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Article

Assessing the Impact of Lean Tools on Sustainability—A Case Study

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Abstract: This article assesses the impact of the structured application of Lean tools on the sustainability of the operations of a Portuguese industrial company dedicated to the design, manufacture, and marketing of machinery for the industrial sector. The main goal was to understand how the integration of Lean practices can simultaneously strengthen an organization's economic, social, and environmental performance. At the same time, it was intended to address the scarcity of studies that systematically examine the selection and adaptation of these tools in medium-sized companies, characterized by high product variability and complex logistics flows. To this end, the Action Research methodology was used, which combines theoretical review with practical application. The initial diagnosis, conducted through Value Stream Mapping, identified waste and opportunities for improvement. Based on this survey, an action plan was developed and executed using the A3 Problem Solving methodology, highlighting the implementation of a Kanban system between the warehouse and the Product 2 assembly line. The results demonstrated significant progress in the three dimensions of sustainability: a reduction in the average supply lead time from 16.05 h to 11.57 h per module (economic aspect); increased material availability, shifting constraints previously attributed to the warehouse to items from pre-assembly or not included in the system (social aspect); and an approximately 30% reduction in the energy consumption of the supply support device (environmental aspect). Therefore, it is concluded that the integration of Lean practices, framed within the Triple Bottom Line perspective, constitutes an effective approach to enhance the sustainable performance of organizations, in a balanced manner on three fronts: economic, social, and environmental.

Keywords: lean philosophy; sustainability; VSM; A3 problem solving; operational efficiency

1. Introduction

Today, organizations face increasingly complex environmental, social, and economic challenges, requiring management capable of balancing these dimensions while simultaneously creating business value [1]. Increasing market competitiveness and the demand for customized products have intensified the need to optimize resources, reduce waste, and increase operational efficiency [2,3]. In this context, the Lean philosophy stands out as a strategic approach by promoting the systematic elimination of waste, standardization of operations, and continuous improvement, consolidating its position as an essential tool for sustaining corporate competitiveness [2,3].

The Lean philosophy has its origins in the Toyota Production System (TPS), developed in Japan in the 1940s. In today's competitive environment, companies face pressure to reduce costs, speed up processes, and increase reliability, while adapting to external changes and continually improving their methods. However, waste remains significant, directly impacting costs, productivity, and the sustainability of operations. Therefore, eliminating waste has become a strategic priority for many companies [4].

In addition to operational efficiency, the Lean philosophy has been increasingly associated with sustainability, a concept that must be understood from the perspective of the Triple Bottom Line (TBL), which integrates economic, social, and environmental dimensions [5]. This articulation between Lean and sustainability essentially allows to align the pursuit of operational excellence with social and environmental responsibilities, strengthening organizational resilience [6,7].

Despite the vast literature documenting the benefits of Lean, many empirical studies have focused primarily on stable and large-scale production environments, typically characterized by standardized assembly lines and repetitive processes. For example, applications of Lean tools such as 5S, VSM, and SMED are frequently reported in automotive and mass production settings, where process flows are relatively stable and variability is limited [8–10]. These studies provide consolidated evidence of improvements in cycle time, inventory levels, and productivity within structured and repetitive production systems.

However, fewer studies explicitly address how Lean tools should be selected and adapted in medium-sized companies operating under conditions of high product variability, technical customization, and complex internal logistics flows. In such contexts, production is less standardized, and the direct transfer of Lean practices developed for mass production environments may not be straightforward. This gap limits the availability of practical guidelines for organizations seeking to implement Lean in more dynamic and non-standardized industrial scenarios.

Within this context, this article aims to evaluate the impact of a structured Lean implementation on the sustainability performance of a Portuguese industrial company specialized in the design, manufacture, and marketing of machinery for the industrial sector, considering the economic, social, and environmental dimensions of the Triple Bottom Line framework.

Additionally, it seeks to contribute to the literature by addressing the scarcity of applied studies that explore the selection and adaptation of Lean tools in complex industrial contexts, offering a practical framework for organizations facing similar challenges.

2. Literature Review

2.1. Lean Philosophy

Lean is a management philosophy derived from the Toyota Production System (TPS), widely recognized for its transformative impact on production processes over the past few decades [2]. Interest in this approach has grown significantly in both academic and business contexts, especially after the publication of James P. Womack's influential book "The Machine that Changed the World" in the 1990s [3,11].

Historically, the evolution of production systems has transitioned from artisanal production, marked by low efficiency, to the mass production introduced by Henry Ford with the Model T, after World War I. This system revolutionized industry and consolidated the United States as a global economic power [12]. However, after World War II, Japan faced the challenge of rebuilding its economy with limited financial resources, which made the adoption of Ford's mass production model unfeasible [3]. It was in this context that Eiji Toyoda, a Japanese engineer, devoted several months to a detailed analysis of the production system developed by Ford and, in collaboration with Taiichi Ohno—universally recognized for his exceptional talent in production—developed the TPS, the basis of what we now know as the Lean philosophy [13].

The TPS was designed to eliminate three major sources of inefficiency in production processes, known as the 3Ms: Muri, Mura and Muda [14]:

- Muti (Overload): refers to excessive stress imposed on workers, machines or infrastructure, which can compromise productivity and safety;
- Mura (Variation): relates to irregularity and inconsistency in processes, reflected in quality, production times or manufactured volumes;
- Muda (Waste): is considered as the elimination of activities without value to the customer, such as excess production, waiting times, unnecessary transportation or defects.

Eliminating these three sources of inefficiency is a central principle of TPS and, by extension, of the Lean philosophy. In addition to prioritizing value creation and customer satisfaction, Lean promotes a systemic view of the value chain, focused on the continuous reduction of waste and effective coordination between internal processes and external partners, ensuring a production flow tailored to the actual needs of the market [15].

2.1.1. Lean Phylosophy Principles

Lean philosophy is based on five fundamental principles, which guide organizations in eliminating waste and maximizing operational efficiency, as described by [16,17]:

- Define the concept of value: clearly identify what represents value for the customer, ensuring that each product or service meets their needs and expectations;
- Identify the value chain: map all stages of the production process, differentiating activities that effectively add value from those that represent waste;
- Ensure a continuous flow: ensure that value flows uninterruptedly throughout the production chain, eliminating delays, bottlenecks and inefficiencies that can compromise performance;
- Implement the pull production system: adjust production to real customer demand, ensuring that products are manufactured only when needed, avoiding surpluses and ensuring greater agility in responding to variations in demand;
- Seek perfection: promote continuous improvement of processes, through the elimination of failures and adjusting practices in order to achieve operational excellence.

2.1.2. Benefits of Lean philosophy

Lean philosophy has established itself as an efficient operational management model, capable of generating significant gains in efficiency, reduced operating costs, and increased customer satisfaction, essential elements for global competitiveness [18]. One of its fundamental pillars is the elimination of waste (Muda), systematized by Taiichi Ohno in the so-called "eight Lean wastes": overproduction, excess transportation, waiting times, unnecessary processing, redundant inventory, inefficient movements, defects, and underutilization of human potential [19].

Since the 1980s, Lean has demonstrated a significant impact on the manufacturing industry, providing substantial improvements in efficiency, cost reduction, and error minimization [16]. Furthermore, its implementation has been associated with additional benefits, such as reduced lead time, greater inventory control, reduced work in progress (WIP), improved customer service quality, enhanced internal communication, better use of physical space, shorter cycle times, and the promotion of continuous improvement, always associated with increased productivity [20].

Several studies confirm these results in different industrial and service contexts. In the manufacturing industry, a study conducted at a furniture factory in Turkey showed that the application of tools such as VSM, 5S, and Kaizen resulted in a significant reduction in waiting times, quality defects, and unnecessary movements, increasing overall productivity. In the specific case of sewing, the average waiting time decreased from 508 to 180 min. Furthermore, the implementation of the changes resulted in savings of 868.67 km in employee walking distance and a saving of 241.30 working hours, equivalent to 30 working days [21].

In the healthcare sector, the gains are also significant. In Italy, at the Policlinico Santa Maria alle Scotte of Siena hospital, the application of Lean combined with mathematical optimization models resulted in a simulated reduction of over 30% in average waiting times for appointments in the hematology department [22]. In France, the introduction of the methodology in the emergency department of a public hospital reduced complaints by 50% and the average length of stay by 30%, while in Ireland, the adoption of Lean practices in the medical device industry has improved operational efficiency, reduced costs, and increased the quality of services provided [23,24].

In the carton packaging industry, the implementation of tools such as SMED, TPM, and Kaizen increased the overall efficiency of production areas by 28.7%, confirming Lean's potential to eliminate waste and strengthen competitiveness [25]. In Portugal, the integration of Lean and Green concepts into the robotic welding process, namely through the application of tools such as Kaizen, VSM, Jidoka, and TPM, has reduced cycle times by 25–40%, reduced energy consumption by 38%, and reduced material waste by 66% [26].

2.1.3. Challenges and Barriers in Implementing Lean Philosophy

Despite the numerous benefits associated with the Lean philosophy, its implementation can be a complex process, fraught with challenges that hinder the achievement of expected results. The most common barriers can be grouped into three main categories: human, organizational, and process-related [27].

Human barriers include resistance to change, difficulty accepting standardization, lack of adequate training, communication problems, lack of trust in management, and high employee turnover—factors that essentially result from how employees perceive and react to the changes promoted by Lean. Organizational barriers are associated with a lack of management commitment, limited resources, misaligned performance indicators, lack of integration between departments, an organizational culture resistant to continuous improvement, and an overly rigid hierarchy. Finally, process-related barriers are related to inefficient workflows and a lack of process monitoring [27].

Empirical studies confirm the relevance of these obstacles. In a survey of 50 North American companies, the main obstacles identified were lack of management support and employee resistance to change, leading many organizations to revert to traditional methods. The study concluded that Lean's success depends on investment in ongoing employee training and active leadership involvement to ensure the consolidation of organizational changes [28]. Similar results were obtained in a study of 49 Polish small and medium-sized companies in sectors such as metallurgy, chemicals, food, and aeronautics: although the benefits of Lean were recognized, 55% of companies had not yet adopted it, highlighting the importance of structured monitoring to ensure successful Lean implementation [18].

2.2. Lean Tools

The implementation of the Lean philosophy relies on a wide range of tools designed to support waste elimination, process standardization, and continuous improvement. These tools play a crucial role in creating a more efficient production flow, ensuring that operations add value and eliminate unnecessary activities [29,30].

The Lean philosophy encompasses a broad range of tools and techniques, including, among others, 5S, Value Stream Mapping, Kanban, Single Minute Exchange of Die, Total Productive Maintenance, Just-In-Time, and A3 Problem Solving. However, this subsection addresses some of the most widely recognized Lean tools, selected due to their strategic relevance in process analysis, flow management, and structured problem-solving, and for their frequent discussion in academic literature. In this regard, the following subsections focus on Value Stream Mapping, Kanban, and A3 Problem Solving, given their recurrent presence in academic studies and their complementary roles within Lean implementation frameworks.

2.2.1. Value Stream Mapping

Value Stream Mapping (VSM) is an essential tool of the Lean approach, used to map the flow of materials and information throughout a production process. Its main objective is to identify value-adding activities and expose waste, providing a clear understanding of the process and highlighting areas of loss and improvement. This approach makes it possible to optimize operational flows, reduce inefficiencies, and increase overall process effectiveness [31].

