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RESEARCH PAPER

Analysis of the product development process to reduce lead time in the engineering sector of a metal-mechanical industry

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ABSTRACT

Goal: This study aims to optimize the product development process (PDP) in the engineering sector of a metal-mechanical industry by applying Lean Manufacturing principles and Value Stream Mapping (VSM) to reduce lead time and improve process efficiency.

Design / Methodology / Approach: A case study was conducted using direct observation, data collection, and VSM to map the current state of the PDP. Waste points were identified, and improvement proposals were developed based on Lean principles. A future-state VSM was then proposed to evaluate potential optimizations.

Results: Implementing Lean tools led to a 39.13% reduction in lead time and a 15.6% decrease in cycle time, improving overall efficiency by approximately 5%. Process standardization and better information flow also enhanced decision-making and waste reduction.

Limitations of the investigation: The study was conducted within a specific industry sector, which may limit the generalizability of the results to other industries with different production characteristics. Moreover, some proposed improvements require further validation through long-term implementation and monitoring.

Practical implications: The findings provide actionable insights for industries aiming to streamline their PDP, reduce inefficiencies, and enhance competitiveness by adopting Lean practices. The approach can be adapted to similar manufacturing environments seeking process optimization.

Originality / Value: This research contributes to the literature by demonstrating the integration of VSM with PDP in a metal-mechanical industry, providing empirical evidence of its effectiveness in reducing lead time and enhancing process performance. The study highlights the relevance of Lean principles in product development beyond traditional manufacturing settings.

Keywords: Product development process*; Lead time;* VSM; Industry.

1 INTRODUCTION

In recent decades, market paradigms have undergone profound transformations due to globalization, a highly competitive environment, and increasingly rapid changes in consumer behavior, which directly impact the global economy. According to Witschel *et al.*(2023), rising international competition has led to the adoption of large-scale Production, technological standardization, and organizational and managerial innovations. In the business landscape, this necessity arises from the demand for market survival. Consequently, organizations

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continuously improve their management methods and processes to achieve better results (Schaefer *et al.*, 2023).

Within this context, Lean philosophy emerges as a knowledge-driven management methodology. Also known as Lean Thinking, it originated from the Toyota Production System (TPS) in the 1960s and is based on the continuous reduction of waste, cost rationalization, efficient resource utilization, and the identification and resolution of bottlenecks in industrial processes (Tardio *et al.*, 2023). As Tapping and Shuker (2010) highlighted, Lean Thinking was developed to eliminate elements that do not add value to processes. This philosophy gave rise to Lean Manufacturing, a management system aimed at reducing lead time, increasing efficiency and productivity, and minimizing losses in industrial Production. Lean Manufacturing revolutionized production systems worldwide by enhancing productive efficiency through waste elimination. By reducing or eliminating waste generated across various company processes, organizations achieve significant benefits and improve their competitiveness (Shah & Ward, 2007).

Many companies have adopted Value Stream Mapping (VSM) to optimize processes and maintain competitiveness to identify and eliminate waste, shorten cycle times, and enhance efficiency (Santos & Souza, 2020). VSM provides a clear and concise visualization of a product or service's value stream. Based on this, VSM is a valuable tool for optimizing the Product Development Process (PDP). By visually mapping the value stream from conception to final product delivery, companies can observe the entire process, identify bottlenecks, reduce cycle time, and enhance efficiency.

From this perspective, product development is a strategic process for differentiation and market success (Rozenfeld *et al.*, 2006). According to Ulrich and Eppinger (2004), new product development involves activities that begin with identifying a market opportunity and conclude with Production, distribution, and sales. The increasing complexity of products and the need for frequent launches have extended development lead times, directly affecting organizational competitiveness (Verrier *et al.*, 2016). Customer demands are becoming increasingly complex and personalized, requiring companies to respond quickly and effectively.

The combination of Lean Manufacturing, VSM, and PDP presents a valuable opportunity for companies seeking to remain competitive in a globalized and dynamic market. By implementing these practices, companies can accelerate new product launches, enhance quality, and meet specific customer needs, thereby gaining a competitive advantage in an increasingly demanding and challenging environment.

This study proposes improvements to reduce lead time and enhance the value stream in the engineering sector of a metal-mechanical industry responsible for the PDP development phase. Following Rozenfeld *et al.*'s (2006) model, the PDP is divided into three macro phases: "Pre-Development, Development, and Post-Development." The contributions of this research are twofold. First, it provides empirical evidence on the effectiveness of integrating Lean Manufacturing and VSM within the PDP framework, demonstrating measurable reductions in lead time and efficiency improvements. Second, it offers a structured methodology for identifying waste and implementing targeted improvements, which can serve as a reference for other manufacturing industries seeking to optimize their development processes. By bridging the gap between Lean principles and product development, this study enhances understanding of how VSM can drive operational excellence beyond traditional manufacturing settings.

2 THEORETICAL BACKGROUND

2.1 PDP Concepts

After World War II, the Toyota Production System (TPS) emerged to address Japan's industrial challenges by improving efficiency and eliminating waste (Ohno, 1988). Fordism had previously introduced mass Production, both shaped by their socio-economic contexts. These systems enhanced product development through standardization, waste reduction, and quality improvement (Hopp & Spearmann, 2008). Product development transforms market opportunities into competitive advantages through structured activities that define product specifications (Tardio *et al.*, 2023). Effective management ensures resource optimization and minimizes inefficiencies (Kahn *et al.*, 2006). However, incomplete information and market uncertainties complicate the process, requiring adaptive strategies (Romeiro *et al.*, 2010).

