

Article

Implementation of SMED Workshops: A Strategic Approach in the Automotive Sector

Sofia Sousa ¹, Miguel M. Silva ² and Pedro D. Gaspar ^{1,3,*} 

¹ Department of Electromechanical Engineering, University of Beira Interior, 6201-001 Covilhã, Portugal; sofia.sousa@ubi.pt

² Aspöck Portugal S.A., 3720-796 Oliveira de Azeméis, Portugal; miguel.mouradasilva@aspoeck.pt

³ Center for Mechanical and Aerospace Science and Technologies (C-MAST), 6201-001 Covilhã, Portugal

* Correspondence: dinis@ubi.pt

Abstract

Strong technological development and competitive pressures have driven organizations, especially in the automotive sector, to implement strategies that enhance operational efficiency, thereby improving their performance. One critical topic is the reduction in machine setup times, where the Single Minute Exchange of Die (SMED) methodology has shown significant potential. However, SMED is mostly approached as a technical tool to improve efficiency, but with limited emphasis on how its implementation can be improved through the implementation as a participatory and strategic approach based on structured workshops. This study addresses this gap by presenting the planning and execution of systematic SMED workshops to engage cross-functional teams in setup time optimization. The field tests were conducted in an automotive manufacturing firm. The setup time on a selected injection line was reduced from 48:30 to 29:41 min (38.8% improvement). Its broader applicability was validated with improvements up to 53.66% across other machines. This study contributes a practical, replicable framework for SMED implementation that integrates structured training workshops into continuous improvement processes in automotive manufacturing and highlights the importance of employee engagement and standardized work in a Lean approach.



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Keywords: Lean Philosophy; Single Minute Exchange of Die; setup times; automotive industry; SMED workshop; continuous improvement

1. Introduction

Strong technological development and the evolution of the labor market have driven organizations to seek increased operational efficiency, which has consequently improved their performance [1,2]. With this goal in mind, companies are investing in continuous improvement to meet growing customer demands and help solve the challenges imposed by top management [2]. In this way, it is possible to fulfill all economic, social, and environmental responsibilities [3].

Continuous improvements have emerged within organizations to eliminate waste resulting from production operations, thereby enhancing competitiveness in the labor market. Awareness of the change and the results to be achieved led to the development of principles, techniques, and tools aimed at reducing product delivery times and improving business efficiency [4]. To answer this demand, Lean Philosophy emerged, based on the principles of the Toyota Production System (TPS) [5]. This is often understood as

a combination of tools, accompanied by effective management of workers, promoting improved performance in organizations [6]. Its principles are based on specifying the value of products and services, as well as their production flow. However, many activities within an organization are considered wasteful, such as overproduction, transport, and unnecessary movement [7]. In an organization, this type of activity is detrimental not only to its productivity but also to customer satisfaction. Given this situation, companies must focus their objectives on increasing efficiency and productivity while reducing production times and minimizing costs, all while fostering a culture of continuous improvement [3,8].

Lean Philosophy is based on a wide range of tools and methodologies designed to eliminate waste and create value in any production process, with several success stories already verified in engineering, construction, and architecture [9,10]. In these sectors, the use of Lean tools has increased productivity and profitability by offering new methods for identifying customer value and eliminating non-value-added activities [9,10]. This enables companies to respond quickly to customer demand, promoting their success in today's competitive environment [11].

Among the main Lean tools, such as JIT (Just-in-Time), 5S, TPM (Total Productive Maintenance), Kanban, and VSM (Value Stream Mapping), SMED (Single Minute Exchange of Die) stands out. This methodology is widely used in the automotive industry, and its primary objective is to reduce the setup times of a machine or equipment to achieve effective operational efficiency [1,5]. In this way, organizations can optimize production times, improving their productivity and, in turn, their competitiveness in the global market [1,5].

The implementation of SMED has been the subject of relentless pursuit by the automotive industry, as excellent results have already been achieved. Given this, organizations have invested in their application, aiming to minimize equipment or machine setup times. In this way, companies can respond quickly to market demand, promoting their development and increasing their competitive advantage [12,13]. But, in general, research studies focus on the technical application of SMED across various industrial sectors, demonstrating its effectiveness in reducing setup times. There is limited research on the structured integration of SMED through workshop-based training that combines employee involvement, conceptual education, and hands-on implementation. Particularly, Company A, where the case study was performed, has already implemented some Lean tools, with positive results, such as increased productivity and operational efficiency. However, when the Continuous Improvement Department analyzed the setup times of the injection lines, it identified significant losses, which indicated periods of inactivity and/or downtime associated with some machines. To minimize this problem and, consequently, reduce waste caused by activities performed with the machine stopped, the company decided to implement the SMED methodology in the production areas. To achieve these objectives, the company invested in workshops for its employees, aiming to present the results obtained and highlight the benefits observed. Thus, the research question of this work is: Can a structured, workshop-based SMED implementation lead to significant reductions in machine setup times while simultaneously promoting standardized work practices and cross-functional learning in a real-world manufacturing environment?

The main objective of this work is based on the planning and implementation of SMED workshops for the analysis and optimization of the setup times of the injection lines in the production process of Company A. To achieve this goal, it is essential to understand in detail all the steps related to the implementation of the SMED methodology throughout the workshop as well as the definition of the target audience. In this case, a multidisciplinary group was selected, consisting of workers from various departments, providing relevant information to increase the company's productivity, accompanied by proposals for improvement. The methodology was initially applied to a production line,

implementing an SMED Workshop, divided into three phases, ensuring the completion of all activities.

The workshop aims to boost teamwork through the participation of multidisciplinary groups, alongside the promotion of Standardized Work throughout the factory. Furthermore, increasing the availability of equipment or production lines, along with optimizing employee working time, can translate into improvements in the efficiency and effectiveness of manufacturing processes. Similarly, setup time can be reduced by transforming tasks performed while the machine is stopped into value-added activities. Other benefits resulting from the implementation of the SMED Workshop may include improved response times to internal and external customers, as well as a potential reduction in stock, due to the possibility of minimizing production batch sizes. In this way, the company will be able to enhance the quality and innovation of its products and ensure effective management of all its resources. So, this study addresses the operationalization of SMED not just as a Lean tool, but as a strategic, pedagogical, and educational intervention that enhances both engagement and implementation efficacy. The case study shows the generalizable and practical value of how a training-based structured SMED workshop model can serve as a Lean training mechanism that simultaneously achieves technical efficiency gains and workforce engagement.

2. Theoretical Framework

The description of the origin and evolution of the Lean concept, followed by a presentation of the eight wastes, according to the Toyota Production System (TPS), provides the theoretical framework for the current study. Lean Philosophy, its principles and objectives, as well as its importance for organizations and its main tools, are also highlighted. In this context, the methodology under study, SMED, is described, and some practical cases of success, already verified with its implementation in industry, are presented.

2.1. Origin and Evolution of the Lean Concept

Lean Philosophy emerged in the 1950s after engineer Taiichi Ohno, while an executive member of Toyota Motor Corporation, accompanied by his colleagues, developed the TPS for the automotive industry [1,14]. With the evolution of industry, a new challenge arose: producing as much as possible using the fewest resources and thus reducing production costs. This paradigm shift drove organizations to conquer the global market by offering more attractive sales prices, leading to increased customer demand for products [1]. The Toyota Production System is based on reducing costs by eliminating waste and maximizing the productive capacities of workers. It is described as a set of concepts that underpin production activities [1,15]. The TPS can be compared to a house, as its structure is based on four principles: Total Productive Maintenance (TPM), Heijunka, Standardized Work, and Kaizen, supported by two essential pillars, Jidoka and Just in Time [11,14–16]. It has been studied and adapted by various organizations around the world. However, with the technological advances seen in recent years, accompanied by product and process innovation, companies must invest in the use of more modern tools and methodologies, such as the concept known as Lean Philosophy [1,14,17].

2.2. Waste

As discussed earlier, the main objective of the Toyota Production System focuses on eliminating all waste within an organization [11,14]. The concept of waste originated from the Japanese term 'MUDA' and means any activity that consumes resources but does not add value to the consumer, the company, or the product [11,14]. One way that organizations have found to reduce existing waste is by using Lean tools in their processes [18]. Waste

can be classified into eight types: Overproduction, Waiting Times, Transportation, Motion, Inventory, Overprocessing, Defects, and Unused Talent [1,9]. To make it more appealing to read, Table 1 has been outlined with the correct definitions for each type of waste.