VSM implementation is developed in four main phases: (i) selection of the product or family of products to be analyzed, prioritizing the most representative processes; (ii) mapping the current state, which represents the flows of materials and information, as well as the times, distances, and resources involved, allowing the identification of waste, inefficiencies, and bottlenecks; (iii) mapping the future state, designing an optimized scenario through improvement proposals that eliminate unnecessary activities and promote a continuous flow of work; and (iv) defining an action plan, which establishes the necessary steps for the transition between the two states mentioned, assigns responsibilities, and sets deadlines for implementation, ensuring the sustainability of the improvements [32].

In practice, VSM has demonstrated significant impacts in different sectors. In the automotive industry, its implementation allowed the identification of 26 critical points and promoted a 62% reduction in cycle time on an assembly line, in addition to reducing the number of operators from 4 to 3 and dipping the inventory of unfinished products by approximately 25% [8]. In a factory in Punjab, India, the use of VSM in the production line of piston pins for railway engine maintenance promoted an 80.09% reduction in in-process inventory, 50% in finished product inventory, and 82.12% in lead time. Furthermore, cycle time decreased by 3.75%, setup time reduced by 6.75%, and the number of operators required decreased from 12 to 10, increasing the productivity and overall efficiency of the line [9]. In another case, in a paint factory, the application of VSM reduced total production time from 8.5 to 6 days and value-added time from 68 to 37 min [33]. In addition to industry, more recent studies demonstrate its applicability to areas such as the circular economy, to measure the efficiency of material recirculation and identify opportunities for improvement in resource management, and, on the other hand, in education, where VSM has made it possible to optimize administrative activities and reduce teachers' work stress [34,35].

2.2.2. Kanban

Kanban is one of the main subsystems of the TPS, designed to monitor production flow, manage inventory levels, and coordinate material supply. The Japanese word "kanban" means "card" or "visual signal", reflecting its function of organizing and regulating production. The system, essentially, ensures that each stage of the production line receives only the necessary quantity and the right type of material, at the right time, avoiding waste and promoting efficiency [36,37].

Kanban management relies on visual communication as a means of transmitting production information, issuing work orders, and preventing excess inventory [36]. Various Kanban modalities have been developed to adapt to the particularities of each process, including the physical production or transport card, painted markings on the floor, the two-bin system, light signaling, e-Kanban, and the gravity model [38].

The application of Kanban in various sectors has demonstrated its potential to reduce waste and optimize workflows. In the apparel industry, for example, implementing the system to control production flow reduced fluctuations in work-in-process (WIP) inventory and increased efficiency by 22% [39]. In the maritime sector, the introduction of Kanban boards applied to production order management resulted in a 50% reduction in lead time [40].

In retail and e-commerce, Kanban has been primarily used to improve inventory management and order fulfillment rates. In a Portuguese supermarket, adopting the system in high-turnover warehouses reduced stockouts, increased the order fulfillment rate from 92.5% to 94.5%, and reduced the out-of-stock rate to 0.30% [41]. Also in Portugal, at a company specializing in the design and manufacture of automated material handling and storage systems, the use of Kanban in 115 materials reduced wait time variability, stabilized workflow, and ensured greater operational continuity, contributing to a 16% reduction in annual logistics costs [42].

Finally, in the modular construction sector in Singapore, the integration of e-Kanban with Just-In-Time (JIT) deliveries reduced cycle time by 81.27%, decreased WIP by 74.30%, and increased productivity by 4.58% [43].

2.2.3. A3 Problem Solving

A3 Problem Solving is a Lean tool developed by Toyota to structure problem-solving and support the implementation of improvements in production processes. Its name comes from the A3 format, used to clearly and objectively condense all relevant information about a problem, thus encouraging teams to adopt a structured and collaborative analysis aimed at identifying effective solutions [44,45].

Although there are different variations, all types of A3 Reports follow the logic of the PDCA (Plan-Do-Check-Act) cycle, allowing for visual and organized representation of problems, facilitating communication, and fostering more informed decision-making [45,46]. In general, the A3 methodology structure includes the following elements: defining the topic and problem, quantifying the current situation, clarifying objectives, analyzing causes, identifying improvement proposals, developing an action plan, and defining verification mechanisms [44,47].

The methodology's effectiveness has been proven in various contexts. In a study conducted at a Japanese motorcycle manufacturing company, the A3 methodology reduced setup time from 152 min to 45 min, increasing operational efficiency and avoiding additional costs associated with the need to create a new shift [48]. Similarly, in a brake cable assembly line for the automotive industry, the application of the tool enabled the elimination of waste, a 49% increase in productivity, a 33% reduction in cycle time, and an 11% increase in overall line efficiency [10]. In the healthcare sector, its use in the operating rooms of a university hospital resulted in a 46% reduction in the number of door openings during operations—from an average of 54.9 to 31.97 openings per surgery—thus mitigating infection risks [49].

2.3. Sustainability

The concept of sustainability has been widely debated in recent decades, consolidating its position as a central element in defining strategies for the balanced development of societies. Despite its popularity, the term continues to be interpreted in different ways, varying depending on the context in which it is applied. This diversity of meanings reflects its historical evolution and the attempt to harmoniously integrate economic, social, and environmental dimensions [50].

The contemporary notion of sustainability has its origins in the environmental movements of the 1970s and 1980s, fueled by landmark events such as the first Earth Day (1970) and the United Nations Conference on the Environment, held in Stockholm (1972). However, it was with the publication of the book "Our Common Future" (1987)—also known as the Brundtland Report—prepared by the World Commission on Environment and Development, that the concept acquired a widely recognized definition. In this document, sustainable development is described as the ability to meet present needs without compromising the ability of future generations to meet their own needs [5].

In parallel, the debate on sustainability was fueled by reflections that questioned the limits of economic growth and the impact of the overexploitation of natural resources. During the 1970s, publications such as Schumacher's "Limits to Growth" (1972) and "Small is Beautiful" (1973) drew attention to the finiteness of the planet's resources and the risks associated with an economic model based on continuous growth, highlighting the need for more responsible production and consumption patterns [50]. These discussions converged on the formulation of the concept of sustainable development, presented in the aforementioned 1987 Brundtland Report, which is based on two fundamental principles: prioritizing the meeting of the basic needs of the most vulnerable populations, promoting equity in access to essential resources; and recognizing the limitations imposed by both technological advances and social conditions, which, in turn, condition the planet's ability to sustain long-term economic growth and quality of life in the future [51].

In the 1990s, according to John Elkington, the "second great environmental wave" (green wave) was taking place, marked by a growing appreciation of sustainability as one of the 20th century's most important contributions to global prosperity. In this context, the debate on sustainability intensified, incorporating approaches that explicitly integrated economic, social, and environmental dimensions into development strategies. It was in this context that the concept of the Triple Bottom Line emerged, which argues that organizational performance should be evaluated not only by economic results, but also by social and environmental impacts [5].

Triple Bottom Line

The concept of the "three pillars of sustainability"—economic, social and environmental—is one of the most widespread ways of representing sustainability, normally illustrated by means of three interconnected circles, as shown in Figure 1 This approach highlights that sustainability is the point of intersection between the three dimensions [50].

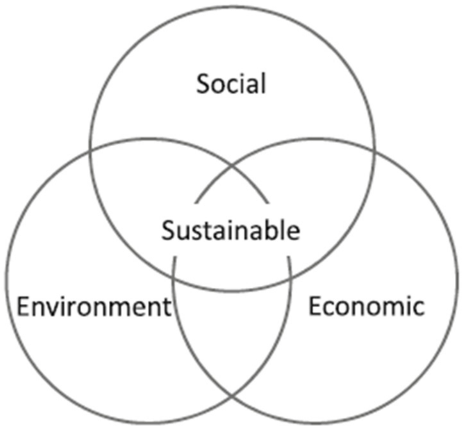


Figure 1. The Three Pillars of Sustainability [50].

Despite the success of this conceptual model, its practical application has revealed difficulties, especially regarding quantifying and monitoring the impact of sustainability in organizational contexts. To address this challenge, John Elkington introduced the Triple Bottom Line (TBL) concept in 1997. Inspired by the tripartite logic of the three pillars of sustainability, the TBL expanded this vision by explicitly integrating the economic, social, and environmental dimensions [50,52].

As a practical tool for organizational management and evaluation, TBL proposes that the performance of organizations be measured along three fundamental lines [52]:

- Economic: assesses the economic impact of business activities, ensuring that the organization's value creation contributes to economic growth without compromising future sustainability;
- Social: refers to the organization's commitment to fair and ethical practices that benefit workers, communities, and society at large;
- Environmental: focuses on adopting practices that minimize environmental impact, promoting the efficient use of resources and reducing the company's ecological footprint.

The TBL therefore constitutes a practical framework for operationalizing sustainability, offering a structured method for assessing organizational impact in a balanced manner. Although conceived primarily within the corporate environment, this model has been progressively adopted in various sectors as a tool for monitoring sustainability performance.

2.4. Lean and Sustainability

Lean philosophy and sustainability have increasingly been understood as complementary approaches to improving organizational efficiency and reducing waste, promoting more sustainable development. Beyond its traditional focus on eliminating inefficiencies and optimizing processes, Lean has demonstrated a significant impact on promoting sustainability. The connection between these concepts is revealed, above all, in the reduction of raw material consumption, the minimization of waste, and the increase in the efficiency of production processes [53].

In this sense, a study was conducted with the objective of identifying and clarifying the main points of convergence between the Lean philosophy and the three pillars of sustainability, demonstrating how the application of Lean can positively impact each of these aspects [54]. Table 1 presents a summary of these synergies.

Table 1. Synergy between Lean and Sustainability.

Pillar	Sustainability Synergy with Lean
Environmental	Reducing the amount of waste and the consumption of natural resources, such as energy and water; Reducing carbon emissions; Improving energy efficiency;
Social	Improved workplaces (safer and more organized); Improved employee motivation; Local development and strengthening of community ties;
Economical	Reduced production costs; Increased productivity, process efficiency, and competitiveness; Continuous improvement.

The literature review included a significant number of studies demonstrating the benefits of the Lean philosophy and its tools, primarily in stable, large-scale production contexts. Therefore, there is a significant lack of research that systematically and explicitly addresses the criteria for selecting and adapting Lean tools in medium-sized companies, characterized by high product variability, a strong technical component, and complex logistics flows.

Most existing publications focus on environments with standardized lines or mass production, which ultimately offer little guidance on the principles that should guide the selection of the most appropriate Lean tool when processes involve customized products and a significant number of components required for their construction. This lack of practical guidelines and applied examples limits the support available to organizations seeking to optimize their internal flows and reduce waste in more dynamic and demanding scenarios.

In this context, this study aims to fill this gap by investigating the process of analyzing, selecting, and implementing Lean practices in a real-world environment, as well as evaluating the impact of these tools on corporate sustainability, considering the three dimensions of the TBL: economic, social, and environmental. By quantifying the results obtained and presenting informed recommendations, the study aims to contribute to the advancement of knowledge about the applicability of Lean tools in complex industrial contexts, offering a practical framework for organizations facing similar challenges.