Bouwman *et al.* (2018) highlight that product development systematically converts concepts into tangible products, requiring cross-functional collaboration for long-term competitiveness (Takahashi & Takahashi, 2007). A structured, iterative approach ensures continuous improvement, optimizing resource allocation and reducing inefficiencies (Liker, 2004). Product development models must be tailored to organizational needs, as standardized frameworks may create challenges (Romeiro *et al.*, 2010). The process includes three phases: pre-development (strategic planning), development (from concept to launch), and post-development (continuous improvement) (Rozenfeld *et al.*, 2006). Integrating Lean principles accelerates time-to-market and enhances competitiveness in a dynamic market (El Marghani, 2010).

2.2 Lean Manufacturing

Lean manufacturing is a management philosophy integrating advanced techniques with continuously improving equipment to maximize production efficiency while minimizing resource consumption. The ultimate goal is to provide customers with precisely what they need, in the right quantity, at the right time (Ohno, 1997). Womack and Jones (1996) describe lean thinking as a structured approach to defining value, organizing value-creating activities in the most efficient sequence, executing them seamlessly upon request, and continuously improving them to enhance efficiency. The core of lean philosophy lies in identifying and eliminating waste—anything that does not add value to the customer.

The Toyota Production System, pioneered by Taiichi Ohno in 1990, served as the foundation for Lean Manufacturing, which later evolved from Lean Philosophy (Dhingra *et al.*, 2019). The term "lean" was first introduced in the book The Machine That Changed the World by Womack, Jones, and Roos (1990), highlighting the superior performance of the Toyota Production System regarding productivity, quality, and development. The primary objective of lean manufacturing is to eliminate waste, which is defined as any activity that consumes resources without generating customer value (Suhardi *et al.*, 2019). Lean manufacturing identifies seven primary waste categories: overproduction, defects, excess inventory, inadequate processes, waiting time, unnecessary transportation, and excessive motion. Shingo (1981) initially defined these waste types, while Bauch (2004) later introduced three additional waste forms related to Product Development Processes (PDP): reinvention (repetitive problem-solving for existing solutions), lack of discipline (poorly defined objectives and unclear roles), and inefficient integration of information technology (IT), leading to compatibility and availability issues.

Although lean manufacturing originated in the automotive industry, its principles and tools have been widely adopted across various sectors, including manufacturing, services, and supply chain management. Lean manufacturing incorporates numerous tools and techniques, such as Value Stream Mapping (VSM), Kanban, 5W2H, 5S, and poka-yoke (Alefari, Salonitis & Xu, 2017). These tools are practical instruments for implementing a lean system and guiding organizations in following lean principles. Lean is a "toolbox filled with methods and techniques designed to reduce or eliminate waste" (Leksic *et al.*, 2020). Purushothaman *et al.* (2020) demonstrate that lean tools directly impact waste reduction by continuously identifying and minimizing inefficiencies.

To effectively implement lean practices and realize its value-enhancing benefits—such as waste reduction and customer focus—five fundamental principles underpin the lean philosophy: value, value stream, continuous flow, pull Production, and perfection (Liker, 2004). Understanding waste types in PDP is crucial, as they are the starting point for lean development and implementation. Womack *et al.* (2004) highlight that these principles aim to create seamless production flows, enabling immediate feedback and transforming waste into value:

- Value: Defined by the end customer and only meaningful when expressed in terms of a specific product that meets customer needs at a given price and time.
- Value Stream: A holistic view of all necessary activities from product design to completion, focusing on eliminating waste.
- Continuous Flow: A system where raw materials are converted into finished products without unnecessary movement or waiting time, focusing on product needs rather than departmental efficiency.
- Pull Production: Processes initiate only upon demand from the subsequent stage,

reducing inventory levels and enhancing product value.
- Perfection: Pursuing continuous improvement across all processes, as there is always potential for further waste reduction, time optimization, and efficiency gains.

Hicks (2007) argues that lean thinking, particularly waste elimination and continuous improvement, applies to any system where products or services flow to meet customer demand. Consequently, lean principles benefit any domain where processes can be mapped, objectives measured, and resources managed effectively (Soares & Teixeira, 2014). The lean approach enhances process quality by eliminating waste, reducing lead time, and minimizing production costs through continuous improvement (Suhardi *et al.*, 2020; Tortorella & Fettermann, 2018).

2.3 Lead-Time

Manufacturing Lead Time (MLT) refers to the total time required to produce a product, from the start of Production to the final output. It includes both processing time and waiting time (Filho, 2014). As a time-based metric, lead time is directly linked to the flexibility of a production system in responding to customer demand. A shorter lead time results in lower production costs and improved responsiveness to customer needs (Tubino, 1999). Effective control and management of lead time provide companies with crucial insights into each production stage, enabling them to identify errors, reduce waste, and shorten delivery times (Pakdil & Leonard, 2014). Christopher (2009) emphasizes that reducing operational lead-time begins with mapping activities to identify non-value-adding time, thereby increasing supply chain transparency and efficiency.

2.4 VSM

Value Stream Mapping (VSM) is a lean tool developed within the Toyota Production System under Taiichi Ohno, aiming to visualize and optimize production processes (Ghinato, 1996). It enables organizations to identify inefficiencies, reduce lead times, and enhance operational performance by mapping an entire product family's value stream (Rother & Shook, 1999). VSM illustrates the material and information flow across the supply chain, making hidden processes visible and facilitating lean implementation (Carvalho, Carvalho & Silva, 2019; Pradella, 2012). By distinguishing value-adding activities from wasteful ones, organizations can develop structured improvement plans (Jasti & Sharma, 2014; Santos & Souza, 2020). The methodology provides a comprehensive view of the production system, allowing companies to create future-state maps that envision streamlined workflows and improved efficiency (Silva *et al.*, 2021).