Table 1. TPS waste and its definitions [1,9,10].

Waste	Definition
Overproduction	Waste from making more products than customers demand
Waiting Times	Waste of time spent waiting for the next step to occur or when the machine is inactive.
Transportation	Wasted time, resources, and costs when unnecessarily moving products and materials
Motion	Wasted time and effort related to unnecessary movements by people
Inventory	Waste resulting from excess products and materials that are not processed
Overprocessing	Waste related to more work or higher quality than is required
Defects	Waste from a product or service failure to meet customer expectations
Unused Talent	Waste due to the underutilization of people’s talents, skills, and knowledge

2.3. Principles and Objectives of the Lean Philosophy

The Lean Philosophy has played a crucial role in solving efficiency problems in organizations, regardless of their sector of activity and respective market [6,19]. To adopt this philosophy, it is essential to follow five principles that focus on creating value for the customer, ultimately leading to the elimination of waste, as illustrated in Figure 1 [1,5,6,19]. All these principles are described in detail below:

- Value definition: involves identifying what is important to the customer. Value can only be defined by the customers themselves, and, for this reason, it is crucial that an organization adequately meets all requirements and needs [1,19,20].
- Value chain: It is essential to understand how the value chain is mapped, that is, to understand the flow of value to the consumer. This flow serves to redefine and organize all activities and/or tasks that add value to the process and the customer within an organization [1,19,20].
- Continuous flow: this value flow must be constant, to eliminate all existing waste and contribute positively to the optimization of the company [1,19,20].
- Pull system: based on customer demand. The flow is triggered by the customer, i.e., the consumer “pulls” the product according to their needs [1,19,20].
- The pursuit of perfection consists of directing all an organization’s efforts towards the continuous improvement of all production processes, to continuously achieve perfection [1,19,20].

The application of Lean Philosophy in an organization is much more than the adoption of five principles; it is also important to highlight its objectives. In addition to offering methodologies and tools that contribute to increased efficiency and productivity, it also promotes the development of an environment focused on improving quality, combined with the speed of production processes. Companies can then focus their efforts on eliminating waste and reducing product delivery times and total costs, thereby achieving better results and a distinctive position in the global market [1].

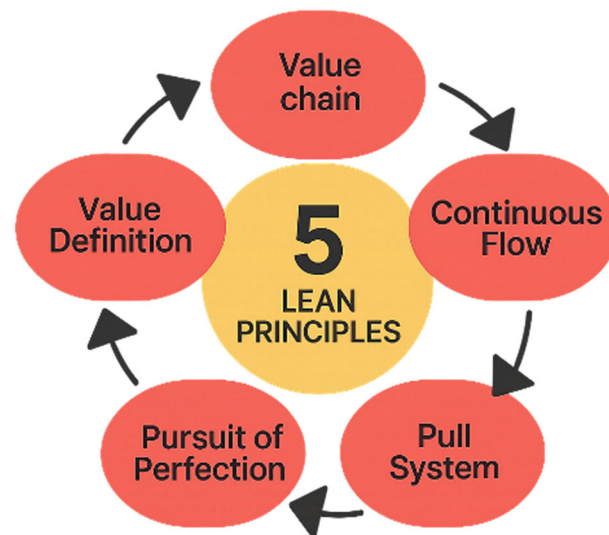


Figure 1. Five Principles of Lean Philosophy (adapted from [1,6]).

2.4. Importance of Lean Philosophy in Organizations

The global market imposes demands that defy organizations to attend, such as increasing the quality of products and services, strictly complying with customer requirements, reducing costs, and expanding production. These demands, accompanied by technological advances and the development of knowledge, have raised uncertainties regarding the competitive orientation and strategic choices of organizations [7]. In response to these challenges, organizations have been forced to follow a Lean Philosophy-based approach, as their success depends on their ability to respond quickly, continuously, and systematically [7].

The focus of the Lean Philosophy is on optimizing the value flow within an organization, as it adopts an approach geared towards adequately meeting customer needs, directing all its values towards process improvement, unlike other methods, which concentrate their efforts on improving production processes exclusively without meeting customer requirements [21,22]. Its implementation in organizations allows positive results to be achieved, such as increased revenue and operating margin, as well as reduced costs arising from the manufacture of products of lower quality than desired by customers and excess stock. In this way, it is possible to achieve high levels of quality and innovation, accompanied by improved gross income and productivity. Organizations can therefore focus on entering global markets, which are characterized by high levels of competitiveness and performance [14].

2.5. Lean Tools

One of the key aspects when approaching Lean Philosophy is the use of various techniques and tools that help the organization identify, measure, and eliminate waste, to continue improving its production processes. This approach offers a wide range of tools, adaptable to any sector or industry, depending on the needs of the processes, organizations, and customers [19]. All these tools have different purposes to answer different challenges, but they are based on the same objective: to achieve high levels of quality in manufactured products at the lowest possible cost. However, they must act in an integrated manner to make the workflow more flexible and adequately resolve the inefficiencies caused by process waste [19]. Among the various tools most used in the industry, the following stand out: Total Productive Maintenance (TPM), Single Minute Exchange of Die (SMED), Value Stream Mapping (VSM), 5S, Kanban, Poka-Yoke, the Plan-Do-Check-Act (PDCA) cycle, Key Performance Indicator (KPI), Overall Equipment Effectiveness (OEE), among others [7,14]. The various methodologies mentioned above are presented below.

- TPM: This method aims to balance the production process by maximizing the availability of machines and/or equipment. Thus, organizations can reduce failures and possible defects generated during the production process [7,21].
- SMED: It is a Lean methodology that was developed to reduce the setup times of a machine and/or equipment [12]. This will be explored in more depth, as it is the tool under study in this paper.
- VSM: It refers to mapping the flow of the process, from product design to delivery to the customer, i.e., the entire journey that the product takes until it is finished and the customer is satisfied. This method helps organizations identify waste and opportunities for improvement [19,21].
- 5S: This tool assists in the organization and improvement of the workplace by identifying and eliminating existing waste. It is important to recognize that this method is based on five words, which cannot be dissociated since their joint application is essential for correct implementation. Thus, it can be said that these words are sort, set, shine, standardize, and sustain [9,19,23].
- Kanban: This method uses a card system, combined with a visual board, which contains all the stages of the workflow, facilitating the tracking of information. In this way, organizations can know which stage is being carried out, as well as what materials are needed to proceed to the next stages [10,19].
- Poka-Yoke: Poka-Yoke: this is an error-proof Lean device, designed to help workers decrease failures and possible defects that occur during the production process [9,19].
- PDCA cycle: This tool was developed to continuously improve an organization's production processes. To achieve the expected results, the four steps listed above must be established. First, you must start by planning all issues and improvements and identifying the methods used. The second step is to execute the plan (Do), and then all data must be analyzed and verified (Check). To complete this cycle, all steps must be adjusted (Act) according to the results obtained [24].
- KPI: This method provides essential benchmarks for performance analysis and decision-making within an organization. As its name suggests, this method is a key indicator that allows companies to measure their progress towards their strategic objectives [25].
- OEE: Quantitative tool used to assess the effectiveness of equipment in a production process and is based on three components: Availability, Efficiency, and Quality. According to its formula, a score of 100% represents perfect production, with the manufacture of quality products without waste [10].

2.6. SMED—Single Minute Exchange of Die

The pressures demanded by the labor market, due to the expansion of the diversity of products and services, in addition to the increase in the volume of small orders, lead organizations to invest in optimizing the reference times (setup) of machines and equipment, adjusting their production to the various batches and/or volumes of products. This pressure, combined with the emergence of changes in equipment setup times, is considered a critical issue within organizations [1,5]. Given this information, it is beneficial to focus on reducing operations or activities without added value, with the aim of reducing machine downtime. In this way, organizations can make their production processes faster [5]. One solution to overcome this problem was the emergence of the SMED methodology, a tool widely used in the automotive industry [1,5]. This methodology was developed in 1950 by Shigeo Shingo with the aim of minimizing the setup times of equipment or machines, enabling a rapid response to market demand. In this way, organizations can increase their competitive advantage [12,13]. SMED encompasses a set of techniques

that help reduce setup times and, in turn, contribute to reducing machine downtime. With this tool, organizations can implement a continuous flow of products, promoting increased production yield and overall performance. However, before implementing this methodology, the company must determine a few steps [5].