3. Materials and Methods

3.1. Research Methodology

For the development of this study, the use of the Action-Research research methodology was crucial, characterized by the combination of practical action and theoretical reflection, with the aim of finding effective solutions to concrete problems faced by the organization [55]. The Action-Research methodology is characterized by an iterative cycle that includes five fundamental stages: diagnosis, action planning, implementation, evaluation, and learning specification, all of which are essential for a comprehensive definition of the methodology (Table2). The diagnosis phase involves an in-depth analysis of the company’s current situation, focusing on the processes and areas requiring intervention, to identify the causes of the problems and establish action priorities. Action planning defines the necessary strategies and selects the tools and methodologies best suited to the organization’s needs. The implementation phase involves applying these strategies to previously identified processes, in collaboration with the company, promoting the participation and direct involvement of those involved in achieving the proposed solutions. During the evaluation, the results obtained are analyzed and compared with the initially established goals. Finally, the learning specification consists of recording the main lessons learned, as well as suggestions for future improvements. Therefore, it constitutes a reflection to consolidate the progress achieved and ensure the sustainability of the implemented changes. The choice of this research methodology is justified by its ability to integrate theory and practice, promoting a continuous process of learning and improvement, fundamental to solving organizational problems in an effective and sustainable way [55].

Table 2. Overview of the Action Research cycle (adapted from [56]).

Step	Content
Diagnosis	The current situation of the internal logistics flow was analyzed through Value Stream Mapping (VSM), identifying inefficiencies, bottlenecks, and waste sources. Data on lead time, cycle time, OEE, and material availability were collected and complemented with field observations and informal interviews with operators and supervisors.
Action Planning	Based on the diagnosis, improvement opportunities were structured using the A3 Problem Solving methodology. The main causes of delays were analyzed with the Ishikawa diagram and prioritized using the GUT matrix, which led to the definition of the main improvement action: implementing a Kanban system between the warehouse and the Product 2 assembly area.
Implementation	The Kanban system was implemented following the 5W2H plan. This included defining box types (SUC), organizing articles on Kanban shelves, establishing labeling and color-coding standards, training operators, and validating the physical layout with the logistics and assembly teams.
Evaluation	Performance was assessed through Key Performance Indicators (KPIs) aligned with the Triple Bottom Line (economic, social, and environmental). Quantitative indicators included cycle time, supply lead time, OEE, employee satisfaction, and PDA energy consumption.
Monitoring	The implemented system was monitored to ensure process stability and continuous improvement. The KPIs defined in the verification plan were used to track progress and evaluate the long-term sustainability of the Kanban system.

To provide a clear overview of how the Lean tools applied in this study were integrated and supported each other, Figure 2 presents the conceptual framework. The diagram shows the logical sequence from process diagnosis (VSM + OEE) to action planning: opportunities were structured with A3 Problem Solving; the supply process was mapped with SIPOC; internal movements were quantified with a spaghetti diagram; root causes were explored using the Ishikawa diagram; and improvement actions were prioritized with the GUT matrix. Next, 5W2H was used to structure the action plan for the top-ranked initiative, clarifying purpose, responsibilities, deadlines, and resources. The sequence culminated in the implementation of the Kanban system. This framework highlights the interdependence of the tools and how their combined use enabled a structured, continuous improvement pathway, serving as a practical reference for similar industrial contexts.

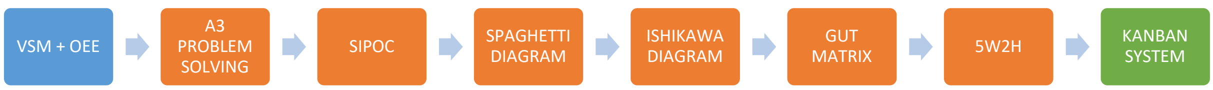


Figure 2. Conceptual framework.

3.2. Company Characterization

This study was conducted at a leading Portuguese industrial company. In keeping with the organization's request for confidentiality, its identity was deliberately concealed, using the fictitious name XPT S.A. throughout the study. XPT S.A. is dedicated to the design, manufacture, and sale of machinery for the industrial sector, with a consolidated presence in both the domestic and international markets, devoting more than 80% of its production to exportation. The company has over 500 employees and a global network of representatives and partners. Regarding its technology portfolio, XPT S.A. offers diverse industrial solutions grouped into six major functional categories, covering different stages of the production chain—from core operations to complementary processes, finishing, and digitalization. This diversity allows companies to respond to the needs of small manufacturing units as well as large-scale industrial facilities, ensuring high levels of customization, stability, and technological integration. Regarding its production model, XPT S.A. adopts a highly verticalized approach, in which most operations—from raw material cutting to final assembly and shipping—are performed internally. The study focused specifically on Business Unit 2.1—Final Equipment Assembly, considered the core of highest added value, as it concentrates the final steps before delivery to the customer. This unit integrates components produced internally or purchased from suppliers, resulting in the company's final products. The workflow encompasses sub-assembly operations, final assembly, functional testing, quality control, and shipping preparation.

3.3. Initial Diagnosis

The study followed structured logic, supported by the Value Stream Mapping (VSM) methodology, complemented by the Overall Equipment Effectiveness (OEE) metric, to map the current state of processes, plan a more efficient future scenario, and identify constraints, waste, and opportunities for improvement. The articulation of these concepts allowed for the integration of the qualitative characterization of the production flow with the quantitative measurement of production efficiency, which reinforced the robustness of the diagnosis and improvement measures targeted to the reality of XPT S.A.

3.3.1. Selecting the Products' Family

The first step in implementing the VSM methodology was selecting the product family to be analyzed. Based on an analysis of sales volume, revenue, and average selling price of the machines in 2024, it was concluded that the selected product family, referred to in this study as "Product 2", although representing only 6% of the units sold (34 out of a total of 541 units), accounted for approximately a quarter of the company's total revenue in 2024. Its high financial contribution, combined with the complexity and technical demands of its production process, justified its selection as the focus of the study. For confidentiality reasons, the product family under analysis is anonymized under the designation "Product 2". In practice, this designation encompasses a set of product variants and configurations that share a common production route, similar assembly operations, and the same internal logistics flow. Therefore, despite being referred to as a single product, Product 2 corresponds to a product family in VSM terms.

3.3.2. Mapping the Initial Situation

The second stage involved building the current-state map for Product 2, covering all phases from the reception of raw materials to the shipment of the finished product. In addition to analyzing the manufacturing orders for Product 2 manufactured throughout 2024, the following quantitative data were collected: number of employees per workstation, average cycle time per module, setup time, distances traveled between workstations, OEE, the presence of intermediate stocks between stages, the frequency of communication with suppliers and customers, and, finally, the information flow. To complement the study, we also conducted field observations and informal interviews with operators and supervisors. These inputs informed the current-state VSM for Product 2, presented in Figure 3. The graphical representation of the value stream allowed to identify several operational conditions that compromise the system's performance, among which the following stood out:

- High assembly cycle time, with an average of 89.57 h per module;
- Significant setup time for assembly, reaching 25 h;
- High distance between machining and painting, over 230 m;
- Low OEE in welding, with an average value of 49.82%.

Thus, the identified constraints constitute clear sources of waste, particularly related to transportation, waiting, and process inefficiencies. The current state map thus highlights significant potential for improvement, supported by eliminating this waste and developing a more efficient, synchronized, and value-creating future state.

3.3.3. Future State Mapping

The third stage of the VSM methodology consists in building a future-state map, whose main objective is to define an optimized target condition for the value stream by eliminating waste, reducing inefficiencies, and improving the production processes flow. This future state was developed based on the critical analysis of the current state map, which revealed several constraints, namely high cycle times in assembly, excessive intermediate inventories, long material handling distances, frequent material shortages, and low overall equipment effectiveness (OEE).

The future-state Value Stream Design (VSD), presented in Figure 4, reflects a set of concrete changes aimed at stabilizing and simplifying the internal logistics flow. In particular, intermediate buffers upstream of the assembly process was reduced, and the material supply to the Product 2 assembly area was redesigned according to a pull-based logic. The introduction of a Kanban system between the warehouse and assembly enables a more predictable and continuous material flow, reducing waiting times and minimizing unplanned interruptions caused by material shortages.

Additionally, the future state assumes a clearer synchronization between production and logistics activities, limiting unnecessary movements and reinforcing the availability of materials at the point of use. These changes create the conditions for reducing lead time, improving flow efficiency, and increasing the robustness of the assembly process, thereby serving as the foundation for the improvement actions detailed in the subsequent section.

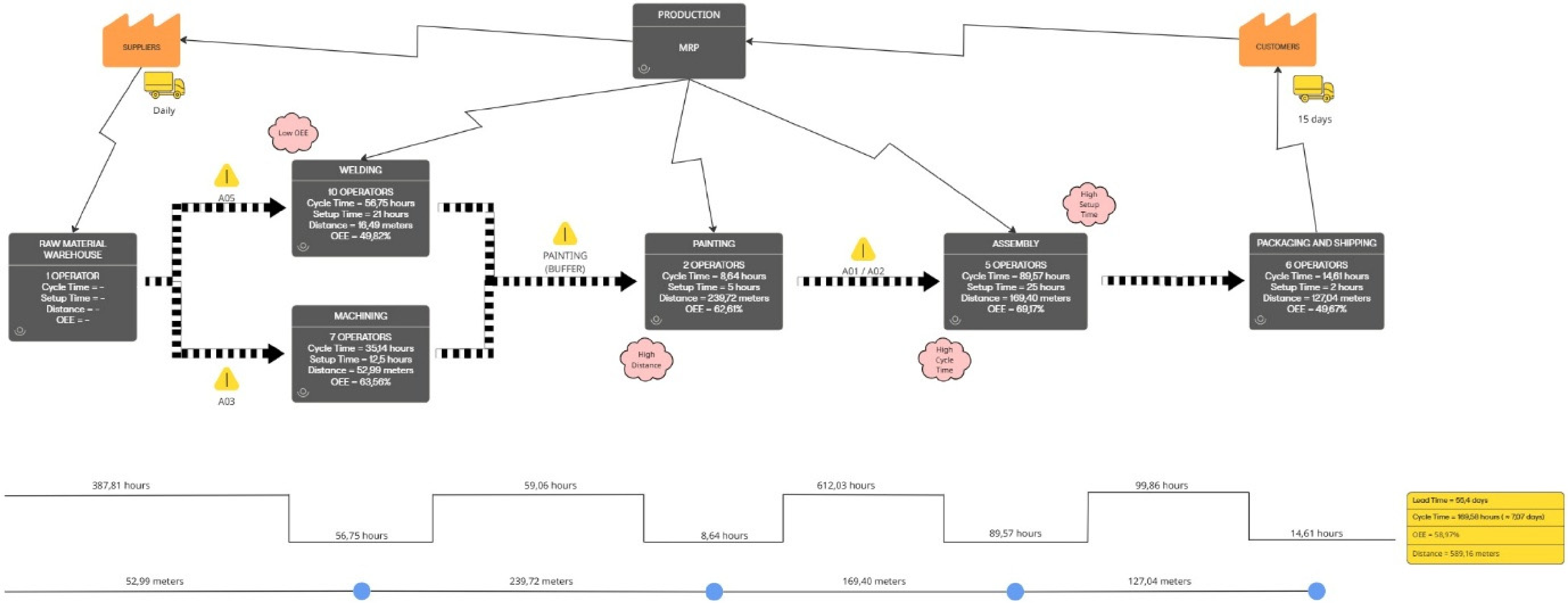


Figure 3. Current State VSM.