VSM supports organizations in mapping both current and future states, ensuring a seamless material and information flow (Librelato *et al.*, 2014). It traces the entire production journey from supplier to customer, helping to eliminate inefficiencies throughout the value chain rather than implementing isolated optimizations (Andrade, 2001; Mayser & Gronau, 2021). The primary contribution of VSM lies in its ability to simplify complex production systems, fostering a clear understanding of interdependencies and guiding continuous improvement strategies (Santos & Souza, 2020). Additionally, VSM enables real-time process measurement, helping organizations identify bottlenecks and align production with actual customer demand through a continuous flow or pull-based system (Rother & Shook, 2003).

The structured analysis of processes necessitates tools that evaluate the value-added aspects of Production, whether in goods or services. In this context, Value Stream Mapping (VSM) is a key instrument for identifying inefficiencies and supporting continuous improvement initiatives (Rother and Shook, 2003). According to Rother and Shook (2003), the VSM is divided into four steps.

- Step 1 - Select a Product Family: Establish a product family, which is defined as a group of products that go through similar processing stages and use common equipment in their processes. According to Womack (1996), the better the identification of product families, the greater the benefits for the company, as the flow and decisions will be aimed at this purpose.
- Step 2 - Mapping the Current Situation: Map the current situation, which is a visual representation of each process with material and information flows, using standardized and predetermined icons to represent details and situations in the

process, including inventories, transportation, and material and information flows, as shown in Figure 1.

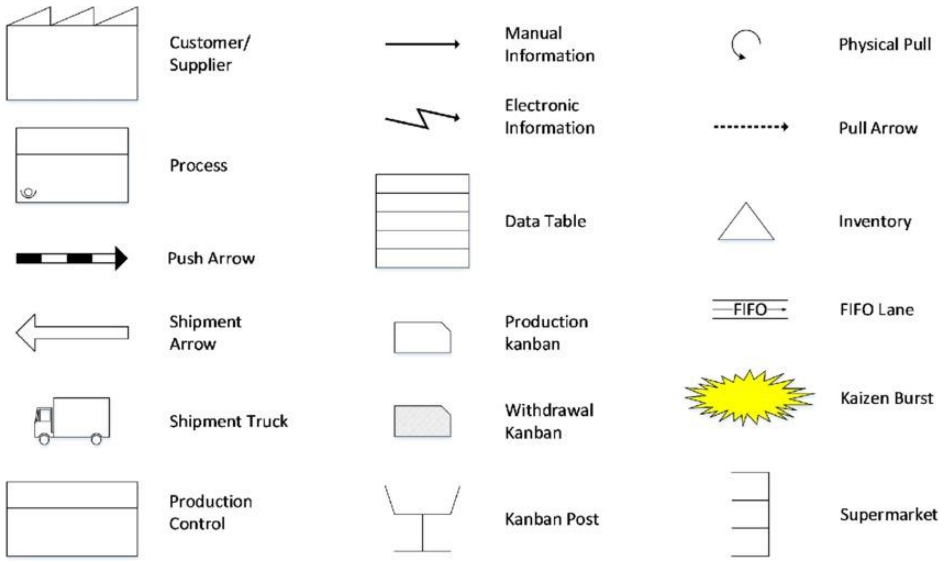

Figure 1 - Standardized icons used in the VSM tool
Source: Rother e Shook (2003).

This initial mapping uses data collected from the shop floor and process monitoring. Achieving this state is challenging, as performance obstacles in the value stream are direct effects identified during current state mapping. However, the information gathered is crucial for developing the future state, incorporating proposed improvements to reduce waste. Improving the value stream is based on recognizing challenges encountered during the current state mapping. According to Rose *et al.* (2020), when mapping, it is important to document all activities that constitute the material flow, such as machine operations, manual operations, inventory, and movement. Additionally, it is essential to record the information flow, which includes communication between customers, suppliers, sales areas, production planning, shipping, receiving, and the production team.

- Step 3 - Mapping the future situation: Mapping the future state requires that everyone involved understands the value stream mapping; however, the implementation of the future state must be led by a single person—someone who can see beyond the boundaries of the value streams within a product family and drive change. Value stream mapping is a technique; thus, the real key to becoming lean lies in mapping and effectively implementing the lean value stream. Wang *et al.* (2023) emphasize that producing products in a continuous flow with a short lead time allows for the Production of only confirmed orders, minimizing setup between different products. To achieve this, numerous future state maps are needed. This process must be continuous, meaning the future map becomes the current map that should be improved to reach a new future map. Each map is leaner and closer to the ideal, with the supplier process doing only what the customer process needs when it needs it. Wang *et al.* (2023) clarify that the main benefits obtained by organizations analyzed in selected studies with the adoption of VSM were the reduction of lead time and cycle time, focus on waste elimination, and following the lean philosophy. Benefits such as value-added time (TAV) improvements, takt time, and pitch were also mentioned. Thus, it can be concluded that these criteria can serve as metrics for companies to evaluate VSM, as they provide measurable benefits in the value stream across different sectors.
- Step 4 - Improvement plan: Establishing an improvement plan based on the future state map should include measurable goals, assignment of responsibilities, and setting deadlines. Once the future state becomes a reality, a new future map should be created, as the VSM tool aims for continuous improvement. Wang *et al.* (2023) highlight that mapping the current situation should be an ongoing process within companies.

3 METHODOLOGY

This study adopts an instrumental case study approach (Stake, 1995), which allows an in-depth understanding of a real-world process and enables the generation of transferable insights rather than universal generalizations. While the findings are context-dependent, the structure of the method—including VSM application, waste identification, and improvement actions—can serve as a replicable framework for other engineer-to-order or customized production environments. In this research, data from the current situation of the PDP were collected to understand how the routine works and what practices are adopted in the company. Next, the current scenario was outlined, highlighting its main challenges. Based on the theoretical framework, the report of the current situation, the data collected, the VSM of the current state, and the main problems/wastes present in the company's PDP, the next step consisted of developing the proposal for the VSM of the future state. Finally, an analysis of the results obtained was conducted to draw conclusions and final considerations. To facilitate the understanding of how the research was conducted, the research procedures were divided into stages, as illustrated in Figure 2.