The organization should start with an analysis of the current situation, as well as measuring the setup times of machines and/or equipment, so that it can then determine which operational procedures need to be changed [1,5]. According to the overall analysis of the production process, the company must identify existing waste, followed by all activities carried out, differentiating between internal and external activities, to reduce equipment downtime in the manufacturing process [1,5]. So, it is important to distinguish between them. While internal operations are carried out with the equipment immobilized, external operations are carried out with the machine in operation [1,5].

With knowledge of all the operations in the process, the company proceeds to organize them, restructuring all tasks and transforming internal activities into external ones, ensuring that all the objectives outlined are met. In this way, it is possible to optimize machine setup times. Finally, for the company to ensure the implementation of SMED, it must communicate all changes to employees through training and workshops, promoting the standardization of work [5]. The implementation of SMED in a production process brings several advantages to the organization, such as reducing machine downtime using simple and easy techniques [1]. Among the other advantages, the following can be highlighted:

- Greater flexibility, as it is not necessary to have a very high stock of raw materials due to constant changes;
- Faster product deliveries, as the batches produced are smaller;
- Increased operational efficiency, due to reduced tool change times;
- Guaranteed better product quality and maintenance, due to reduced cycle times;
- Increased return on invested capital;
- Greater occupational efficiency of space reserved exclusively for stocks;
- Greater availability of machines and/or equipment;
- Greater production capacity;
- Reduction in the hiring of skilled workers [1,5].

When implementing this tool in a production process, it is necessary to be aware of some critical points for its proper application. First, the organization must know all technical aspects of the equipment, machinery, and tools used in the production process, as well as the working hours of operators and their tasks. In addition, it is essential to understand the working method used and its organization. This makes workers more motivated, enabling them to carry out their activities without causing problems and meeting all the proposed requirements [1].

Several practical cases have been successful after implementing the SMED methodology in their production processes, from engineering to civil construction and architecture [9,10]. However, the objective is to present practical cases in the automotive industry. To meet this requirement, three successful cases will be presented below: the first related to the production of tubes for vehicle air conditioning systems, the second to the manufacture of electrical components through injection, and the third to the production of control cables for vehicles through assembly.

The study conducted by [26] was carried out in a company in the automotive sector dedicated to the production of tubes for vehicle air conditioning systems using deep stamping equipment. The objective was to reduce the setup time of a stamping machine by 20% and, in turn, increase its availability and production. To achieve this result, the organization chose to implement the SMED methodology. Analyzing this scenario, in addition to SMED, another Lean tool, Poka-Yoke, was also implemented to control all

manufactured parts and reduce problems related to the type of material and method used in the process. To ensure the effectiveness of the methodology in question, this company used OEE to verify production efficiency, based on an analysis of the behavior of the machines and/or equipment [26]. Moving on to a more detailed analysis of all stages of the stamping process, it was observed that, before the implementation of SMED, there were four internal activities (operations performed with the machine stopped) and three external activities (performed with the machine running). Of the total setup time, internal operations accounted for the most time, taking up about 72%, equivalent to 34 min of the total time. Among these stages, the most time-consuming activity was 'Machine programming' (internal activity), with a total duration of 25 min. The total setup time for this production process was 47 min [26]. With the implementation of the SMED methodology, significant changes were recorded, particularly in the setup time for the 'Machine Programming' operation, which decreased from 25 to 7 min, representing a reduction of 18 min. This change contributes to a reduction in the total setup time for internal activities to 16 min, which corresponds to 55%, resulting in a total final setup time of 29 min. Regarding the OEE results, there was an increase in availability of approximately 7.7%, reaching the minimum required value of 95% [26]. Given these results, it can be concluded that there was an increase in the production capacity of the machines, accompanied by a 38% improvement in total setup time and a 53% improvement in internal operations time. However, it is important to note that the implementation of new techniques can result in advantageous improvements for this company, reducing setup time by at least 50% [26].

Bhade and Hegde [27] developed a practical case study in an automotive company dedicated to the production of electrical equipment, in which equipment produced from the injection process is used. The objective of this case study was to evaluate the downtime lost by a machine when a reference change was made, accompanied by an improvement in the OEE of that equipment. To this end, the company decided to implement SMED to minimize setup times, thereby eliminating the waste caused by waiting time. Analyzing the methodology of this specific case, it was found that a Pareto Diagram was designed to classify the lost time that occurred throughout the production process. This diagram helps companies to organize the defects found according to the frequency, severity, origin, and nature of the problem. Moving on to a more detailed analysis of all the steps performed during the reference change, it was observed that, before the implementation of SMED, the process consisted of 13 internal activities, taking a total of 4124.4 s, which corresponds to 68.74 min. Among these steps, the most time-consuming operation was the 'Removal of the coolant connection,' which accounted for 918.2 s of the total setup time, approximately 15.3 min. Additionally, the OEE value was 58.74% [27]. After implementing the SMED methodology, significant improvements were recorded, namely by transforming three internal activities into external ones, in addition to reducing the total setup time. Thus, it can be stated that the time was reduced from 1470 s to approximately 24.5 min, representing a decrease of 44.7 min, about 65.06%, compared to the initial total setup time. As for the most time-consuming operation, the setup time decreased by 300 s, which corresponds to a reduction of 618.2 s. Regarding the overall effectiveness of the equipment, the OEE progressed to 68.41%, with an increase of 9.67% [27]. With these results, setup times were reduced by more than half, with a 25.63% increase in the productivity of the injection machine. Thus, it can be said that this case study was a success because it achieved the objectives initially set out, applying SMED to improve the OEE of an injection machine [27].

The case study proposed by [28] was developed in a company belonging to the automotive sector responsible for manufacturing control cables for vehicles of different brands, to reduce setup times related to tool changes. To this end, an approach was developed on an assembly line, called a pilot project, and the SMED methodology was implemented,

together with other Lean tools, such as 5S, Visual Management, and Standardized Work. Analyzing the assembly line under study, over a week, 15 different references are produced, distributed across 8 workstations, of which four stations (1, 3, 4, and 5) are common to the production of all references. Before the implementation of the SMED methodology, the total setup time, including all stations, was 90 min, with the most time-consuming sequence of references occurring at station 5, with the mold change stage on the machine, carried out by the tuning technician, lasting approximately 30 min. In terms of total weekly time, it took 360 min to produce all references [28]. This analysis revealed that the pilot line had several problems, as six internal operations were identified, and activities performed with the production line were stopped. Thus, solutions were proposed that optimized setup times and transformed internal activities into external ones through the implementation of SMED [28]. After its implementation, it was possible to transform five internal activities into external ones, with only the mold change operation remaining internal. This improvement made it possible to optimize setup times at several workstations. Starting with the most problematic station, the mold changes on the machine at station 5 were reduced to 10 min, which corresponds to a 66.6% decrease in total time. In this case, this reduction was possible thanks to the simultaneous performance of tasks by the tuning technician and the operator. The improvements identified made it possible to halve the total setup time, from 90 to 45 min (a 50% decrease) [28]. These results allow us to conclude that the implementation of SMED brought significant benefits, with a 58.3% reduction in total weekly setup time, taking only 150 min, representing a decrease of 210 min. This gain allowed for increased flexibility and productivity, improving production flow and, in turn, reducing costs [28].