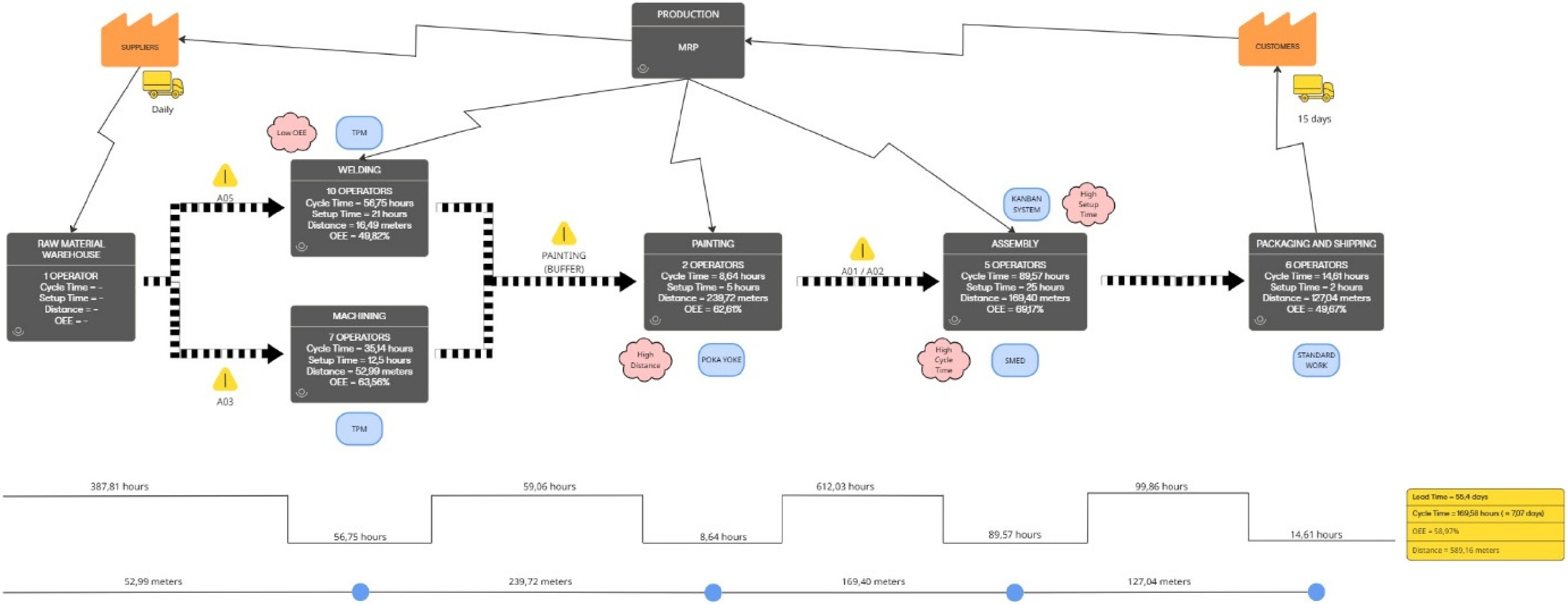


Figure 4. Future State VSD.

3.3.4. Preparation of the Action Plan

Following the development of the future-state map and the identification of improvement opportunities, a structured action plan was defined, corresponding to the fourth phase of the VSM methodology. To support this phase, the A3 Problem Solving methodology was used, a well-established tool in the Lean context designed to guide structured problem-solving. Based on the PDCA (Plan-Do-Check-Act) cycle, this approach allows for the documentation of logical reasoning, analyses performed, and proposed actions on a single page, facilitating communication between teams and ensuring a focus on eliminating the root causes of problems.

The Product 2 assembly area was chosen for the A3 application because it corresponds to the target product family of this study and, simultaneously, presents the longest cycle time (89.57 h per module) and setup time (25 h), thus representing the main bottleneck in the production system. Given the direct impact of these constraints on competitiveness and delivery deadlines, cycle time reduction was defined as the priority focus of the A3 methodology.

To characterize the process under analysis in greater detail, the SIPOC tool (Supplier, Inputs, Process, Outputs, Customer) was used, which allowed mapping, in a structured way, the supply process, namely, the entities involved, the necessary inputs, the activities performed, the outputs generated and the respective recipients. Additionally, a spaghetti diagram was created with the intention of identifying and quantifying the movements made in the warehouse during the supply of materials for the assembly of Product 2. Once the main goals were defined, the underlying causes of the high cycle time in the assembly of Product 2 were identified. To structure this analysis, the Ishikawa diagram was used, which enabled the identification and organization of critical factors into five main categories: labor, method, machine, material and environment.

Based on this diagnosis, improvement proposals were drawn up to address the root causes of the high cycle time in the Product 2 assembly area. Initiatives were prioritized using the GUT (Severity, Urgency, and Trend) matrix, which assigned a rating to each proposal based on three criteria: the severity of the impact on organizational performance, the urgency of resolution, and the likelihood of worsening if the situation is not corrected. The results of this prioritization are presented in Table 3.

Table 3. GUT matrix.

Actions	Severity (G)	Urgency (U)	Trend (T)	G × U × T	Rank
Implement a Kanban system between the warehouse and Product 2 assembly	5	5	5	125	1
Consolidate supply by common-part groups instead of module-by-module	5	4	4	80	3
Final checklists before carts leave the warehouse	3	3	4	36	8
Operator training (warehouse)	3	4	4	48	6
Regular cross-team meetings (warehouse–assembly–engineering)	3	3	4	36	8
Create supply KPIs	4	5	3	60	5
Preventive maintenance plan for carts/stackers	3	3	4	36	8
Evaluate/acquire new handling equipment	4	3	4	48	6
Introduce high-adhesion, durable labels	4	4	4	64	4
Review and update warehouse stock	5	4	5	100	2
Redesign warehouse A01 layout	2	2	3	12	12
Improve lighting in the supply area	3	3	3	27	11

The results of this analysis showed that implementing a Kanban system between the warehouse and the Product 2 assembly area was the priority action (125 points), clearly standing out from the others.

Given the work's time constraints and its alignment with XPT S.A.'s management's strategic objectives, the decision was made to exclusively implement this solution because it was the highest ranked improvement action. Accordingly, the action plan was structured using the 5W2H methodology, a widely used planning tool in Lean projects that ensures systematic clarification of improvement initiatives by addressing six guiding questions: what will be done, why it is necessary, who is responsible, when and where it will be implemented, how it will be executed, and how much it will cost.

The application of the 5W2H methodology to the implementation of the Kanban system between the warehouse and the Product 2 assembly area is detailed in Table 4.

Table 4. Application of the 5W2H methodology to the implementation of the Kanban system.

5W2H	Definition
WHAT?	Implement a Kanban system between the warehouse and the Product 2 assembly area.
WHY?	• Reduce assembly cycle time; • Eliminate recurring errors in material deliveries from the warehouse; • Reduce time waste associated with manual checks; • Ensure a stable and continuous material flow at the point of use; • Increase assembly efficiency and release operators from non-value-added tasks.
WHO?	Intern (responsible for data collection, system parameterization, and implementation); Warehouse operators (material preparation and supply); Assembly coordinator and team leader (validation of items and categories); Assembly operators (system use).
WHEN?	Implementation carried out during the internship period, between January and July 2025.
WHERE?	Between warehouse A01 and the Product 2 assembly area.
HOW?	• Collection and analysis of consumption data for the fabric of Product 2; • System parameterization (monthly production and coverage stock); • Selection of eligible items and definition of the appropriate SUC box type; • Organization of items on Kanban shelves by functional categories; • Creation of a database and identification labels; • Installation of the storage areas in the warehouse, with an optimized layout for supply and consumption; • Training and system initialization, with periodic data collection and review by the responsible logistics operator.
HOW MUCH?	Costs associated with Kanban shelves, labeling system, SUC boxes (A, B, C, D, and special types), and related materials.

Finally, a verification plan (Table 5) was defined, with performance indicators (Key Performance Indicators—KPIs) aligned with the three dimensions of sustainability, according to the TBL concept. This approach ensures not only the monitoring of operational gains but also the contribution of actions to the organization's social and environmental objectives.

Table 5. Verification plan.

Dimension	Indicator	Goal	Measurement Method
Economical	Average cycle time for final assembly of Product 2	Reduce 25% by Dec/2025	Time recording via Sage X3 and tracking manufacturing orders
Economical	Average supply lead time	Reduce 50% by Dec/2025	Measurement between material order and delivery in the assembly sector of Product 2
Economical	Overall Equipment Effectiveness (OEE)	Increase ≥ 80% by Dec/2025	OEE monitoring via the intranet
Social	Number of work accidents	Keep 1 accident with time off until Dec/2025	OSH Department Reports
Social	Employee satisfaction	Average response ≥ 4 in all categories until Oct/2025	Satisfaction survey
Environmental	Energy consumption of the Personal Digital Assistant in the supply process	Decrease 50% by Dec/2025	$Energy\ Consumption\ (Wh) = \frac{Battery\ Capacity\ (mAh) \times Voltage\ (V)}{1000}$

The outcome of applying the A3 Problem Solving methodology, the structured improvement plan developed for Product 2, is shown in Figure 5.

A3 Problem Solving Methodology

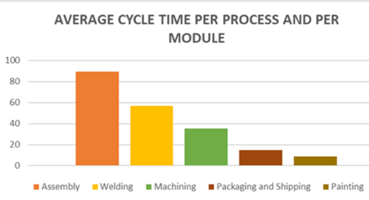
1 - THEME: LEAD TIME REDUCTION – PRODUCT 2 ASSEMBLY:

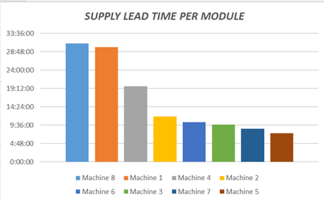
High cycle time in the Product 2 assembly area.

2 - PROBLEM DEFINITION:

The current-state value stream map revealed that the Product 2 assembly area presents the longest cycle time across the entire XPT production flow. This situation compromises overall efficiency and negatively affects the company's ability to meet customer orders. The limitation has a direct impact on delivery deadlines, representing a risk to both competitiveness and customer satisfaction.

3 - CURRENT SITUATION QUANTIFICATION:

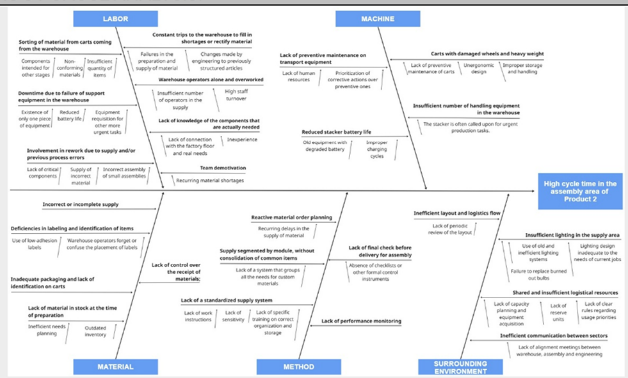




4 - OBJECTIVES:

- **Objective 1 –** Reduction of cycle time per module: Reduce the average assembly cycle time of Product 2 by at least 25% by December 31, 2025;
- **Objective 2 –** Reduction of average supply lead time per module: Decrease the average material supply lead time from the warehouse by at least 50%, considering the period between the request and delivery to the assembly area, by December 31, 2025;
- **Objective 3 –** Minimization of warehouse movements: Reduce by 50% the number of movements required to prepare carts in warehouse A01 by October 30, 2025.