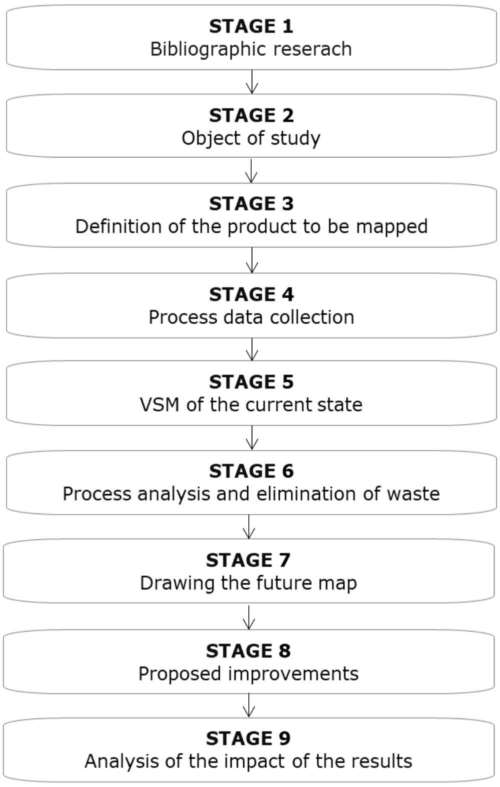

Figure 2 - Research stages
Source: Authors (2025).

Stage 1 - Bibliographic Research: To support the research, an initial literature review was conducted to map and analyze the most recent scientific literature on the application of Value Stream Mapping (VSM) in the context of the PDP. Academic databases such as SciSpace, Connected Papers, Web of Science, Scopus, and Google Scholar were used. To keep up with the latest trends and advancements in product development, the research focused on articles published from 2020 onwards. This temporal delimitation is justified because only a bibliographic review was conducted to understand the guiding themes of the research better, seek recent applications of PDP and VSM, and identify potential research gaps. Authors Boote and Beile (2005) recommend that the review include the most recent publications to reflect the updated knowledge in the field. So, the literature reviews typically focus on the most recent studies (from the last 5 to 10 years), which helps contextualize current research. Additionally, the keywords "PDP," "VSM," and "Product Development Process" were used. This approach allowed for a visualization of the main contributions and advancements in the field and the identification of the main applications of VSM for optimizing product development processes.

Stage 2 - Object of study: The company subject of this study has been in the hydraulic equipment market for over four decades. Located in the southern region of Brazil, the organization has a diversified product portfolio that manufactures equipment for cargo handling, personnel lifting, and vehicle recovery. The company has stood out for its ability to innovate and meet the specific demands of its customers. Driven by an increasingly demanding market, the company continually invests in research and development (R&D) to improve its products and processes. Currently, with a focus on a made-to-order production model and customized products, the organization demonstrates its flexibility and capacity to meet each customer's individual needs. A well-defined organizational structure supports this market dynamic and the pursuit of delivering personalized solutions. In this organizational structure, the product development phase is represented by the engineering department, which comprises seven employees. The research was conducted by the author of the study, who was appointed as the team leader, along with the engineering department employees, all of whom are directly involved in the product development phase of the PDP.

Stage 3 - Definition of the product to be mapped: Defining the value stream to be improved is necessary when different families and processes are involved in manufacturing the company's products. This study selected the product with the highest sales and production volume to develop the value stream, specifically the aerial basket equipment from the personnel lifting family, to be used in height-related work.

Stage 4 - Process data collection: Data collection was conducted based on the model proposed by Rother and Shook (2003), using VSM for this stage. Since this study is an action research, the researcher was actively involved in the process from a technical procedure perspective. Data collection occurred through the analysis of the current situation of the product development phase (PDP) via direct observation and time tracking to understand how the routine works and what practices are adopted. Subsequently, data collection and the current state of the VSM were conducted without formal interviews or structured questionnaires. Through discussions with the team of employees, it was possible to outline the current situation, understand its main problems in the flow of materials and information, and identify the activities that add value to the final product. The choice of this model is justified by its broad application across various industrial sectors and its ability to integrate different data sources.

Stage 5 - VSM of the current state: Following the approach of Rother and Shook (2003), the current state map of the product development process was created. Through data collection and direct observation of the process, it was possible to map the value stream of the PDP development phase in detail, identifying the cycle time of each activity, information flow, and opportunities for improvement. Excel was used to construct the map. The current state map is a foundation for proposing a desired future state and implementing improvement actions. The following equations were used for calculating times and efficiency:

• Lead time: The time it takes for an order to go through all the stages of the value stream, from start to finish, as shown in Equation (1).

$$\text{Lead Time} = \text{Processing Time} + \text{Waiting Time} \tag{1}$$

• Cycle time (CT): Corresponds to the available working time, excluding downtime and waiting, divided by the quantity produced. Cycle time is represented by Equation (2).

$$\text{CT} = \text{Production Time} / \text{Number of Units Produced} \tag{2}$$

• Efficiency: To calculate the efficiency of the value stream, Equation (3) was used:

$$\text{Efficiency} = (\text{Cycle Time} / \text{Lead Time}) \times 100 \tag{3}$$

Stage 6 - Process analysis and elimination of waste: The detailed mapping of the current state, through the construction of the value stream map, allows for identifying waste, non-value-added activities, and other bottlenecks impacting the process performance. This analysis provides a solid foundation for proposing improvement actions to reduce cycle time, increase efficiency, and ensure the delivery of higher-quality products.

Stage 7 - Drawing the future map: Based on the detailed analysis of the current state mapping, the future state VSM was developed, which consists of a new value stream map aimed at eliminating waste and creating a leaner, more efficient process capable of meeting customer demands more quickly and with higher quality. The new map was developed collaboratively, with the participation of all engineering department employees, and served as a guide for implementing improvement actions.