Marcella and Widjajati [29] apply the SMED methodology in a plastic injection molding facility, achieving a 16.68% reduction in setup time. Their approach follows classic SMED phases including observation, internal/external task classification, and layout improvements. Besides technical SMED applications as presented above, SMED implementation frameworks and success factors have also been studied. Dora et al. [30] highlighted that successful SMED implementations require integration with broader Lean frameworks and cross-functional engagement. On the other hand, McIntosh et al. [31] explored rapid SMED deployment using video-based learning and standardized improvement cycles, showing measurable time reduction effects. In terms of Lean training, team engagement, and behavioral aspects, Shah and Ward [32] indicate that the workforce training and standardized work as behavioral enablers are relevant for the success of Lean implementation. Vinodh et al. [33] evaluated the effectiveness of structured Lean workshops and their influence on employee participation and sustainability of improvements. Moreover, empirical SMED case studies in high-mix manufacturing were described by Abdi et al. [34], who presented the SMED use in flexible job-shop scheduling environments and highlighted the importance of balancing internal-external changeovers. Additionally, Cakmakci [35] and Vieira and Lopes [36] demonstrated measurable efficiency gains from integrating SMED with visual controls and real-time feedback loops in the automotive sector and screw cap manufacturing, respectively. Both studies emphasize how structured employee involvement, continuous improvement cycles, and problem-solving practices can lead to enduring process enhancements. Khakpour et al. [37] introduce “SMED 4.0”, which gathers classical SMED techniques with Industry 4.0 technologies, such as IoT devices, connected tooling, and live digital dashboards, in a home appliance manufacturing setting. Although it is not in the same manufacturing process, their work shows how technological integration enhances not only changeover efficiency but also traceability and decision-making. The potential of digitizing setup time reduction initiatives and extend the workshop model

using real-time data feedback was described. Thus, there is a clear indication that SMED interactive, participatory workshops improve the efficacy results of the Lean tool application.

3. Materials and Methods

The materials and methods used for the planning and execution of the SMED Workshop, accompanied by the implementation of the methodology, to assist in the analysis of the setup times of the injection lines of the manufacturing process of Company A, are described in the following sections.

3.1. Materials

Several materials and tools were used in the execution of tasks associated with the planning and implementation of the SMED methodology, applied throughout the workshop. Despite the structured implementation of all tasks, it is essential to describe the equipment used in the initial planning of the workshop, which was carefully developed to ensure the efficient execution of all stages.

The technical resources used for planning the workshop included a stopwatch and a video camera to record the footage, as well as a computer and spreadsheet software. The latter was used to record and organize all data relating to the reference change selected for study in the workshop, facilitating the subsequent analysis of the setup time and other results obtained. A spreadsheet was formatted to assist in the planning of the workshop, in which the steps to be performed during a reference change of an injection machine are recorded. As part of this planning, a document containing a detailed history of setup times per injection machine and per shift was also analyzed. As for the tools used during the workshop, it was held in a company training room, equipped with a projector, a whiteboard, and two flipcharts. Starting with the first piece of equipment, selected videos and formatted documents were used to help participants understand the theory and practice of the workshop. The boards served as a basis for developing improvement proposals. In addition, each participant had a notebook for individual data collection and subsequent group discussion. All this equipment was used to promote interaction and optimize learning throughout the workshop. For the practical activities, spreadsheets were used, based on footage filmed of the change about the line under study, enabling subsequent rigorous evaluation. The record sheets used were organized by type of task: "Film Analysis", "Waste Analysis", "Transformation of Internal Tasks into External Tasks", "Balance of Operations", "Standard Work", and "Corrective/Preventive Action Plan (PDCA)". Although the structure of the analyses is the same for both technicians, it was decided to present the record sheets separately: one with the records of Technician 1 and another with the parameters of Technician 2, for better reading and analysis. This division was made to ensure a clearer reading of the documents.

3.2. Methods

A conceptual framework was designed to address a theoretical model to guide the empirical component. This framework links theory to practice, aligning workshop design and analysis with established Lean and SMED models. This framework connects the Lean Thinking Theory [38], (a) identifying value, (b) mapping value streams, (c) creating flow, (d) establishing pull, and (e) pursuing perfection, and the SMED-specific phases [39]: (a) observe current setup, (b) separate internal/external setup steps, (c) convert internal to external steps, (d) reorganize remaining internal activities, and (e) standardize and train. This model was extended by including organizational learning and engagement components, specifically, (a) the use of structured workshops as a means of employee empowerment and knowledge transfer, (b) incorporation of PDCA cycles for continuous

refinement, and (c) emphasis on standard work to improve replicability and gains. A graphical diagram of the conceptual framework is shown in Figure 2.

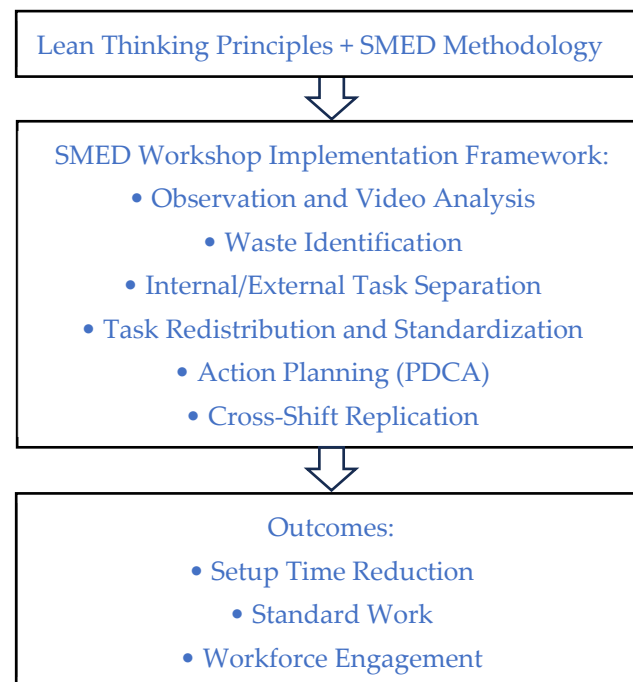


Figure 2. Conceptual Framework Diagram Summary.

Specifically, for the case study, the methods applied in the SMED Workshop, including all the techniques and steps carried out throughout the process, are described below. To ensure effective execution, the workshop was carefully planned, with all activities to be carried out defined. The 17 tasks performed are identified below:

- Introduction to the first phase of the SMED Workshop;
- Presentation of the objectives of the SMED Workshop;
- Introduction to the company's new system;
- Presentation and explanation of the SMED methodology;
- Viewing and analysis of example videos;
- Viewing videos on the change in reference of the line under study and validation of the sequence of initial tasks and their respective times;
- Identification of waste resulting from the tasks involved in the change in reference to be produced;
- Identification of internal and external tasks;
- Analysis of waste to be reduced and/or eliminated;
- Analysis of the possibility of transforming internal tasks into external ones;
- Analysis of the balance of operations between technicians;
- Definition of the standard work sequence (Standardized Work);
- Creation of an immediate and medium-term corrective/preventive action plan–PDCA;
- Planning training and testing of the solution;
- Planning of application to other shifts;
- Validation of all activities;
- Conclusion of the SMED Workshop.

3.2.1. SMED Workshop Planning

The workshop planning was based on 37 observations, and measurements of injection machine setup times were made. This number depended on the availability of the machines.

Additionally, a detailed historical record of setup times for different machines across all three work shifts was analyzed to complement the recorded observations. These documents provided an understanding of the average times for each setup, including the amount spent on each piece of equipment, providing a detailed analysis of the process. Based on this data, it was possible to highlight the critical areas and provide a more accurate view of the impact of the proposed improvements. The combination of real time and historical data allowed for a more complete and concise analysis. To optimize the dynamics of the workshop and make the activity more efficient, four recordings of reference changes on different injection machines were made in advance. After observing machines and analyzing historical data, Machine D was selected due to its high potential for improvement. Figures 3 and 4 show the front and rear views (operator area) of this machine. Since the setup process is identical across all machines, this choice allowed the team to focus on a representative case with the highest impact, ensuring the relevance and effectiveness of the workshop.



Figure 3. Injection machine selected for the SMED Workshop (front view)—Machine D.



Figure 4. Injection machine selected for the SMED Workshop (rear view—operator area)—Machine D.

In addition, due to its length, the workshop was divided into three phases, taking up two full days and one morning, totaling approximately 18 h of training and involving around eight participants from different areas. It took place on three different days under the coordination of the Continuous Improvement department and aimed at a multidisciplinary group consisting of two employees from Process Engineering, the person responsible for the Automatic Supply System (SAA), the head, and a tuner from the first shift, as well as members of the organizing team. The working hours established were from 9 a.m. to 4 p.m., with breaks and a lunch break. The workshop took place from 9 a.m. to 1 p.m., with a break.