5 - ROOT CAUSE ANALYSIS:



6 - IMPROVEMENT PROPOSALS:

- Implement a Kanban system between the warehouse and the Product 2 assembly area
- Consolidate material supply by groups of common items
- Implement final verification checklists before carts leave the warehouse
- Provide specific training for warehouse operators
- Establish regular communication meetings between warehouse, assembly, and engineering teams
- Create performance indicators (KPIs) for material supply
- Implement a preventive maintenance plan for carts and stackers
- Evaluate and acquire new handling equipment
- Introduce high-adhesion and durable labels
- Review and update warehouse stock
- Redesign the warehouse A01 layout
- Improve lighting in the supply area

7 - ACTION PLAN:

5W2H	DEFINITION
WHAT?	Implement a Kanban system between the warehouse and the Product 2 assembly area.
WHY?	Reduce assembly cycle time; eliminate frequent errors in material deliveries from the warehouse; reduce time wasted in manual verifications; ensure a continuous and stable material flow at the point of use; increase assembly efficiency and free operators from non–value-adding tasks.
WHO?	Intern (data collection, system setup, and implementation); warehouse operators (material preparation and replenishment); assembly coordinator and team leader (validation of parts and categories); assembly operators (system use).
WHEN?	Implementation carried out throughout the internship period, between February and July 2025.
WHERE?	Between warehouse A01 and the Product 2 assembly area.
HOW?	1. Data collection and analysis of material consumption for Product 2 manufacturing; 2. System parameterization (monthly production and safety stock); 3. Selection of eligible items and definition of suitable SUC box types; 4. Organization of items on Kanban shelves by functional categories; 5. Creation of a database and identification labels; 6. Installation of shelves in the assembly area with an optimized layout for supply and consumption; 7. System training and startup, with regular collection and replenishment by MIZO.
HOW MUCH?	Costs associated with shelf acquisition, labeling system, SUC boxes (types A, B, C, D, and special), and related materials.

8 - VERIFICATION PLAN:

DIMENSION	INDICATOR	OBJECTIVE	MEASUREMENT METHOD
ECONOMIC	**Average cycle time of Product 2 assembly**	Reduce by 25% by Dec/2025	Time tracking via Sage X3 and production order monitoring
ECONOMIC	***Average material supply lead time***	Reduce by 50% by Dec/2025	Measure the time between material request and delivery to Product 2 assembly
ECONOMIC	**Overall Equipment Effectiveness (OEE)**	Increase to ≥80% by Dec/2025	OEE monitoring through intranet
SOCIAL	**Work accident rate**	Maintain ≤1 lost-time accident by Dec/2025	Reports from the Health & Safety Department
SOCIAL	**Employee satisfaction**	Average score ≥4 in all categories by Oct/2025	Employee satisfaction survey
ENVIRONMENTAL	**PDA energy consumption**	Reduce by 50% by Dec/2025	$Energy\ Consuption(Wh) = \frac{(Batery\ Capacity\ (mAh)\ x\ Tension\ (V))}{1000}$

Figure 5. A3 Problem Solving.

The social dimension of sustainability was analyzed based on two main indicators: the number of work-related accidents and employee satisfaction. From these indicators, it is possible to assess not only the state of health and safety at XPT S.A. but also the employees' perception of the working environment—factors that directly influence motivation, productivity, and talent retention. Within the scope of evaluating the social dimension of sustainability at XPT S.A., a questionnaire was conducted with the operators of the Product 2 assembly sector. The main objective was to collect the employees' perspectives regarding working conditions, with particular focus on safety, ergonomics, communication, and material supply.

The questionnaire was structured with eight closed-ended questions, complemented by open fields for comments. Responses were given on a scale from 1 to 5, where 1 corresponds to "Strongly Disagree" and 5 to "Strongly Agree." The questionnaire was administered between 11 and 15 April 2025, covering 11 employees from the target sector, including the coordinator and the Team Leader. All collected responses were validated and considered for the calculation of the average scores, accompanied by an interpretative analysis.

To complement the individual analysis of the eight questions, a graphical representation was used to observe, in an integrated manner, the variability of perceptions among the operators. A radar chart was chosen, a visual tool particularly suitable for representing multivariate data and for simultaneously comparing different individuals across the same set of variables.

In this case, the chart allows visualization of each operator's evaluation concerning the analyzed aspects, with each vertex representing one of the following dimensions: Safety, Physical Effort, Repetitive Tasks, Material Handling, Team Communication, Material or Equipment Shortages, Material Waiting Time, and Cleanliness and Hygiene.

The main advantage of this graphical approach lies in its ability to quickly identify response patterns, as well as discrepancies or convergences among employees—elements that are not always evident through traditional statistical analysis. Thus, the visual representation not only reinforces the interpretation of the average agreement levels but also highlights the degree of homogeneity or dispersion of individual opinions. In this sense, the radar chart constitutes a complement to the previously conducted statistical analysis, validating the obtained results and adding important nuances for their understanding.

3.4. Improvements Proposal

Once the diagnosis and prioritization phase of improvement opportunities was completed, we moved on to implementing the action considered most critical: the introduction of a Kanban system between the warehouse and the assembly area of Product 2. This section describes the methodology followed, from the theoretical framework of the tool to the design process and the steps taken until its effective implementation on the factory floor, highlighting the decisions made and the logic underlying each of them.

3.4.1. Tool Framing and Operation

According to the literature review, Kanban is a visual control system that regulates the flow of materials and information on the factory floor, following the logic of the pull production system. It is a versatile tool that can take different forms—such as physical cards, floor signs, two-bin systems, electronic versions, among others—as long as it maintains its purpose: to communicate, simply and unambiguously, what to produce, in what quantity, and when [38].

In the case under study, the two-box model—also called fixed Kanban—was chosen due to its simplicity, effectiveness, and because it is a methodology familiar to operators, since it is already applied in other sectors of XPT S.A. Additionally, as the Product 2 assembly line is characterized by relatively stable and repetitive consumption, it reinforces the suitability of this model to sustain a regular and predictable supply at the point of consumption.

The system operates by assigning at least two identical boxes to each item, positioned near the line edge—the area surrounding the stations or work areas where the material is actually used. Each box is identified by a Kanban card, which contains essential information about the item: code, description, quantity, and location on the shelf. Whenever one of the boxes is empty, it is transferred to the Kanban shelf collection area (lower level—OUT), serving as a visual signal to the logistics operator that it is necessary to replenish it before the second box is depleted, to avoid interruptions in the production process or stockouts. After replenishment, the box returns to the line edge with the previously defined quantity, ensuring the continuity of the material flow and contributing to the stability and predictability of the process.

3.4.2. Implementation Objectives

The introduction of the Kanban system fits into the logical sequence of the work performed: after identifying the main causes of the high cycle time in the assembly of Product 2, using the Ishikawa diagram, several improvement measures were proposed to mitigate these causes. Subsequently, the application of the GUT matrix allowed for the prioritization of these actions and the implementation of a Kanban system as the highest priority, given the high severity of the problems it solves, the urgency of their resolution, and the risk of worsening if they remain unchanged.

It was found that Kanban has a particular impact on XPT S.A. since, in addition to being classified as a priority action, it also helps to respond to some of the most critical causes identified in the Ishikawa's diagram, as can be seen in Table 6.

Table 6. Relationship between the causes of high cycle time in the assembly of Product 2 and the effects of Kanban.

Cause	Description	Kanban Effect
Pre-sorting of material in carts	Warehouse carts filled with incorrect or unnecessary items	Eliminates the need for prior sorting, ensuring that only items consumed on the line are supplied
Constant trips to the warehouse to fill in shortages or rectify material	Operators interrupted tasks to request missing material	Automatic and advanced replacement of materials, reducing unplanned movements
Downtime due to failure of support equipment in the warehouse	Dependence on a single stacker, causing interruptions in the material cart preparation process	Regular and consolidated replenishments, mitigating peaks in simultaneous demand for equipment and increasing their availability for other tasks
Warehouse operators alone and overloaded	Preparation of individual and complex carts for each machine, requiring significant effort and difficulties in managing tasks, which increased the risk of errors	Simplified and concentrated process, reducing effort and the occurrence of errors
Involvement in rework due to supply and/or previous process errors	Material shortages or non-conformities were detected late	Standardized cards that reduce the risk of identification errors, supply failures, and the need for rework or unscheduled downtime
Supply segmented by module, without consolidation of common items	Articles common to the various modules prepared at multiple times	Consolidated supply, reducing duplication of movements and displacements, ensuring a more continuous, fluid and efficient flow of materials to the assembly line

3.4.3. Data Collection and Database Construction

The first step in defining the items to be integrated into the Kanban system consisted of a detailed analysis of the 24 units of Product 2 produced in 2024 (excluding discontinued models and recovery orders). Based on the complete list of items for each machine, a consolidated database was created, eliminating duplicates and standardizing descriptions. For each item, the highest consumption observed among all variants was recorded, a value used as a reference for system sizing. This criterion ensured that Kanban would be able to support all configurations of Product 2, including the most complex ones, thus automatically covering all other (simpler) variants.

3.4.4. Defining Kanban Parameters

After consolidating the database, the system sizing parameters were defined, considering two assumptions: monthly production of 7 units of Product 2 (≈ 1.75 per week) and a 4-week coverage stock (consistent with standard company policy and previous Kanban implementations). Thus, the total quantity required for each item (QTY_{TOTAL}) was calculated as a function of the unit quantity required per product (QTY_{UNIT}), the planned production volume, and the defined stock coverage, according to the following expression:

$$QTY_{TOTAL} = QTY_{UNIT} \; x \; Production \; x \; Stock \tag{1}$$

The result served as an initial estimate to support production continuity for a full month, without interruptions due to material shortages. In a second phase, the studied sizing was compared with assembly experience, through validation by the respective Team Leader, who introduced corrections based on actual assembly consumption. Discussions with the warehouse were carried out to align the quantities with the suppliers' packaging and replenishment schedule, thus simplifying the process and optimizing the box filling stage.

For operational purposes, the final quantities were rounded up to avoid slow unit counts and distributed across at least two boxes per item. The iterative process—initial calculation, validation during assembly, and logistical adjustment—resulted in the final parameter that underpins Kanban: quantity per box and number of boxes assigned to each item.

3.4.5. Technical Characterization of Items

To support the selection of items to be integrated into Kanban, a technical and economic characterization was performed. For each item, the code, description, unit of measurement, dimensions, and unit weight, as well as the current location in the warehouse, were recorded. From an economic perspective, the average unit cost (CM) and the possession cost (CP), calculated as 20% of the average unit cost (CP = CM × 0.20), were considered [57]. These values were used to compute the unit inventory cost (CS), defined as the sum of CM and CP. The total inventory cost (CST) was then calculated as the product of the total required quantity (QTY_{TOTAL}) and the unit inventory cost (CST = QTY_{TOTAL} × CS). Additionally, the condition of each item (active, out of stock, or unusable) was assessed, enabling the immediate exclusion of non-viable materials. Whenever possible, an image was also associated with each item to enhance the reliability of visual identification.

3.4.6. Functional Classification and Grouping of Items

After technical characterization, the articles were classified in terms of functionality, in collaboration with the assembly Team Leader, with the aim of understanding the concrete application of each component in the assembly process and, mainly, confirming its relevance to the Kanban system.