Stage 8 - Proposed improvements: The continuous update of the VSM is essential to ensure the effectiveness of the improvements. Based on the future state map, actions were proposed to eliminate waste and optimize the process, bringing the process closer to the ideal state and encouraging the search for new optimization opportunities. The methodology employed in this study allowed for a thorough contextualization and investigation of the object of study. The results are presented in the next section, highlighting the use of the VSM tool and its contribution to the analyzed process.

Stage 9 – Analysis of the impact of the results: This stage of the research aimed to analyze the results obtained concerning the proposed objective and compare the data before the implementation of the VSM and after the interventions of the proposed improvements.

4 RESULTS

Before presenting the results obtained in the case study, Figure 3 summarizes the structured methodological approach applied to redesign the PDP using Lean principles and VSM.

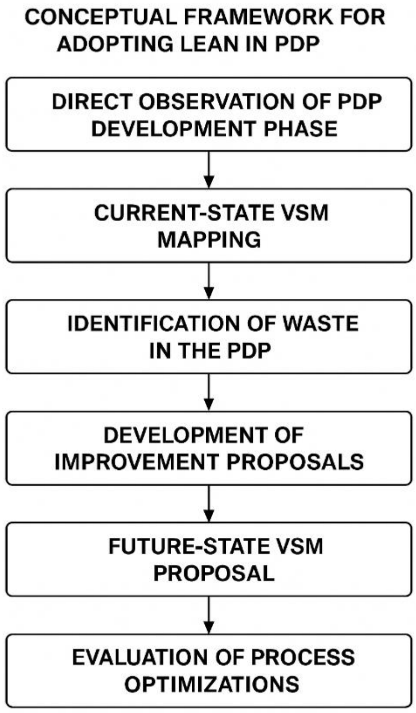

Figure 3 - Methodological approach
Source: Authors (2025).

4.1 VSM Current State Map

During the process of creating the Current State VSM, a total of five macro processes were identified for this phase, as outlined below:

1. Order Coding: All sales and negotiations carried out by the sales department are emailed to the engineering department to trigger the project requirements. Each employee is responsible for a specific product family to improve the organization. The designer reviews the configurator's information once the order is classified according to its product family. This document, prepared by the sales department, describes the equipment's dimensions, technical characteristics, the vehicle that will house the equipment, and the customer's requirements. With all the necessary information, the final assembly code for the equipment is generated in the company's system.

2. Information Confirmation: To avoid design changes during development due to scope modifications requested by the customer, which can lead to rework, cost issues, delays, and reduced capacity for other orders, the engineering department conducts an assembly study. This study simulates the truck's appearance with the equipment, indicating whether it can meet all the customer's requirements. Once the final solution configuration is defined to meet the customer's needs, the sales department sends the project drawing to the customer for validation. The process only continues after the customer's feedback, proposing improvements, or accepting the design. Additionally, this formal system for customer acceptance of the project proposal serves as a gate.
3. Project Configuration: After assigning a designer and gathering the necessary information, the equipment's three-dimensional (3D) modeling begins using Solid Edge. The main goal of this phase is to generate solutions that satisfy customer needs and provide a basis for the detailed product design. This is done by searching for, creating, representing, and selecting solutions for the design problem. All projects developed by the company have electrical, hydraulic, or both functions. These activities are assigned to specific people, including structural calculations. These two employees work as shared resources for all the company's products. The projects are calculated using a computational model and finite element method.
4. Registration and Technical Drawing: Once the project configuration is completed, the components are registered in the ERP system, and the product structure is defined, considering the quantity of each part to be manufactured. In this phase, the technical drawing of the components is created, defining the complete form of the product components, considering material specifications, tolerances, and the necessary manufacturing information.
5. Project Review: Since there is no foolproof method for ensuring that projects are flawless, as even with great care, something may still be overlooked that could affect the equipment's performance, all projects undergo a review before being handed over to the process engineering team. The responsibility for this review lies with the area supervisor, who has the most experience.

In addition to the details mentioned above, the PDP development phase has some other characteristics:

- Structural calculations for the equipment are carried out by the responsible engineer when the product is launched or in special cases.
- All products the company sells are made to order and can be customized.
- Customization is requested and agreed upon during the sales negotiation, where the customer can choose to add tooling and accessories predetermined by the company.

The map was constructed using standardized icons (Figure 4), indicating material and information flows at the top. The flow at the bottom is drawn from left to right, illustrating the sequence of macro process stages with cycle time and lead time data collected through work routine monitoring. Thus, through data collection on-site, it was possible to observe in the Current State VSM that the lead time (LT) is 23 days, of which 70.5 hours correspond to the cycle time (CT) or the activities that add value. Additionally, the wastes/issues affecting the PDP's performance were identified.