3.2.2. Description of the Methods Applied in the SMED Workshop

The workshop was divided into three phases, each corresponding to different activities. To facilitate the presentation and discussion of the results obtained, the first subsection describes the first phase of the workshop, with the theoretical presentation and initial analysis of the selected videos. The second subsection involves the second phase, that is, the identification of existing waste and the classification of tasks, as well as proposals for improvements in terms of the balance between the internal tasks of the technicians. The third subsection, related to the third phase, describes the validation of the proposed solutions (definition of standard work) and the planning of future actions.

Description of the First Phase of the SMED Workshop

The first phase of the workshop started with a brief introduction, in which the plan of activities to be carried out until the conclusion of the workshop was presented. Next, the main objectives to be achieved were detailed, as well as an introduction to the new company system under development. Before proceeding with the analysis of the practical activities of the workshop, a presentation of the SMED methodology was given, the tool applied throughout the workshop, complemented by the viewing and analysis of illustrative videos. This last stage marked the end of the theoretical component of the workshop, allowing the proposed concepts to be consolidated.

In the practical part of the first phase of the workshop, participants watched videos about the change in reference of the line under study, to validate the sequence of initial tasks and the respective times recorded for each operator, by the document developed for this phase, the "Film Analysis". After validation, the last two activities of the first day were carried out: the identification of waste and the distinction between internal and external tasks, according to the document "Waste Analysis". During these activities, participants identified the types of waste that existed, as well as the main problems associated with the change in reference under study. These observations were recorded on whiteboards and flipcharts for further development of the corrective/preventive action plan. After completing the first phase of the SMED Workshop, the multidisciplinary team moved on to the second phase.

Description of the Second Phase of the SMED Workshop

The second phase of the SMED Workshop began with an introduction to the second part of the activity. Initially, there was a brief overview of the operations carried out in the first phase, to remind all participants of the activities already completed. Continuing with the agenda, the identified waste was analyzed to reduce and/or eliminate it, according to the eight types of waste defined by the Lean Philosophy.

Once this analysis was completed, the possibility of transforming internal tasks into external ones was analyzed by the document "Transformation of Internal Tasks into External Ones". This action aimed to balance the time spent on operations with the machine stopped with the activities carried out with the machine in operation. The last step in this phase

consisted of analyzing the balance of operations between technicians, with the purpose of adjusting the time of each one's internal tasks. Although this step was started during the second phase of the workshop, it was not possible to complete it successfully. For this reason, the last phase began with the continuation of this analysis to ensure its completion in an integrated manner.

Description of the Third Phase of the SMED Workshop

The third and final phase of the workshop began with a recapitulation of the topics covered previously, followed by the presentation of the agenda to be developed in this phase and the continuation of the analysis of the balance of operations between technicians, as indicated in the previous phase. Once this analysis was completed, the team proceeded to define the standard work sequence, according to the "Standard Work" record sheet. This document made it possible to structure all the instructions to be followed about change, to create an efficient and consistent environment, where all employees perform their work in the same way. This made it possible to minimize production line downtime and, consequently, increase productivity.

After defining the standard work, the multidisciplinary team developed a plan of immediate corrective/preventive actions to address the problems identified during the workshop. To carry out this task, the team relied on the SMED analysis performed in the first two phases of the workshop. In addition, medium-term improvements were suggested. This action plan was developed according to the PDCA methodology to ensure the correct implementation of the proposed improvements and subsequent monitoring and evaluation. The last activities carried out in the third phase of the SMED Workshop were the planning of training and testing of the solution, as well as its application in the remaining work shifts, optimizing Standardized Work throughout the production area. To conclude the workshop, the participants validated all the activities carried out and the proposed dates.

Based on the methodologies applied in the workshop, the team expects to achieve excellent results, namely an improvement in the setup time of the machine under study, accompanied by the elimination of identified waste and a significant improvement in the distribution of tasks among the technicians involved in a reference change. These results are analyzed with the presentation of the initial and final setup times, the new standard work sequence defined, and the corrective/preventive action plan developed in the workshop.

4. Analysis and Discussion of Results

Firstly, the results obtained in the first phase of the workshop are presented and discussed, relating to its planning and contextualization. Then, the same chronological order is followed, with the presentation and analysis of the results obtained in the following phases of the workshop: the second and third phases.

4.1. Results of the First Phase of the SMED Workshop

During the initial phase of the workshop, the main objectives, the approach to the company's new system, and the SMED methodology were presented. These steps allowed for initial alignment with the multidisciplinary team around the workshop's objective: to reduce setup times during reference changeover on an injection line, as well as the fundamentals of SMED and its advantages.

Moving on to the practical part of the workshop, during the first phase, all the steps performed by each operator were validated, as well as their respective times, after viewing the selected videos on the reference change under study. Once the initial analysis was completed, the main existing wastes were identified and accounted for, and the internal and external tasks assigned to each operator were classified. This analysis also made it

possible to quantify the total time for internal and external operations, as well as the time associated with waste. To assist in the analysis, Table 2 shows all the data obtained in the first phase of the workshop, according to the spreadsheet “Film Analysis”.

Table 2. Initial Analysis of Activities by Technician.

Category	Technician 1		Technician 2	
	No.	Time [min:s]	No.	Time [min:s]
Wastes	5	11:27	6	13:14
Internal Tasks (setup)	44	48:30	31	30:57
External Tasks	2	2:45	0	0:00
Total Tasks (Int + Ext)	46	51:15	31	51:15

Before proceeding with the analysis of Table 2, it is important to note that, within the SMED methodology, setup time corresponds to the time when the machine is stopped. This time is defined by the duration of internal tasks, i.e., the interval between the machine stopping for reference change and the moment when production of the new part (reference) begins. For this reason, although two technicians perform the change, the total setup time is determined by the longest duration of the internal tasks.

Analyzing the results in Table 2, it was found that five instances of waste were identified with Technician 1, totaling 11:27 min:s of setup time, and six instances of waste with Technician 2, corresponding to 13:14 min:s of setup time. In total, 11 inefficiencies were quantified. Regarding the type of waste identified, in the case of Technician 1, two waiting times and three unnecessary movements were recorded. For Technician 2, only waiting times were observed. These results reflect flaws in the organization of the workplace and the coordination between technicians during the reference change, indicating that the process is not being carried out efficiently. This analysis is a critical area for possible process improvements.

Regarding the distribution of tasks, Technician 1 performed 44 internal activities, corresponding to 48:30 min:s, and two external activities, with a total duration of 2:45 min:s. Technician 2, on the other hand, performed only internal tasks, about 31, with a total time of 30:57 min:s. The total time recorded, resulting from the sum of internal and external tasks for machine D, according to the data in Table 2, was 51:15 min:s. It is also worth noting that the setup time considered in this change corresponds to the time of Technician 1's internal tasks, with 48:30 min:s, the highest recorded.

Based on this data, it can be highlighted that Technician 1 had a considerable load of internal tasks compared to Technician 2. Regarding external tasks, it was found that Technician 2 did not perform any activities, which represents an opportunity for improvement. Thus, as external tasks, Technician 2 could perform actions to prepare for the reference change while the machine is still running, or else perform them after the setup is complete.

All the results obtained during the first phase of the workshop provided a clear view of the inefficiencies present in the setup change process, identifying critical areas that support the creation of proposals for improvements and the implementation of corrective and preventive actions. Given this, it is essential to implement solutions based on the SMED methodology, with a view to improving the productivity and efficiency of the process. These solutions will be verified and validated after analysis of the results during the second and third phases.

4.2. Results of the Second Phase of the SMED Workshop

After completing the first phase, the team moved on to the second phase of the workshop, which focused on analyzing waste, to reduce and/or eliminate it, thereby improving

setup time. Based on the completion of the “Waste Analysis” document, which included the inefficiencies observed, the team proposed opportunities for improvement. Tables 3 and 4 present the data obtained after the waste analysis for the two technicians, respectively. These results show the reduction and/or elimination of the number of inefficiencies identified, as well as the direct impact on the setup time initially recorded (internal task time).

Table 3. Analysis after reduction/elimination of waste—Technician 1.

Technician 1					
Category	No. (Initial)	No. (Final)	Time (Initial) [min:s]	Time (Final) [min:s]	Potential Improvement
Wastes	5	0	11:27	0:00	23.6%
Internal Tasks (setup)	44	39	48:30	37:30	

Table 4. Analysis after reduction/elimination of waste—Technician 2.