The items were therefore grouped into 15 functional categories, which, broadly speaking, encompass structural and electrical elements, fastening materials, and parts for connecting modules. Due to confidentiality reasons imposed by the company, it is not possible to detail the composition of each category. Nevertheless, the division allowed for a critical and objective analysis of the set of items and ensured that only those deemed essential to the assembly process were considered.

3.4.7. Item screening and Exclusion

Once the characterization was complete, the items were screened to determine their eligibility in the Kanban system. Items that were out of stock or unusable, had high unit costs, were not compatible with the available boxes, or were deemed unnecessary after joint validation with the assembly team. The analysis was conducted on a case-by-case basis, as the complexity of the process and the specificities of each item prevented the definition of universal rules.

3.4.8. Sizing of Standardized Boxes

Based on the technical characteristics and consumption of each item, the most appropriate box type (A, B, C, D, or special) was determined. To validate this choice, physical simulations were performed to assess the containment capacity and resulting weight, avoiding incompatibility situations, such as overloaded or difficult-to-handle boxes. Final validation, in conjunction with the warehouse team, confirmed the suitability of the proposed solutions, ensuring that all items could be integrated into the Kanban system without compromising the efficiency of the replenishment process or operator safety.

3.4.9. Kanban Shelves

To support the implementation of the system, XPT S.A. company provided four shelves, whose layout was strategically planned in the center of the Product 2 assembly hall. This location, close to the warehouse and equidistant from the seven assembly areas, reduced travel times and waste associated with internal transportation.

The racks were arranged in a back-to-back configuration, allowing warehouse operators to access their rear to collect empty boxes and replenish material, while assembly operators use the front to retrieve necessary items. The system thus establishes a clear separation between replenishment and consumption zones, avoiding flow intersections, reducing unnecessary maneuvers, and promoting a safer, more fluid, and organized environment. At the same time, the spatial organization reflects the principles of the pull methodology, in which materials are replenished based on actual consumption rather than fixed forecasts, ensuring a flow more adapted to actual demand. The resulting layout is shown in Figure 6.

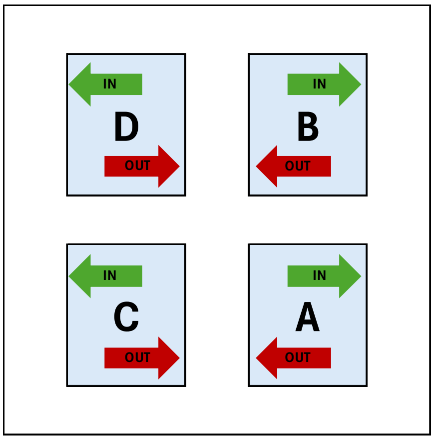


Figure 6. Kanban shelving layout.

Each rack consists of four supply levels (IN), with rollers that move boxes by gravity to the front area, and a lower level for collecting empty boxes (OUT). The layout was designed to ensure ergonomics, versatility, and proper circulation of transport carts, approaching the concept of an "internal supermarket".

3.4.10. Organizing items on Kanban shelves

The arrangement of items on the shelves was defined according to four functional categories:

(1) Purchase Material: items purchased externally (such as fasteners: screws, washers, females, pins; pneumatic components and electrical materials);
(2) Mechanical components;
(3) Structural and connection elements;
(4) Remaining material.

The organization adheres to frequency of use and ergonomic criteria: less frequently used items were placed on the upper levels, while those with greater use and greater weight were allocated to the intermediate and lower areas. The rationale followed was to reduce the physical effort required by operators and facilitate material handling. Thanks to this organizational logic, which combines functional and ergonomic aspects, it promotes a more efficient flow of materials, reduces the likelihood of errors in both supply and collection, and reduces the time spent on activities that do not add value to the final product.

To reinforce standardization, a four-digit coding system was created, in which the first identifies the shelf (from A to D), the second the level—with the letter A referring to the lowest—and the last two refer to the exact horizontal position of the article on that level (e.g.,: AA01 = shelf A, level A and first position counting from the left).

3.4.11. Identification and Labeling System

The Kanban system implementation was complemented by a visual identification mechanism based on labels developed with Labeljoy software. Its main function was to correctly identify each item present in the system, simultaneously simplifying the work of assembly operators and logistics personnel responsible for replenishment.

The labels were designed with a color scheme that associates each item with its functional category, allowing for immediate recognition. A color key was affixed to the shelves to reinforce the system's clarity (Table 7).

Table 7. Color scheme for Kanban system categories.

Category	Color
Purchase Material	(red)
Mechanical Components	(yellow)
Structural and Connection Elements	(blue)
Remaining Material	(green)

In relation to the labeling system, three complementary identification layers were defined, each with distinct functions:

- Shelf structure: labels affixed to the front and back faces of the shelves, containing the item's code, description, position and category (Figure 7);

Figure 7. Shelf frame label.

- Front face of the box: simple labels, positioned on the front face of each box, with the item code and description, in order to avoid inconsistencies between the label on the shelf structure and the label on the box (Figure 8);

Figure 8. Front box label.

- Back face of the box: more complex labels, intended for the warehouse operator, containing the code, description, image of the item, QR Code, supply warehouse, point of use, position of the item on the shelf and, finally, the quantity of material (Figure 9);

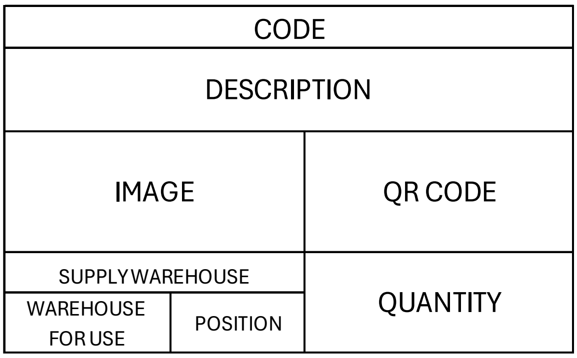


Figure 9. Back box label.

Before the practical application, Excel simulation was performed to validate the item distribution and optimize space utilization. This analysis allowed for the virtual testing of different combinations of standard and special boxes, the assessment of each shelf level's capacity, the grouping of similar items to facilitate searching, and the anticipation of potential space constraints.

3.4.11. Sets Formation

During the material flow analysis, it was identified that certain items were sent directly to assembly, despite previously requiring intermediate operations in other departments. In practice, this situation forced assembly operators to reroute materials to these locations, leading to additional trips and wasted time.

To overcome this limitation, sets with specific codes were created so that items only reached assembly after all necessary operations in other departments had been completed. Thus, instead of being sent individually and in an intermediate state, they were integrated into already prepared sets, ready to be consumed directly in the assembly process. The introduction of this solution simplified material flow, as well as eliminated unnecessary trips between departments, and reduced the workload of assembly operators, who no longer needed to manage incomplete materials or route them to other stations. As a result, these professionals were able to focus on their higher-value-added tasks, increasing productivity and process stability. At the same time, the coherence of the Kanban system was reinforced, since the Product 2 assembly area began to receive exclusively materials ready for immediate use.

During the development period of this research, four additional sets were structured, the implementation of which allowed the release of six positions previously occupied by items that, from a technical point of view, were not yet ready to be incorporated into the assembly of Product 2.

4. Results

4.1. KPI Measurement—Initial Situation

To assess the impact of the Kanban system implementation on XPT S.A.'s sustainability performance, the key performance indicators (KPI) defined in the verification plan (Table 5) were measured. The values presented in this section correspond to the initial state of the process and serve as a reference for comparison with post-implementation results. To ensure consistency, all indicators were measured over the same timeframe, between January and April 2025. Data were collected from the company's internal information systems, occupational safety records, and structured questionnaires, using standardized calculation criteria defined in advance.

4.1.1. Economic Dimension

The economic analysis considered three indicators:

- Final assembly cycle time for Product 2: the average was 35.03 h per module, calculated by dividing the total recorded assembly time of each machine by the number of modules assembled, based on production records from the company's internal system;
- Average supply lead time: between the material request and delivery to the assembly sector, an average of 16.05 h was recorded per module, measured as the elapsed time between the issuance of the material request and its physical delivery to the assembly area, based on a representative sample of production orders;
- OEE: the overall equipment effectiveness of the line was 43.05%, a value obtained directly from XPT S.A.'s internal system. The reduced performance stems mainly from availability losses (downtime caused by material shortages) and rework required to correct nonconformities—factors that constrain overall effectiveness and highlight the instability of the logistics process as one of the main barriers to improving operational efficiency.

4.1.2. Social Dimension

From a social point of view, the following indicators were evaluated:

- Work Accidents: there has been a downward trend in recent years (2022: 2 accidents with time off; 2023: 1; 2024; 0), although there was 1 accident with time off until April 2025, based on official occupational health and safety records provided by the company;
- Employee Satisfaction: A questionnaire (scale of 1 to 5) was implemented regarding 11 employees, applied to operators and supervisors from the Product 2 assembly area during the analysis period. The average results showed positive evaluations in Safety (4), Team Communication (4), and Cleanliness and Hygiene (4). On the other hand, weaknesses emerged in Cargo Handling (average 3 and high standard deviation: 1.31) and recurring problems related to Material Shortages and Waiting Time (average 4, with over 90% of respondents confirming the existence of problems in these areas).

4.1.3. Environmental Dimension

The environmental analysis focused on the energy consumption of the PDA (Personal Digital Assistant) used for recharging. The estimated value was 14.8 Wh per full charge cycle, calculated based on the average battery capacity and nominal operating voltage of the devices in use. It was also found that the average battery life of the devices corresponds to approximately two work shifts (about 16 h), in line with the previously identified average recharging lead time of 16.05 h. Therefore, the consumption associated with this period is considered equivalent to a full battery charge.

4.2. KPI Measurement—Final Situation

To consistently assess the impacts of implementing the Kanban system, the performance indicators defined in the verification plan (Table 5) were remeasured, as was done in the initial situation. Data collection took place between August and September 2025, a period conditioned on company vacations and adaptation to the new system, factors that partially influenced the results.

4.2.1. Economic Dimension

- Final assembly cycle time for Product 2: increased from 35.03 to 42.47 h per module. While this result may at first glance suggest a loss of efficiency, the increase reflects circumstantial circumstances (fewer machines evaluated, post-holiday returns, and greater technical complexity of the machines) and does not invalidate the expected gains from Kanban. The goal of reducing average cycle time by 25% by December 2025 has not yet been achieved, and it is recommended to continue monitoring the indicator and reassess it in phases of greater production stability;

- Average supply lead time: reduced from 16.05 to 11.57 h per module (−28%). Additional studies on three more recent orders showed reductions of over 50% when most items were already in Kanban. The goal of halving this indicator by December 2025 is therefore on a very positive and plausible trajectory;
- OEE: increased from 43.05 to 91.93%. Although it appears to be a significant gain, the reading requires caution by the following reasons: (i) capacity was expanded with two additional areas, with the incorporation of two operators, which naturally inflates available capacity; and (ii) there was an atypical concentration of machine completions in August: in just two weeks, three machines were completed, a situation that accentuated the perception of higher productivity compared to the usual pace. Thus, the value reflects not only the effects of Kanban, but also the circumstances explained above. Even so, the result indicates that the Kanban system helped bring the assembly line closer to benchmark performance and suggests that, in more stable scenarios, it will be possible to sustain higher levels of efficiency.