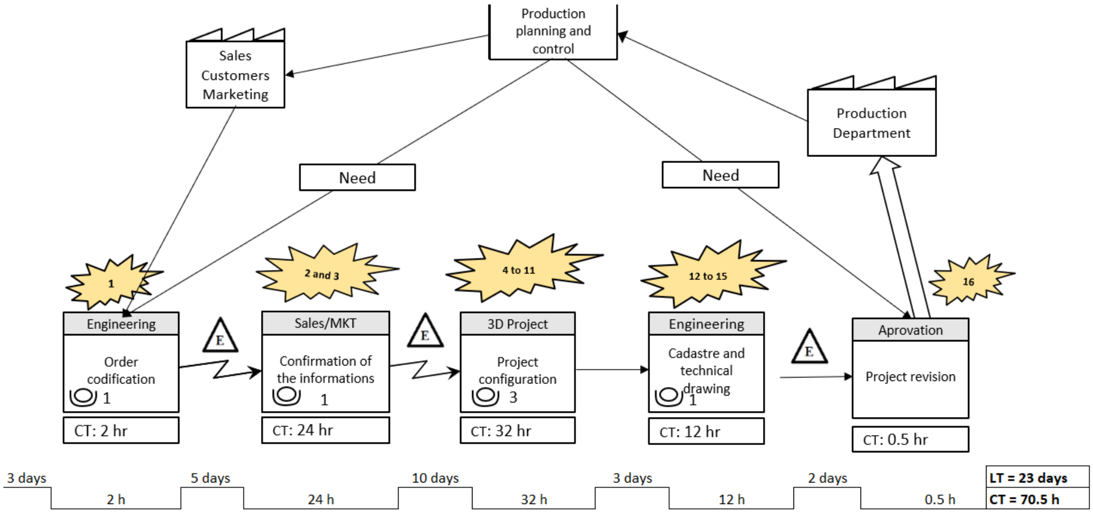

Figure 4 - Current state map
Source: Authors (2025).

After drawing the current state's value stream, the process's main wastes were identified and listed in Table 1.

Table 1 - Problems identified in the PDP development phase

Macro Process	Problems
Order coding	1. When the configurator is sent to the engineering department, there is a significant amount of defective data and missing information. As a result, the order is accepted, and throughout the project development, uncertainties are clarified, leading to delays, distortions, rework, and duplication of information, which constitutes a waste of movement.
Confirmation of information	2. **Waste due to waiting** occurs in two cases: first, when the configurator is received with incorrect input data and is sent back to the sales department for completion, requiring contact with the salesperson to clarify and adjust the situation. Second, it arises from the concentration of responsibilities with the supervisor. Although customer participation in the approval process is essential, it also contributes to longer delivery times, as approval stages tend to be slow. A significant amount of waiting waste is observed, directly impacting delivery deadlines. 3. Waiting leads to bottlenecks in the order coding process, resulting in excessive data storage, which is considered inventory waste.
Project configuration	4. Due to the high number of projects exceeding the engineering team's capacity, the flow is inconsistent, leading to waiting and inventory waste. As a result, the project completion rate is lower than the established target. 5. The specialization of designers by product families results in inventory waste of orders, as only the specific employee has the necessary knowledge to proceed with the process, causing delays, rework, and urgent solutions. 6. Lack of deadline alignment between departments in the flow often results in Production being unable to meet the established delivery date. 7. Process waste is observed for special projects, which involve equipment made exclusively to meet a customer's specific needs. This is due to frequent questions from manufacturing, requiring an engineering department representative to oversee Production, a

	high-cost resource. 8. There is no manual guiding designers regarding manufacturing limitations and best practices for project development in the company. As a result, rework is common due to process engineering's critical analysis or when the equipment is already being manufactured, leading to waste from reinventing solutions. 9. Experiences are often not documented, resulting in the repetition of past mistakes since knowledge is implicit in people rather than explicit in records. This is considered waste from reinventing, as many opportunities for improvement are forgotten in employees' desks and files. 10. Due to being a shared resource with other departments/divisions and having a limited number of professionals, there is waste from waiting, where information is left pending for people. 11. Rework is a consequence of the previous issue, as the electrical professional often needs to assist in material purchasing and supplier support since the purchasing department lacks the necessary knowledge, and adjustments or installations may be required on the equipment.
Cadastre and technical drawing	12. There is a noticeable presence of duplicated components with different codes, which is considered a waste of knowledge and reinvention. This issue arises from the fragility of the information system, either due to the database's limitations in search functionality, non-standardized descriptions, or lack of commitment from the individuals involved. 13. It is frequently observed that similar components and assemblies are detailed for the factory in different ways, with missing information, specification errors, and tolerance issues, indicating a lack of standardization in the drawings and representing a waste of reinvention. 14. The designers themselves are responsible for creating the detailed drawings. This configuration is costly for the development of this activity. Moreover, during this time, designers could focus on tasks that add more value to the organization, which constitutes a waste of inadequate processes. 15. The designers are also responsible for entering data/structure into the ERP system, representing a waste of inadequate processes, as this task is an expensive resource. Currently, the transfer of information from Solid Edge to the ERP is done manually, which is slow and prone to errors.
Project revision	16. Before projects are released, they must undergo a critical review by the supervisor (department head) to ensure they meet manufacturing requirements and to prevent any flaws from being overlooked. However, due to the supervisor's workload and the excessive number of projects, the reviews are often superficial, failing to filter out problems and prevent them from advancing to the next phases, which constitutes a waste of lack of discipline.

Source: Authors (2025).

4.2 Proposals for the future state

After identifying the waste, proposals for improvements were developed for the company's PDP development phase, based on the practices adopted by the lean philosophy, from the order coding process to the release of the project to the PPCP (production planning, scheduling, and control) sector. To achieve this, the theoretical framework and reference model discussed in section 2 were used as a basis, adapting it to the company that is the subject of this study. Table 2 presents the improvement proposals for the PDP development phase.