Technician 2					
Category	No. (Initial)	No. (Final)	Time (Initial) [min:s]	Time (Final) [min:s]	Potential Improvement
Wastes	6	2	13:14	2:41	34.1%
Internal Tasks (setup)	31	27	30:57	20:24	

Starting with Table 3, the multidisciplinary team concluded, after joint analysis and discussion, that all waste associated with Technician 1 could be eliminated. As a result, setup time was reduced to 37:30 min:s, which corresponds to a decrease of 11:27 min:s compared to the initial situation. This reduction represents a potential improvement of 23.6%.

Analyzing the data in Table 4, corresponding to Technician 2, it was possible to reduce 4 types of waste, which allowed for an internal task time of 20:24 min:s. This decrease represents a reduction of 10:33 min:s, translating into a potential improvement of 34.1%.

These results reflect the direct impact of the SMED methodology on the selected setup change process. In the case of Technician 1, the complete elimination of waste resulted in a significant reduction in setup time, since the internal tasks associated with waste were removed. The same happened with Technician 2; however, although improvements were also recorded, it was only possible to reduce some inefficiencies. This result is a direct consequence of the dependence of certain activities of Technician 2 on the completion of Technician 1's tasks.

Although the identified potential for improvement was higher for Technician 2, at around 34.1%, for this study and by the principles of the SMED methodology, the longest setup time was considered to be the time corresponding to the interval between the last non-defective part produced from the previous reference and the first non-defective part from the new reference. In this case, analyzing the data from the previous tables, the potential for improvement considered was that of Technician 1, representing 23.6% after eliminating waste.

After analyzing the waste, the team continued with the evaluation of the record sheets relating to the ‘Transformation of Internal Tasks into External Tasks’, on the possibility of transforming internal tasks into external ones. The main purpose of this analysis is to reduce setup time by converting activities performed with the machine stopped into activities with the machine running. Tables 5 and 6 present the data collected for both

technicians after the implementation of the improvements. As indicated above, the tables are the basis for comparison between the number and time of internal and external tasks before and after the improvements were implemented.

Table 5. Analysis after transformation of internal tasks into external tasks—Technician 1.

Technician 1					
Category	No. (Initial)	No. (Final)	Time (Initial) [min:s]	Time (Final) [min:s]	Potential Improvement
Internal Tasks (setup)	44	34	48:30	29:41	38.8%
External Tasks	2	6	2:45	9:51	

Table 6. Analysis after transformation of internal tasks into external tasks—Technician 2.

Technician 2					
Category	No. (Initial)	No. (Final)	Time (Initial) [min:s]	Time (Final) [min:s]	Potential Improvement
Internal Tasks (setup)	31	19	30:57	16:14	47.5%
External Tasks	0	4	0:00	2:25	

An analysis of Table 5 shows that the number of internal tasks has been significantly reduced. Initially, Technician 1 performed 44 internal activities, but after eliminating waste and converting internal tasks to external ones, he now performs 34 activities. This improvement resulted in a decrease in setup time from 48 min and 30 s to 29 min and 41 s. This value corresponds to a potential improvement of 38.8% of the initial setup time recorded in the first phase. As a result, the number of external tasks increased from two to six activities, totaling a final time of 9 min and 51 s. Reflecting on these values, there was notable progress compared to the time recorded for Technician 1, with the distribution of tasks performed with the machine stopped and in operations performed with the machine running. This restructuring followed the objectives outlined, the reduction in setup time, according to the implementation of the SMED methodology.

Moving on to the analysis of Table 6, relating to the operations performed by Technician 2, considerable improvements were also observed. Looking at the data collected, the number of internal tasks was reduced from 31 to 19, allowing a reduction in setup time to 16:14 min:s. This figure corresponds to a potential improvement of 47.5% compared to the initial setup time of 30:57 min:s. In this analysis, it is important to note that only 4 internal tasks were transformed into external tasks, with the remainder being assigned to the Robotics Technician. This reallocation of functions contributed to a reduction in the downtime of machine D, accompanied by greater efficiency in the setup process, because of a more balanced workload among the operational team. Analyzing the line of external tasks, it was found that four internal operations were transformed, increasing by 2:25 min:s.

Having completed the analysis of the transformation of internal and external tasks for the two technicians, it is essential to note that, for the work carried out and by the principles of SMED methodology implementation, the setup time considered for the final analysis was the setup time of Technician 1, in this case, 29:41 min:s, corresponding to an improvement of 38.8% compared to the time initially recorded in the analysis of the videos of the selected reference change.

To conclude the second phase of the workshop, the team began the process of balancing the internal operations between the two technicians involved to distribute the tasks

performed during the setup change equally. Despite attempts to achieve the objective of the proposed activity, it was only completed in the third phase. The results obtained in the final phase of the SMED Workshop are presented and discussed below, where the standard work sequence was defined, the immediate and medium-term corrective and preventive action plan was drawn up, and training and testing of the solution and its application to the remaining work shifts were planned.

4.3. Results of the Third Phase of the SMED Workshop

The final phase of the SMED Workshop began with the completion of the internal task-balancing activity among technicians. Analyzing the results obtained from the record sheets developed for this purpose, “Operations Balancing”, it was observed that there were no further improvements in setup time. Although three internal operations were transferred from Technician 1 to Technician 2, these could only be started after Technician 1 had completed his work, as it was not feasible to perform them simultaneously. For this reason, it was not possible to achieve improvements in setup time, which remained at 29:41 min:s (setup time for Technician 1) after the second phase of the SMED Workshop. Thus, since the time related to the stoppage of machine D did not change, with this attempt to balance internal tasks, it was not considered relevant to present a new table of results for this activity.

Once all the analyses carried out on the spreadsheet data were completed, the participants moved on to defining the standard work sequence, by the “Standard Work” document. As verified in previous analyses, the reference change was not carried out in a consistent and standardized manner, so it was possible to achieve advantageous improvements. It was therefore essential to create a structure that clearly defined all the steps to be performed. This approach aimed not only to promote improved operational efficiency but also to increase productivity.

After a debate and rigorous evaluation of all the tasks performed by the technicians, the team decided to create a structured work sequence, with a clear assignment of responsibilities and activities for each technician. At the same time, a structure was also outlined for the robotics and SAA technicians, considered necessary resources in the reference change process.

Figures 5–8 below show the sequence defined during the workshop for each team member, accompanied by an indication of the setup time and the machines involved. In addition, Figure 5 corresponds to the Robotics Technician, Figure 6 to the SAA Technician, Figure 7 refers to Technician 1, and Figure 8 to Technician 2.

Based on the analysis of the sequences and after observing the procedures created, the team identified beneficial improvements in the organization of work. This new structure contributed not only to ensuring operational stability but also to reducing setup time. Analyzing the sequence created for the robotics and SAA technicians, Figures 4 and 5, it was found that the procedures allowed the integration of the additional resources needed in the reference change process. This structure favored the definition of the responsibilities assigned to each element, allowing for improved coordination with the rest of the team and enabling more efficient task execution.

Analyzing the models defined for both technicians, Figures 6 and 7, and considering the data collected, the opportunities for improvement discussed, and the analyses previously carried out, it was found that these sequences represented the best solution at present. Although the models still present imbalances, since Technician 1 performs more activities than Technician 2, it was evident that there is still waste that has not been eliminated. The reorganization and uniform redistribution of tasks by both technicians is, therefore, a goal

to be achieved through the implementation of medium-term actions, which may require additional investment.

Standard Work - SMED	
Target time: 29 minutes - Applicable machines: 50T, 80T, 100T, 110T, 120T, 140T, 200T (K1)	
Robotics Technician	
External actions before the change	
1	Check peripheral equipment needed for the change (e.g. hand grip)
2	Check the condition of the tool and perform maintenance if necessary
3	Take the equipment to the machine
Start of Change Setup	
4	Shut off the air supply to the robot + peripherals, if applicable
5	Disassemble and remove peripherals and auxiliary equipment (if applicable)
6	In agreement with the injection technician, replace the clamping hand, run the programme and open the air supply
7	Assemble all external peripherals of the machine during the reference change
External actions after change	
8	Check the condition of the tool and perform preventive maintenance if necessary
9	Store peripherals and accessories from the previous reference

Figure 5. Standard Work Sequence—Robotics Technician.

