutes and distances in meters.

Table 2 Production data for each process

	Connectors	**Magnum**	**pringles**	**Cassests**	**Bushway**
Lead Time (Min)	56	55	100	11	15
Value added time	38	43	95	15	14
Change-over time	3.5	2.5	4.5	5	5
Manpower Needed	2	1	2	2	2
Distance Travelled	4	1	1	2	2

At the bottom of the map, there are two key components integrated into the timeline. The first component represents processing time, while the second component accounts for inventory time. Additionally, the map provides insights into value-added time, non-value-added time, and Process Cycle Efficiency (PCE). The calculation of value-added time involves summing up the processing time for each individual process. Total inventory time is identified as the built-in non-value-added time, and various inventory-related activities, such as storage, production push, and pull between different stages, are denoted using distinctive icons, including triangles, striped arrows, and semi-round arrows, respectively.

Table 3 Cost of current state activity

Process	worker cost (USD)	Production Support cost	Equipment cost	Material Cost	Total Cost
Connectors	10	12	80	300	402
Magnum	10	12	95	1600	1717
pringles	10	13	70	3600	3693
Cassests	15	14	136	2	167
Bushway	15	14	86	110	225
				Total	6204

The future state map is crafted through the implementation of recommended enhancements aimed at addressing the deficiencies identified in the current state map. This process assumes the willingness of all relevant personnel to embrace Lean principles. Within the map, the utilization of the Kanban system is depicted using boxes with arrows, while the supermarket concept is symbolized by the letter 'E' in reverse orientation. Lightning bursts symbolize the supporting improvements proposed for the system.

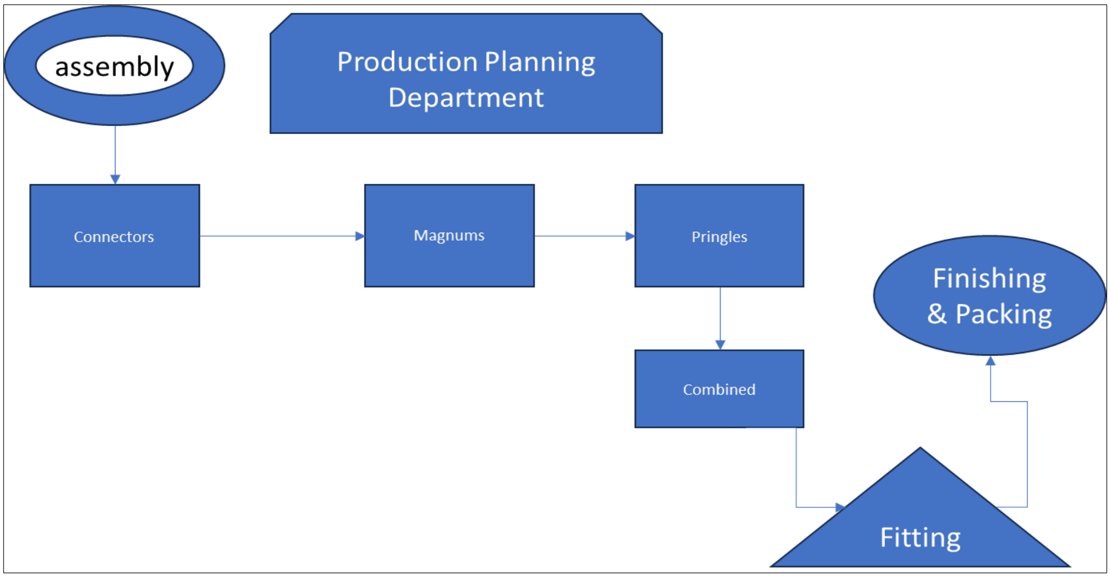

Figure 3 Proposed Process flow diagram

To gauge the financial implications of the proposed modifications, the value stream costs outlined in the future state map, as detailed in Table 4, are calculated, and subsequently compared with the costs associated with the current state map, as presented in Table 3. The analysis reveals a notable reduction in the total cost, amounting to 11.25%. This observation underscores the potential for cost savings and signifies that the implementation of the suggested improvements holds promise for enhancing the industry's competitive standing in the market.