Table 2 - Improvement proposals for the PDP development phase

Proposal	Problem addressed
1. Create a Detailed Checklist: To address the gap of defective, low-quality, and missing input data, a detailed checklist will be developed to ensure all necessary information is collected and standardized.	1, 2, 10, 11
2. Establish Clear Communication Channels: Establish clear and efficient communication channels (corporate email, intranet) between the teams involved to enhance collaboration and reduce misunderstandings.	1
3. Define Approval Deadlines: Structure and review the approval process by establishing a maximum approval deadline with the client to streamline decision-making and avoid unnecessary delays.	2, 10
4. Develop Performance Indicators: Implement key performance indicators (KPIs) related to the department's performance and delivery timelines to track progress and highlight improvement areas.	4, 5, 6, 11
5. Delegate Supervisor Responsibilities: Distribute some of the supervisor's responsibilities to other team members, equipping them with the skills to make decisions and resolve problems, thus improving efficiency and reducing bottlenecks.	2, 6, 7, 16
6. Daily Meetings and Task Distribution: Introduce daily meetings and level the distribution of tasks by recognizing potential bottlenecks in advance, ensuring tasks are evenly allocated and progress is continuously monitored.	4, 5, 6
7. Create a Manual for Activity Execution: Develop a manual containing detailed information for department activities to ensure consistency and minimize errors or miscommunication.	5,7, 11, 13, 14
8. Implement a Pull System with Accountability: Introduce a pull system with clearly assigned responsibilities for results, using status boards in each functional area to ensure progress and highlight issues promptly.	4, 6
9. Standardize Component Descriptions: Develop standardized descriptions for components to ensure consistency across projects and reduce departmental misunderstandings.	4,12
10. Kaizen Movement: Establish a Kaizen movement, engaging selected employees in continuous improvement initiatives. According to Ohno (1997), Kaizen aims to eliminate waste through common-sense, low-cost solutions driven by employee motivation and creativity, improving processes with a focus on continuous improvement.	1, 2,4,
11. Standardize Product Family Folders: Create a standardized folder system for product families within the database, ensuring easy access for all project team members to a single source of information related to product development.	7, 8, 9
12. Map Employee Competency Matrix: Map the employees' competency matrix to develop a structured plan for progressive monitoring and development of specific technical skills, ensuring the team continuously improves and adapts to new challenges.	9, 10

Source: Authors (2025).

4.3 VSM Future State Map

After implementing all the improvement proposals suggested in Table 3 to eliminate the waste that impacts lead time, the future state VSM (Figure 5) was proposed to visualize the optimized value flow and the reduction in lead time. Firstly, the focus was on analyzing intermediate stocks, followed by the activities that consumed the most time or added little value.

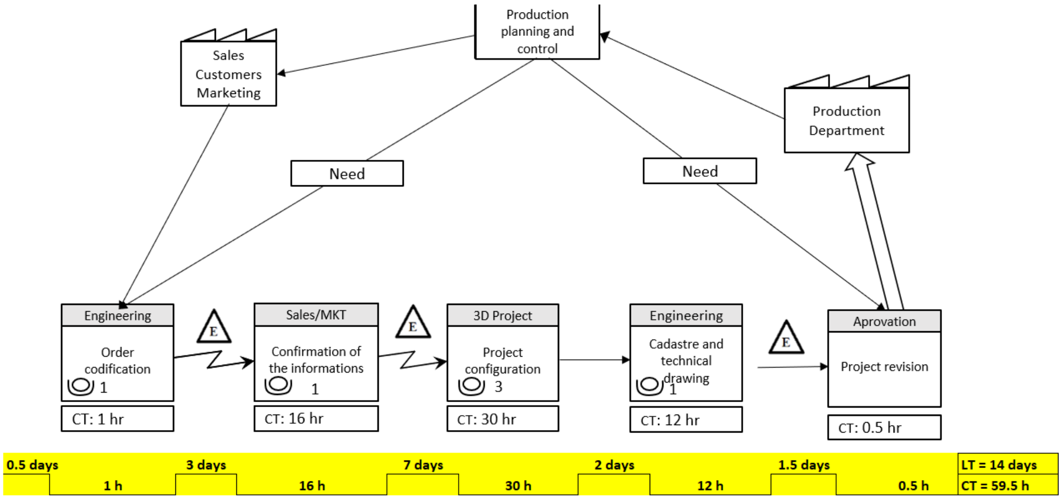

Figure 5 - PDP future state map
Source: Authors (2025).

4.4 Analysis of the impact of results

By analyzing the two maps (current and future), it was possible to obtain a reduction in lead time, achieving the initial objective proposed. Figure 6 illustrates a comparison between the current state and the future state of the analyzed process.

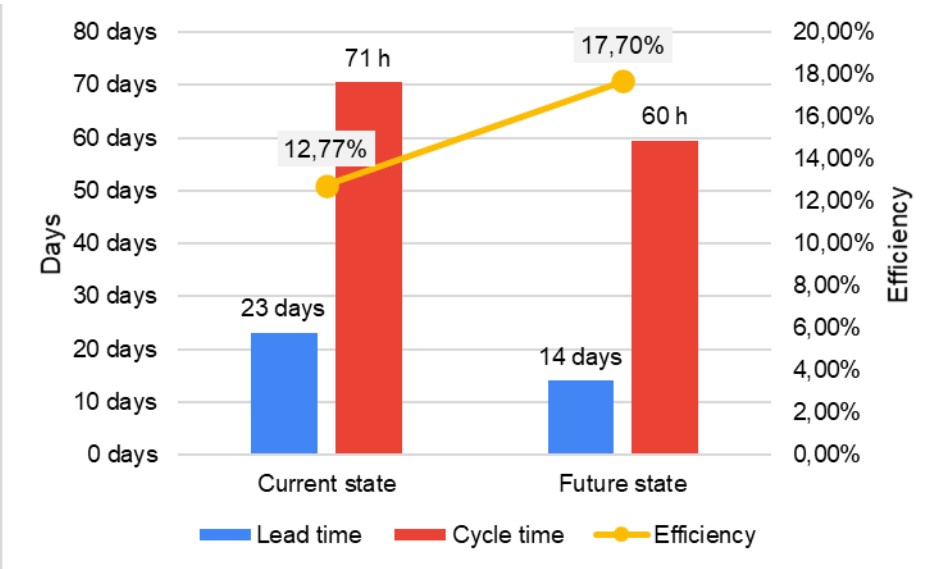

Figure 6 - Comparison between the current state and the future state of the analyzed process
Source: Authors (2025).