Standard Work - SMED	
Target time: 29 minutes - Applicable machines: 50T, 80T, 100T, 110T, 120T, 140T, 200T	
SAA Technician	
External actions before the change	
1	Cut off the machine's supply in a timely manner (ENSURING MATERIAL IS AVAILABLE UNTIL THE END OF PRODUCTION)
2	Clean the line
3	Take the cleaning equipment to the machine (e.g. vacuum cleaner, bags, air gun)
Start of Change Setup	
4	Remove excess material
5	In agreement with the injection technician, clean the receiver and hopper
6	Check for potential vacuum leaks (e.g., pipes, seals, etc.)
7	If necessary, replace and repair them
8	Clean the machine
9	Close the drawer and send a new reference
External actions after change	
10	Weigh and identify previous reference material
11	Send previous reference material to SAA granules (warehouse)
12	Arrange access ladder to hopper (if applicable)

Figure 6. Standard Work Sequence—SAA Technician.

Standard Work - SMED	
Target time: 29 minutes - Applicable machines: 50T, 80T, 100T, 110T, 120T.	
Technician 1	
External actions before the change	
1	Notify SAA of mould change
2	Notify robotics of mould change
3	Place tool trolley next to the machine
4	Place red trolley next to the machine
5	Place purge trolley next to the machine
6	Move tools to be used to the top of the trolley (torque wrenches, Antikor spray, WD40+cleaning cloth, level and mould checklist)
7	Place standard work checklist next to the machine
8	Set production to Semi-Automatic
Confirm between the two technicians that everything is ready to start	
Start of Change Setup	
9	Open door + place Antikor spray on mould + close mould
10	Retract injection nozzle and turn off thermocouples (if necessary)
11	Inject material out (rocket) and clean spindle if necessary
12	Adjust spindle temperature to new reference
13	Remove rocket + close door + place on purge trolley
14	Move hoses to technician 2 blow water
15	Place safety bar + remove extraction key + secure bridge handles
16	Take torque wrench and loosen fixed + movable plate bars
17	Close door + Open movable plate (retract extraction)
18	Open door + remove mechanical extraction shaft
19	Loosen + remove fixed plate bar
20	Take bridge control + remove mould
21	Pull new reference programme
22	Place new mould on fixed plate
23	Place level + tighten fixed plate bars
24	Place mechanical/hydraulic extraction shaft + close door
25	Close movable plate + set mould height + high pressure
26	Open door + tighten movable plate bars
27	Remove bridge handles
28	Close door + open mould + place extraction key + close door
29	Adjust mould extraction
30	Close door + check mould opening and dosage values + check extraction stroke + close mould
31	Check tuning values
32	Open hopper drawer + close door
33	Inject outside
34	Remove rocket + close door + Place on purge trolley
35	Start production
36	Activate robot step-by-step function
37	Set production to zero
External actions after change	
38	Fill in mould checklist + place next to mould
39	Fill in FCP

Figure 7. Standard Work Sequence—Technician 1.

In the sequences developed, the target time to be achieved was highlighted: 29 min, as well as the injection machines where the sequence is applicable. With the standard work sequence established, the team proceeded to develop a plan of immediate corrective and preventive actions, focusing on the opportunities for improvement identified during the SMED Workshop. All proposed improvements were initially recorded on paperboards and whiteboards. Based on the analysis of these records, the action plan was drawn up.

Standard Work - SMED	
Target time: 29 minutes - Applicable machines: 50T, 80T, 100T, 110T, 120T, 140T, 200T (K1)	
Technician 2	
External actions before the change	
1	Place new reference mould in the trolley next to the machine
2	Move bridge next to the machine
3	Prepare cleaning materials (if necessary)
4	Connect the water blowing gun
5	Assess the type of hoses to be used in the setup change - bring them if necessary
6	Check the need to change bars and the existence of heating plugs, hydraulic hoses and extraction limit switches
7	Place the tuning plug next to the machine
8	Set the thermoregulator to a safe temperature (if necessary, before 3/4 injections)
9	Fill in the purge profitability sheet in SAP
Confirm between the two technicians that everything is ready to start	
Start of Change Setup	
10	Move robot to perform hand replacement
11	Open setup programme
12	Turn off thermoregulators
13	Open door + close latch
14	Take hose + gun + blow water and remove hoses
15	Loosen fixed/movable plate bars
16	Remove bars (if necessary)
17	Use WD40 + cloth to clean the fixed and movable plates of the machine
18	Tighten the fixed plate bars
19	Connect the heating plug (if necessary)
20	Tighten the movable plate bars + close the door
21	Open the door + connect the water hoses + pins + close the door
22	Turn on the thermoregulators and adjust the working temperature and check for possible water leaks
23	Check if necessary back for jitos + robot safety door lock
24	Weigh final purge
25	Check new reference with counterproof + validate start-up
26	Fill in data in SAP
External actions after change	
27	Organise tools and vehicles
28	Transport mould from previous reference
29	Arrange water + hydraulic hoses (if applicable)

Figure 8. Standard Work Sequence—Technician 2.

Analyzing the action plan, it was concluded that 23 improvements were identified that aim to optimize the reference change process, enhancing the elimination of inefficiencies and, in turn, reducing setup time. All actions followed the PDCA cycle methodology, promoting a systematic and continuous approach. This plan was structured to achieve improvements in various areas, such as the organization of teams and workstations, the definition of outlined procedures, and the maintenance of equipment used for the reference

change process. In addition, it is important to note that the defined plan specifically identifies the employees and/or teams responsible for each action, as well as the expected dates for their completion, with a view to regularly monitoring their implementation. Among the proposed actions, it can be seen that 1 was completed and validated during the first phase (action No. 6), five during the third phase (actions 1, 2, 3, 13 and 15), and three after the conclusion of the SMED Workshop, on subsequent days, respectively (actions 14, 19 and 20). The following actions were completed and validated:

- Define in the Standard Work that the SAA Technician must be at the machine at the start of the change—action No. 1;
- Create a table per machine with the amount of excess purge weight—action No. 2;
- Include in the Standard Work the phases in which SAP records must be made—action No. 3;
- Define the number of technicians to be used in a setup change, 1 or 2 technicians—action No. 6;
- Include in the Standard Work the phase of filling out the mold checklist at the end of the change, as an external action—action No. 13;
- Analyze the cleaning of the machine plate—with bars or without bars?—action No. 14;
- Include in the Standard Work, before the change, bringing the tuning sheet to the machine monitor—action No. 15;
- Train first shift technicians for the defined Standard Work—action No. 19;
- Monitor and validate setup changes with the first shift according to the Standard Work—action No. 20.

Within the defined action plan, actions 19 and 20 stand out, referring to training and monitoring of setup changes for the first work shift. In Round 2, the new Standard Work sequence was distributed to all first shift technicians for analysis and study. This initiative aims to ensure strict compliance with all steps during reference change. Afterwards, the team responsible monitored and validated 13 setup changes during the first shift on different machines, including the machine D selected for the workshop, demonstrating the application of the new Standard Work sequence on different equipment. The results obtained were positive, with improvements exceeding those defined at the end of the SMED Workshop. To highlight these results, Table 7 was prepared, which compares the actual times measured with the historical average records extracted from SAP during the testing period, including the percentage improvement in setup times.

Table 7. Comparison of average setup times in SAP with actual times obtained in the first shift after the SMED Workshop.

Machine	Before SMED Workshop	After SMED Workshop		% Improvement
	Average SAP Time [min]	Real Time [min] Round 1	Real Time [min] Round 2	
A	58.5176	25	40	44.46%
B	59.0462	33		44.11%
C	57.1059	33		42.21%
D	49.3714	36	24	39.24%
E	73.2522	30	45	48.81%
F	66.2538	35		47.17%
G	86.3250	40		53.66%
H	47.3077	40	30	26.02%
I	50.3182	25		50.32%

Analyzing Table 7, it was found that the results obtained were positive, with significant reductions in setup times after implementing the new Standard Work sequence in the first work shift. A significant improvement was observed in all machines, considering that the average setup times recorded after the SMED Workshop were obtained by different employees. The machine selected for the SMED Workshop, machine D, stands out with an improvement of 39.24% when compared to the average time recorded. This validates the effectiveness of the actions implemented in the first shift, reinforcing the importance of extending them to the other work shifts. These results prove the effectiveness of the approach adopted and support the continuity of the action plan implemented.