4.2.2. Social Dimension

- Workplace accidents: no incidents were recorded during the period analyzed, confirming the continued trajectory of accident reduction. The goal of not exceeding one accident with time off work by 2025 was achieved;
- Employee Satisfaction: The results of the questionnaire administered in the final phase (identical to those in the initial phase) revealed positive progress. The dimensions Safety, Team Communication, and Cleanliness and Hygiene remained stable; Load Handling improved, while Efforts worsened, and Repetitive Tasks were divided. Material or Equipment Shortages decreased, although Waiting Time for Materials remains a barrier. Initially, three dimensions had averages of 3 (Efforts, Repetitive Tasks, and Load Handling), and in the final phase, only Repetitive Tasks remained below the target. Therefore, it can be concluded that the goal was partially met, confirming significant improvements, but with room for improvement within the defined deadline.

4.2.3. Environmental Dimension

- PDA energy consumption in the supply process: reduced from 14.8 Wh to 10.7 Wh (−28%). Although still insufficient to reach the 50% target, the reduction was achieved in just two months, making it plausible to expect the achievement of the target with the stabilization of the Kanban system and the consolidation of its effects on the average supply lead time.

4.3. Results Discussion

The results obtained in this research allow to address the gaps identified in the literature review and demonstrate how the study contributed to filling them. As noted previously, much of the scientific literature on Lean philosophy and its tools focuses on stable, large-scale production environments, offering consolidated guidelines for standardized lines or mass production. However, the definition of criteria that would support the selection and adaptation of Lean tools in medium-sized companies, subject to high product variability, high technical demands, and complex logistics flows, remained unclear.

This article sought to address this gap by designing and applying a structured process for diagnosing, selecting, and implementing Lean practices, developed in the real-world context of XPT S.A. The combination of Value Stream Mapping (VSM), Overall Equipment Effectiveness (OEE), and A3 Problem Solving methodologies allowed for a rigorous characterization of the current state of processes, prioritization of problems, and guidance for decision-making. Based on this framework, it was possible to base the selection of the Kanban system as the priority solution for improving the logistics flow between the warehouse and the assembly area of Product 2, in line with the organization’s strategic objectives.

The tool’s practical application confirmed its viability even in a scenario characterized by a wide variety of items and a high degree of customization. The observed gains—reduced waiting times, stabilization of material flow, greater availability of components on the line, and simplified tasks for operators—transferred into economic benefits by reducing waste and indirect costs, but also into social impacts (improved working conditions, reduced cargo movement and stress) and environmental impacts (reduced energy consumption associated with the supply process).

These results reinforce the idea that, when supported by a rigorous analysis process, Lean philosophy can be adapted to complex industrial contexts, maintaining its potential to combine efficiency and sustainability. Furthermore, the study provides a practical reference for other organizations that, like XPT S.A., operate with diverse products, addressing the lack of explicit guidance on how to select and adjust Lean tools in highly variable scenarios.

In summary, the work shows that the effectiveness of Lean practices does not depend exclusively on stable and standardized environments: their careful application, supported by data and aligned with strategic objectives, allows for significant improvements also in dynamic production systems, contributing simultaneously to the three pillars of sustainability—economic, social and environmental.

5. Conclusions

The work developed allows to demonstrate, in a real industrial context, the potential of Lean tools to optimize production processes and, simultaneously, promote gains with regard to the economic, social and environmental components that characterize sustainability.

The analysis conducted at XPT S.A. began with the application of the VSM methodology in conjunction with the OEE indicator. The diagnosis of the current situation revealed significant constraints in the value stream, notably high assembly cycle times (average 89.57 h per module), significant setup times (25 h), excessive movement between operations (>230 m), and low overall equipment efficiency (OEE = 49.82%). These factors contributed to disproportionate lead time, with only 13% of the time being dedicated to value-added activities, reinforcing the need for a structured intervention aligned with the principles of the Lean philosophy.

Based on the VSM results, a more efficient future state was designed and an action plan developed, prioritized through the GUT matrix and detailed with the support of the A3 methodology. Among the proposed measures, the implementation of a Kanban system between the warehouse and the Product 2 assembly area stood out as a priority action, given that it obtained the highest score (125 points). The system design followed a structured logic: detailed collection of consumption data, technical characterization of items, and definition of sizing parameters. Processes were also carried out to sort and exclude illegible items, as well as functional classification and physical organization on the Kanban shelves. Additionally, an identification and labeling system was introduced, which, combined with the creation of new sets, reinforced the model's coherence, making it more intuitive, reliable, and efficient. The shelving arrangement, the use of a color scheme for categorization, and the standardization of stocked quantities reflect a methodology focused on simplicity, predictability, and error minimization. At the same time, the integration of the assembly, warehouse and coordination teams ensured that decisions were validated collaboratively, respecting real consumption needs and operational feasibility in the warehouse. The final solution, based on the two-box model, ensured operational simplicity, visual clarity and supply stability, allowing operators to focus on value-added tasks, while reducing physical effort, displacements and errors in material preparation.

From an economic perspective, the reduction in supply lead time was highlighted, which, in a complementary study, decreased to at least half the initial value, and a significant improvement in the overall efficiency of the assembly line, despite the current constraints on the average cycle time.

Regarding the social dimension, the survey results showed the maintenance of high levels of safety, communication, and hygiene, as well as a favorable evolution in cargo movement, associated with simplified material handling. However, challenges remain related to the physical effort required by heavy components and the repetitive nature of certain tasks, aspects that should guide future improvement actions. Material availability also saw progress, no longer relying on the warehouse, although delays related to items coming from other departments or not integrated into Kanban continue to occur, which, according to employees, still causes long wait times.

From an environmental perspective, the energy consumption of the Personal Digital Assistant (PDA) in the supply process decreased by 28%, from 14.8 Wh to 10.7 Wh. Although still below the 50% target, this improvement within just two months suggests that the goal is achievable as the Kanban system stabilizes.

Despite the results obtained demonstrating the potential of Lean tools to enhance organizational sustainability, several limitations must be acknowledged. The confidentiality restrictions imposed by the company—although understandable—limited the full disclosure of certain problems and constrained the detailed description of some processes, given the nature of the industry and the sensitivity of the information involved. Moreover, the collection of environmental data did not allow for the consistent acquisition of information regarding indicators such as energy and water consumption per sector, waste generated per unit, or specific recycling rates. This gap revealed a weakness in the company's systematic monitoring of its environmental performance, restricting the analysis to variables of lower absolute impact, such as the energy consumption of the supply device (PDA). Another particularly relevant aspect concerns the timing of the final data collection, which coincided with XPT S.A.'s vacation period, reducing the number of observations and affecting the production pace. This circumstance, combined with the increased technical complexity of the machines produced, may have influenced indicators such as the average cycle time and the overall equipment effectiveness (OEE) of the assembly line. Challenges also remain regarding the management of materials not yet covered by the Kanban system, which continue to cause significant waiting times, highlighting the need for greater integration between departments and solutions adapted to heavier or larger components.

For future work, it is recommended to develop specific indicators for environmental aspects and integrate them into a regular monitoring system, to continue tracking KPIs over an extended period under stabilized production conditions, and to expand the Kanban system to include other items, using alternative storage methods when necessary to accommodate bulkier or heavier materials. From a research perspective, beyond the operational recommendations directed at XPT S.A., it is also suggested to explore the potential of digitalizing the Kanban system through RFID (Radio Frequency Identification) technology, which could automate communication with the ERP system and reduce unnecessary movements—bringing the organization closer to a more integrated Lean model aligned with the principles of Industry 4.0.

Author Contributions

A.I.F., J.C.S. and J.E.S.: conceptualization; A.I.F., J.C.S. and O.M.: methodology; A.I.F. and J.C.S.: data curation, visualization; A.I.F. and J.C.S.: writing—original draft preparation; A.I.F., J.C.S. and M.T.P.: investigation; A.I.F., J.C.S. and O.M.: supervision; A.I.F. and J.C.S.: validation; J.E.S., M.T.P. and O.M.: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

We advocate for the sharing of research data by all authors contributing to publications in Scilight journals. In this section, authors may be asked to provide the raw data of their study together with the manuscript for editorial review and should be prepared to make the data publicly available if practicable. In any event, authors should ensure accessibility of such data to other competent professionals for at least 10 years after publication (preferably via an institutional or subject-based data repository or other data center), provided that the confidentiality of the participants can be protected and legal rights concerning proprietary data do not preclude their release. In instances where novel data were not generated or data remains inaccessible due to privacy or ethical considerations, a clear statement outlining these circumstances is mandatory.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

References

1. Boeske, J. Leadership towards Sustainability: A Review of Sustainable, Sustainability, and Environmental Leadership. *Sustainability* **2023**, *15*, 12626. https://doi.org/10.3390/su151612626.
2. Alsadi, J.; Antony, J.; Mezher, T.; et al. Lean and Industry 4.0: A bibliometric analysis, opportunities for future research directions. *Qual. Manag. J.* **2023**, *30*, 41–63. https://doi.org/10.1080/10686967.2022.2144785.
3. Bhamu, J.; Sangwan, K.S. Lean manufacturing: Literature review and research issues. *Int. J. Oper. Prod. Manag.* **2014**, *34*, 876–940. https://doi.org/10.1108/IJOPM-08-2012-0315.
4. Sá, S.; Ferreira, L.P.; Silva, F.J.G.; et al. The importance of subcontracting and its relationship with Lean philosophy in automotive industry. *Int. J. Ind. Eng. Manag.* **2022**, *13*, 186–193. https://doi.org/10.24867/IJIEM-2022-3-311.