With the proposed implementation of the new value stream, it was possible to reduce lead time by 9 days (39.13%), cycle time by 11 hours (15.6%), and increase efficiency by approximately 5%.

Based on the map of the future situation, the improvement plan is drawn up to implement and control the actions to bring the flow closer to the ideal state. The actions suggested in the improvement plan (Table 3) are essential if the process flow is to become continuous and the work standardized, so the team involved in the process plays a major role in achieving an increasingly lean PDP.

Table 3 - Suggested actions

Item	Activity	Problem adressed	Responsible
1	Train team members in the supervisor's responsibilities, developing autonomy and decision-making skills;	2,16	Engineering supervisor: Mechanical engineer
2	Automate the activity of registering structures by linking them to the design software;	12, 14 e 15	IT analyst
3	Developing work instructions for all the activities carried out in the sector;	5, 7 e 11	Process sector analyst
4	Define and separate content for training and orientation materials;	11, 9	Designers / Engineering supervisor
5	Identify themes for kaizen;	1 ao 16	Designers
6	Develop an indicator to assess the amount of rework carried out in the PDP, with the aim of evaluating/taking action on the critical reasons;	4, 11	Engineering trainee
7	Develop forms as a way of systematically standardizing routine work processes;	1 ao 3	Commercial salesperson / Engineering designers
8	Make information on PDP activities available via dashboards, where product development can be carried out via alignment and visual communication;	3, 6	IT analyst

Source: Authors (2025).

The results will be discussed in the next section based on existing literature.

5 DISCUSSIONS

The collected data and analyses provide a clear perspective on achieving the proposed objectives. Implementing the Value Stream Mapping (VSM) tool, following the step-by-step approach and guidelines outlined in Learning to See by Rother & Shook, proved essential in obtaining meaningful results. This approach contributed to a deeper understanding of the process and helped identify improvement opportunities within the Product Development Process (PDP).

Regarding the specific objectives, data collection was achieved through direct observation, brainstorming, and documentary and bibliographic research. These methods facilitated the gathering of essential information for process comprehension. When mapping the current state, four of the eight Lean Manufacturing wastes were identified: motion, inventory, waiting, and inadequate processes. Additionally, two PDP-specific wastes were observed: reinvention and lack of discipline.

VSM is a key tool for Lean implementation across various sectors (De Steur *et al.*, 2019), enabling companies to visualize their production flow, detect inefficiencies, and refine their processes. It highlights steps that contribute the least to value creation, providing insights for improvement (Tortotella & Fettermann, 2018; Porto *et al.*, 2023; Santos, Lima, & Gaspar, 2023).

Based on the findings, several improvement initiatives were proposed, including the Kaizen application, enhanced communication channels, performance indicators, training programs, standardization, Kanban systems for orders, and using forms and checklists. Implementing these tools leads to significant efficiency gains and reduced processing time, as demonstrated by Rakoski (2020), who achieved a 59% reduction in lead time through Lean application in PDP.

Through VSM, the value flow of the analyzed phase became clearer, allowing the company and its department to enhance performance, improve processes, and minimize losses. The 39.13% lead time reduction aligns with studies by Hassan *et al.* (2024) and Dombrowski *et al.* (2010), suggesting that lead time optimization enhances customer satisfaction while generating cost savings for the company.

According to Tubino (2015), Lean Manufacturing aims to eliminate all forms of waste in manufacturing processes. However, eliminating wait times is challenging in practice, particularly when multiple projects compete for the same resources. Additionally, the customer approval process is a critical factor impacting efficiency in this case. Enhancing cooperation with customers could help shorten approval times, benefiting both parties.

Regarding cycle time (CT), the reduction observed was less significant, likely due to this study focusing on more evident waste areas, particularly process integration. Singh *et al.* (2017) demonstrated that process improvements in a small chemical company led to processing time reductions exceeding 40%. However, it is important to consider that businesses operate in different contexts, which may explain variations in results.

Although this research is grounded in a single metal-mechanical company, the proposed approach can be adapted to other sectors characterized by customized production, limited engineering teams, and strong client integration. The use of VSM in PDP environments—when supported by tailored indicators and participatory mapping—has broad applicability in similar organizational structures.

6 CONCLUSION

The increasing adoption of Value Stream Mapping (VSM) across various industrial sectors—such as automotive, electronics, and pharmaceuticals—highlights its effectiveness in optimizing the Product Development Process (PDP). By identifying and eliminating inefficiencies, VSM enhances process flow and lead time reduction. While its use is more prevalent in large corporations, it also holds significant potential for smaller companies and innovative product development projects.

A detailed observation of the engineering team's workflow was conducted to understand the studied process better. This allowed for collecting key data on activities performed, challenges encountered, and inefficiencies within the workflow. The gathered information was structured into a flowchart (Figure 6), illustrating the process sequence, and subsequently transformed into a Value Stream Map, which provided a clear visual representation of material and information flow, waste points, and opportunities for improvement.

This research aimed to reduce lead time and enhance value flow in the engineering department of a metal-mechanic industry, specifically focusing on the PDP development phase. By applying VSM, the current process was mapped, revealing areas for optimization and efficiency gains. The study began with a literature review on PDP and VSM, establishing a theoretical foundation for understanding its role in waste identification and process enhancement. Following this, a data collection phase was conducted to map the current state workflow of PDP activities. The analysis enabled the quantification of lead time for each activity and the identification of inefficiencies. Based on the findings and proposed improvements, a new value stream flow was designed, projecting a 9-day lead time reduction. However, the successful implementation of these improvements depends on the commitment of all stakeholders and the continuous monitoring of results.

Overall, this study successfully achieved its objectives, serving as a starting point for employee awareness and adopting the lean tool. The findings foster a continuous improvement mindset, allowing the company to move toward greater efficiency and enhanced customer satisfaction.

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