Table 4 Cost of Future state activity

Process	worker cost (USD)	Production Support cost	Equipment cost	Material Cost	Total Cost
Connectors	10	12	80	300	402
Magnum	10	12	95	1600	1717
pringles	10	13	70	3600	3693
Combined	12	15	138	8	173
				Total	5985

4. Discussion and Analysis

This research centers on the application of value stream mapping within the upholstery section of a furniture industry as an initial step towards embracing Lean principles. To achieve this objective, we first constructed a current state map, which served as a tool for identifying and scrutinizing process inefficiencies. Subsequently, a future state map was crafted, incorporating the recommended enhancements. By juxtaposing the current and future maps, we discerned significant improvements in the process, which are succinctly summarized in Table 5.

Table 5 Manufacturing metrics comparison between current and future state

Activity	Current state	Future state	Improvement (%)	Explanation
Percentage	19.81	49.9	30	Increased
Lead Time (Min)	798	130	-66.8	Decreased
Operators count	35	29	-6	Decreased
Capacity of Manufacturing	70	85	15	Increased
Value adding time (Min)	285	241	-44	Decreased
Nonvalue adding time (Min)	410	396	-14	Decreased

5. Conclusion

Value stream mapping serves as a powerful Lean tool, facilitating the visual representation of a target process. It aids in the identification of inefficiencies and areas for enhancement, ultimately promoting the achievement of a smooth and uninterrupted flow from the upstream to downstream production stages. This, in turn, leads to reduced inventory levels, lower production costs, and heightened operational efficiency. In this research, we applied cost-based value stream mapping to a real-life case within the upholstery section of a furniture industry, proposing recommendations to rectify process deficiencies. The execution of these proposed improvements in the future state map is anticipated to yield substantial benefits. These include a remarkable 50 % increase in Process Cycle Efficiency, a significant 24.8% boost in total value-added time, a remarkable 60% reduction in non-value-added time, and an impressive 6.17% reduction in production lead time. Furthermore, the integration of cost-based analysis reveals that the implementation of the future state map is projected to result in an 11.25% reduction in total weekly costs. This substantiates the economic feasibility of the proposed future state map. The significance of this research lies in its ability to demonstrate the financial viability of applying the value stream mapping tool and incorporating the recommended improvements through a structured framework. However, it is important to acknowledge certain limitations. The future state map is based on anticipations rather than real-life applications, and it assumes the willingness of employees to embrace Lean principles while overlooking human factors in production. Additionally, challenges were encountered in collecting precise cost-related data, necessitating approximations due to industry policies and regulations. To address these limitations, future research endeavors can focus on implementing the suggested improvements in real-world scenarios and incorporate simulation for evaluation. Furthermore, a deeper exploration of the impact of ergonomics and environmental factors in the context of value stream mapping can lead to more advanced and comprehensive outcomes.

Future Work

Future research in this domain should focus on the real-world implementation of proposed improvements within the upholstery section of the Electronic and other manufacturing industry, thereby validating anticipated outcomes and providing empirical data. Investigating employee acceptance of Lean principles and addressing their training needs is crucial for effective implementation, while the integration of advanced simulation and modeling techniques can enhance prediction accuracy. A deeper exploration of the impact of ergonomics and environmental factors, along with the expansion of value stream mapping to diverse industries, will provide broader insights. Overcoming data collection challenges and assessing long-term sustainability are essential considerations. Additionally, future work should involve comparing the effectiveness of value stream mapping with other Lean tools, conducting case studies, and fostering industry collaborations to validate findings and enhance applicability, ultimately contributing to ongoing advancements in Lean methodologies and industrial efficiency.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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