5. Elkington, J. *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*; Capstone Publishing Limited: Oxford, UK, 1997; pp. 43–55.
6. Abualfaraa, W.; Salonitis, K.; Al-Ashaab, A.; et al. Lean-Green Manufacturing Practices and Their Link with Sustainability: A Critical Review. *Sustainability* **2020**, *12*, 981. https://doi.org/10.3390/su12030981.
7. Hammer, J.; Pivo, G. The Triple Bottom Line and Sustainable Economic Development Theory and Practice. *Econ. Dev. Q.* **2017**, *31*, 25–36. https://doi.org/10.1177/0891242416674808.
8. Lacerda, A.P.; Xambre, A.R.; Alvelos, H.M. Applying Value Stream Mapping to eliminate waste: A case study of an original equipment manufacturer for the automotive industry. *Int. J. Prod. Res.* **2016**, *54*, 1708–1720. https://doi.org/10.1080/00207543.2015.1055349.
9. Singh, B.; Garg, S.K.; Sharma, S.K. Value stream mapping: Literature review and implications for Indian industry. *Int. J. Adv. Manuf. Technol.* **2011**, *53*, 799–809. https://doi.org/10.1007/s00170-010-2860-7.
10. Pereira, J.; Silva, F.J.G.; Bastos, J.A.; et al. Application of the A3 Methodology for the Improvement of an Assembly Line. *Procedia Manuf.* **2019**, *38*, 745–754. https://doi.org/10.1016/j.promfg.2020.01.101.
11. Danese, P.; Manfè, V.; Romano, P. A Systematic Literature Review on Recent Lean Research: State-of-the-art and Future Directions. *Int. J. Manag. Rev.* **2018**, *20*, 579–605. https://doi.org/10.1111/ijmr.12156.
12. Womack, J.P.; Jones, D.T.; Roos, D. *The Machine That Changed the World: The Story of Lean Production*, 10th ed.; Elsevier: Amsterdam, The Netherlands, 2004; pp. 23–42.
13. Hines, P.; Holwe, M.; Rich, N. Learning to evolve: A review of contemporary lean thinking. *Int. J. Oper. Prod. Manag.* **2004**, *24*, 994–1011. https://doi.org/10.1108/01443570410558049.
14. Mor, R.S.; Bhardwaj, A.; Singh, S.; et al. Productivity gains through standardization-of-work in a manufacturing company. *J. Manuf. Technol. Manag.* **2018**, *30*, 899–919. https://doi.org/10.1108/JMTM-07-2017-0151.
15. Liker, J.K.; Morgan, J.M. The Toyota Way in Services: The Case of Lean Product Development. *Acad. Manag. Perspect.* **2006**, *20*, 5–20. https://doi.org/10.5465/AMP.2006.20591002.
16. Simonsen, E.M.; Herrera, R.F.; Atencio, E. Benefits and Difficulties of the Implementation of Lean Construction in the Public Sector: A Systematic Review. *Sustainability* **2023**, *15*, 6161. https://doi.org/10.3390/su15076161.
17. Kaizen Institute. Compreender o Lean Manufacturing: Guia Kaizen. Available online: https://kaizen.com/pt/insights-pt/compreender-lean-manufacturing-guia/ (accessed on 29 January 2025).
18. Antosz, K.; Stadnicka, D. Lean Philosophy Implementation in SMEs—Study Results. *Procedia Eng.* **2017**, *182*, 25–32. https://doi.org/10.1016/j.proeng.2017.03.107.
19. Leksic, I.; Stefanic, N.; Veza, I. The impact of using different lean manufacturing tools on waste reduction. *Adv. Prod. Eng. Manag.* **2020**, *15*, 81–92. https://doi.org/10.14743/APEM2020.1.351.
20. Singh, S.; Dixit, S.; Sahai, S.; et al. Key Benefits of Adopting Lean Manufacturing Principles in Indian Construction Industry. In *MATEC Web of Conferences*; EDP Sciences: Les Ulis, France, 2018. https://doi.org/10.1051/matecconf/201817205002.
21. Guzel, D.; Asiabi, A.S. Increasing Productivity of Furniture Factory with Lean Manufacturing Techniques (Case Study). *Tech. J.* **2022**, *16*, 82–92. https://doi.org/10.31803/tg-20211010121240.
22. Agnetis, A.; Bianciardi, C.; Iasparra, N. Integrating lean thinking and mathematical optimization: A case study in appointment scheduling of hematological treatments. *Oper. Res. Perspect.* **2019**, *6*, 100110. https://doi.org/10.1016/j.orp.2019.100110.
23. Zouggar Amrani, A.; Garel, B.; Vallespir, B. Lean Transformation in Healthcare: A French Case Study. *Adv. Prod. Manag. Syst.* **2021**, *631*, 383–390. https://doi.org/10.1007/978-3-030-85902-2_41.
24. Trubetskaya, A.; Manto, D.; McDermott, O. A Review of Lean Adoption in the Irish MedTech Industry. *Processes* **2022**, *10*, 391. https://doi.org/10.3390/pr10020391.
25. Shafeek, H. Lean Manufacturing Implementation in Carton Industry—A case study. In *2019 Industrial and Systems Engineering Conference (ISEC)*; IEEE: Jeddah, Saudi Arabia, 2019. https://doi.org/10.1109/IASEC.2019.8686603.
26. Silva, S.; Sá, J.C.; Silva, F.J.G.; et al. Lean Green—The Importance of Integrating Environment into Lean Philosophy—A Case Study. In *Lecture Notes in Networks and Systems*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 211–219. https://doi.org/10.1007/978-3-030-41429-0_21.
27. Vienažindienė, M.; Čiarnienė, R. The Challenges and Solutions to Implementing the Lean Concept: The Case of Lithuanian Companies. *Pol. J. Manag. Stud.* **2023**, *28*, 423–440. https://doi.org/10.17512/pjms.2023.28.2.24.
28. Maware, C.; Parsley, D.M. The Challenges of Lean Transformation and Implementation in the Manufacturing Sector. *Sustainability* **2022**, *14*, 6287. https://doi.org/10.3390/su14106287.
29. Zhang, L.; Chen, X. Role of lean tools in supporting knowledge creation and performance in lean construction. In *Procedia Engineering*; 2016; pp. 1267–1274. https://doi.org/10.1016/j.proeng.2016.04.163.
30. Omogbai, O.; Salonitis, K. The Implementation of 5S Lean Tool Using System Dynamics Approach. *Procedia CIRP* **2017**, *145*, 380–385. https://doi.org/10.1016/j.procir.2017.01.057.

31. Forno, A.J.D.; Pereira, F.A.; Forcellini, F.A.; et al. Value Stream Mapping: A study about the problems and challenges found in the literature from the past 15 years about application of Lean tools. *Int. J. Adv. Manuf. Technol.* **2014**, *72*, 779–790. https://doi.org/10.1007/s00170-014-5712-z.
32. Costa, B.; Varejão, J.; Gaspar, P.D. Development of a Value Stream Map to Optimize the Production Process in a Luxury Metal Piece Manufacturing Company. *Processes* **2024**, *12*, 1612. https://doi.org/10.3390/pr12081612.
33. Rohani, J.M.; Zahraee, S.M. Production line analysis via value stream mapping: A lean manufacturing process of color industry. *Procedia Manuf.* **2015**, *2*, 6–10. https://doi.org/10.1016/j.promfg.2015.07.002.
34. Riezebos, J.; Huisman, B. Value stream mapping in education: Addressing work stress. *Int. J. Qual. Reliab. Manag.* **2021**, *38*, 1044–1061. https://doi.org/10.1108/IJQRM-05-2019-0145.
35. Hernandez Marquina, M.V.; Zwolinski, P.; Mangione, F. Application of Value Stream Mapping tool to improve circular systems. *Clean. Eng. Technol.* **2021**, *5*, 100270. https://doi.org/10.1016/j.clet.2021.100270.
36. Fuentes-Del-burgo, J.; Fernández, J.P.R.; Navarro-Astor, E. Kanban Applied to Construction: A Literature Review. *Constr. Econ. Build.* **2024**, *24*, 43–57. https://doi.org/10.5130/AJCEB.v24i4/5.8642.
37. Lage Junior, M.; Godinho Filho, M. Variations of the kanban system: Literature review and classification. *Int. J. Prod. Econ.* **2010**, *125*, 13–21. https://doi.org/10.1016/j.ijpe.2010.01.009.
38. Pinto, J.P. *Pensamento Lean: A Filosofia das Organizações Vencedoras*, 3rd ed.; LIDEL—EDIÇÕES TÉCNICAS, Lda: Lisboa, Portugal, 2009; pp. 123–137.
39. Ratnayake, R.; Lanarolle, W.; Ratnayake, R. Kanban in Apparel Manufacturing: A Case Study. *Int. J. Emerg. Sci. Eng.* **2021**, *7*, 1–9. https://doi.org/10.35940/ijese.c2509.067321.
40. Powell, D.J. Kanban for Lean Production in High Mix, Low Volume Environments. *IFAC PapersOnline* **2018**, *51*, 140–143. https://doi.org/10.1016/j.ifacol.2018.08.248.
41. Marques, P.A.; Jorge, D.; Reis, J. Using Lean to Improve Operational Performance in a Retail Store and E-Commerce Service: A Portuguese Case Study. *Sustainability* **2022**, *14*, 5913. https://doi.org/10.3390/su14105913.
42. Sá, J.C.; Dinis-Carvalho, J.; Costa, B.; et al. Implementation of Lean Tools in Internal Logistic Improvement. In *Lean Thinking in Industry 4.0 and Services for Society*; IGI Global Scientific Publishing: Hershey, PA, USA, 2023; pp. 110–122. https://doi.org/10.4018/978-1-6684-5606-4.ch006.
43. Goh, M.; Goh, Y.M. Lean production theory-based simulation of modular construction processes. *Autom. Constr.* **2019**, *101*, 227–244. https://doi.org/10.1016/j.autcon.2018.12.017.
44. Kotowska, J.; Burduk, A.; Jagodziński, M. Problem management in production processes with the use of A3 Report. *Econ. Manag. Innov.* **2017**, *1*, 313–315. https://doi.org/10.26480/icemi.01.2017.313.315.
45. Oversluizen, G.; Slomp, J. Use of A3-method by engineering students in industry projects. *Prod. Plan. Control* **2021**, *32*, 489–496. https://doi.org/10.1080/09537287.2020.1742372.
46. Lenort, R.; Staš, D.; Holman, D.; et al. A3 method as a powerful tool for searching and implementing green innovations in an industrial company transport. *Procedia Eng.* **2017**, *192*, 533–538. https://doi.org/10.1016/j.proeng.2017.06.092.
47. Bassuk, J.A.; Washington, I.M. The A3 Problem Solving Report: A 10-Step Scientific Method to Execute Performance Improvements in an Academic Research Vivarium. *PLoS ONE* **2013**, *8*, e76833. https://doi.org/10.1371/journal.pone.0076833.
48. Santos Filho, G.M.; Simão, L.E. A3 methodology: Going beyond process improvement. *Rev. De Gest.* **2023**, *30*, 147–161. https://doi.org/10.1108/REGE-03-2021-0047.
49. Shahroudi, P.; Aarabi, A. Quality improvement through lean A3 method for foot traffic in operating room. *Perioper. Care Oper. Room Manag.* **2021**, *23*, 100155. https://doi.org/10.1016/j.pcorm.2021.100155.
50. Purvis, B.; Mao, Y.; Robinson, D. Three pillars of sustainability: In search of conceptual origins. *Sustain. Sci.* **2018**, *14*, 681–695. https://doi.org/10.1007/s11625-018-0627-5.
51. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
52. Alhaddi, H. Triple Bottom Line and Sustainability: A Literature Review. *Bus. Manag. Stud.* **2015**, *1*, 6–10. https://doi.org/10.11114/bms.v1i2.752.
53. Martínez-Jurado, P.J.; Moyano-Fuentes, J. Lean management, supply chain management and sustainability: A literature review. *J. Clean. Prod.* **2014**, *85*, 134–150. https://doi.org/10.1016/j.jclepro.2013.09.042.
54. de Carvalho, A.C.V.; Granja, A.D.; da Silva, V.G. A systematic literature review on integrative lean and sustainability synergies over a building's lifecycle. *Sustainability* **2017**, *9*, 1156. https://doi.org/10.3390/su9071156.
55. Susman, G.I.; Evered, R.D. An Assessment of the Scientific Merits of Action Research. *Adm. Sci. Q.* **1978**, *23*, 582–603.
56. Marinho, P.; Pimentel, D.; Casais, R.; et al. Selecting the best tools and framework to evaluate equipment malfunctions and improve the OEE in the cork industry. *Int. J. Ind. Eng. Manag.* **2021**, *12*, 286–298. https://doi.org/10.24867/IJIEM-2021-4-295.
57. Courtois, A.; Pillet, M.; Martin-Bonnefous, C. *Gestão da Produção*, 6th ed.; LIDEL—EDIÇÕES TÉCNICAS, Lda: Lisboa, Portugal, 2007; pp. 133–140.