Regarding the remaining actions, it was concluded that they are still in the development phase and are being analyzed for their technical feasibility, as well as their potential impact on the benchmark change process.

With the analysis of the action plan complete, the final steps to highlight are the dates set for planning training and testing the solution in the company's other work shifts, as they have already been validated for the first shift. Given this, the multidisciplinary team decided that the training and application of the standard work sequence in the second and third shifts would be established by Round 3. This measure aims to ensure the standardization of the defined sequence and the continuous monitoring of all improvements implemented.

4.4. Critical Reflections, Challenges, and Theoretical Integration

While the SMED Workshops led to clear and measurable improvements in setup time and team collaboration, the implementation process also revealed several important challenges and trade-offs that must be considered. One of the most challenging issues was initial resistance of some operators to changing their established routines. This issue was overcome by communication, reassurance, and visible involvement during the workshops' hands-on practical sessions. Additionally, the workshops demanded time commitments from cross-functional team members. This trade-off between short-term resource intensity and long-term operational efficiency required careful management. Another critical issue was the limited availability of production equipment for extended observation and testing, particularly across different shifts. This issue constrained the application of immediate improvements to all operating hours.

Additionally, the study was conducted in a single automotive injection molding facility with prior exposure to Lean practices. As such, cultural receptivity to SMED may have been higher than in organizations with limited Lean maturity. Furthermore, the workshop focused on one machine (Machine D) selected based on its high setup time and improvement potential. Although there are expected improvements when applied to other machine types or industries, since the medium-term validation data were applied to a small number of shifts, the results may be limited.

No formal financial analysis was conducted. However, a qualitative cost-benefit reflection highlights that the direct costs were low (the use of internal human resources, existing equipment, and in-house training rooms). The costs were related to the coordination time and workshop duration, which are justified against the benefits of setup time reduction, improvement across multiple machines, increased operator engagement, and development of standard work.

This case study demonstrates how SMED can be implemented not only as a technical efficiency tool but as a structured organizational learning process. The use of workshops aligns with socio-technical Lean transformation, where engagement and standardization play critical roles in promoting improvement efforts [31,32].

4.5. SMED Workshop Conclusions and Suggestions for Future Work

After analyzing the three phases of the SMED Workshop, it can be concluded that the approach used allowed the objectives that were set to be achieved, enabling a reduction in the setup times of the selected machine. Thus, the research question is positively answered: In the first phase of the workshop, the initial setup time recorded was 48:30 min:s, totaling 44 internal tasks for Technician 1. As the analysis progressed, after reducing and eliminating waste, the first positive result was obtained. As a result, the setup time was reduced to 37:30 min:s, representing a potential improvement of 23.6%. This gain was particularly beneficial because it not only demonstrated that the objectives were being met but also contributed to the motivation of the entire team. In this way, participants became more communicative, demonstrating autonomy in decision-making throughout the workshop.

In addition to this result, as well as the other analyses carried out, such as the transformation of internal tasks into external ones, it was possible to achieve a shorter setup time, accounting for only 29:41 min:s, resulting in a new distribution: 34 internal tasks and 6 external tasks for Technician 1, representing an efficient gain of 38.80% compared to the initial time.

Based on the objective set for this work, this value resulted from the implementation of the SMED methodology in the analysis of the selected change, enabling the efficient restructuring of tasks and the creation of a concrete action plan. Its implementation was based on the analysis of the waste identified after viewing the videos, as well as the classification and conversion of internal tasks into external ones. In addition, the new standard work sequence was structured, with a clear definition of all operations involved for all technicians. In this sequence, the target time to be achieved was also defined: 29 min, and all machines to which the sequence was applicable. After developing the action plan and its schedule, the team identified 23 improvements, with emphasis on two actions already completed and validated, actions No. 19 and 20. These resulted in the monitoring and validation of 13 setup changes by the team responsible for different machines, including the machine selected for the workshop. Analyzing the results, there was a 39.24% improvement on machine D. This significant reduction ensures and proves the effectiveness of the approach adopted, enabling compliance with the new stages established, namely the scheduled training and testing of future solutions for the second and third work shifts.

After a brief presentation of all the results, it is essential to analyze the participating team. A multidisciplinary team was selected for this workshop, consisting of employees from different departments, to assess their skills and their ability to work as a team. Overall, the team demonstrated a high level of responsibility, combining analytical skills with excellent technical rigor. This choice proved to be an asset not only for the SMED Workshop but also for the organization. The positive contribution of this team was reflected in a collaborative spirit evident throughout the different phases of the workshop, highlighting good interpretative power and critical capacity in the different analyses carried out. All the suggested improvements were valuable, as they focused not only on the change in reference under study but also on its applicability to all injection lines.

Although these results were, in general, very positive, given that it was possible to reduce setup time, the work is not finished. The implementation of tools and methodologies only results in added value in an organization if daily work is carried out, with constant analysis and validation of the respective results. To this end, there are several crucial suggestions for future work related to the topic addressed, the implementation of the SMED methodology.

To this end, regular audits of the work carried out should be carried out in the future, through the creation of periodic routines focused on reference changes, according to the

defined standard work sequence. These audits are important not only to understand whether employees, in their daily lives, fulfill the previously defined functions, but also to identify additional possible solutions. Thus, the organization must value all ideas and suggestions offered by its employees to validate them and apply them to all work shifts.

It should also be noted that one of the standards to be achieved is the extension of the work sequence to the other machines in the injection area, which have different setup times. To achieve this objective, it will be necessary to develop new sequences and respective medium-term action plans through the implementation of new SMED Workshops. As mentioned previously, these initiatives should also be accompanied by audits and validations, ensuring compliance with the established rules.

The creation of routines on the shop floor, the identification of new waste, opportunities for improvement, and different types of potential constitute a strategic goal for Company A. With these advances, it will be possible to expand the implementation of the SMED methodology to the remaining production areas.

Thus, Table 8 includes an SMED best-practice integration, outlining recognized best practices for SMED applied to this case study.

Table 8. SMED best-practice integration within the case study.

SMED Best Practice	Description	Applied in This Case Study
Separate internal and external setup	Identify which tasks require machine stoppage	Video analysis and task classification worksheets
Convert internal to external setup	Reorder activities to be performed while the machine runs	38.8% setup reduction via re-sequencing
Use of visual aids	Standardized work charts and video learning	Used whiteboards, flipcharts, sequence guides
Cross-functional team involvement	Engage operators, engineers, planners	Multidisciplinary team from 4 departments
Standardize setup procedures	Define consistent setup routines	Created detailed Standard Work for 2 shifts
Continuous improvement cycles	Apply PDCA to identify and implement changes	23 actions created, tracked, validated
Data-driven decision-making	Measure and benchmark all changes	Compared setup times pre/post using SAP data

Due to the nature and scope of this applied industrial case study, and considering the absence of inferential analysis and external benchmarks, the sequence of applying SMED best practices to this case study can be generalized to other cases. Although the results will be different in other contexts, following the workshop's training framework will lead to significant improvements in setup times.

5. Conclusions

This study demonstrated the practical application of a structured SMED Workshop model in an automotive injection molding context, resulting in a substantial reduction in setup time—from 48:30 min:s to 29:41 min:s (a 38.8% improvement). This figure represents the commitment and communication involved among the participating team throughout the workshop, translating into significant gains in productivity and operational efficiency. Standard work sequence was defined, and the immediate and medium-term corrective and preventive action plan was drawn up. Analyzing the action plan, it was concluded that 23 improvements were identified to optimize the reference change process. Among these improvements, two actions that have already been completed and validated stand out, actions 19 and 20, relating to the training and monitoring of setup changes for the

first work shift. These actions resulted in the monitoring and validation of 13 setup changes by the team responsible for different machines, including the machine selected for the workshop. Analyzing the results, it was found that they were positive, with significant reductions in setup times, particularly on machine D, with an improvement of 39.24%. This figure is higher when compared to the gain resulting from the second phase, proving the effectiveness of the approach adopted. Consequently, the improvement in setup time contributed to a more flexible and dynamic response between internal and external customers, as well as to a potential reduction in stock, resulting from the possibility of minimizing production batch sizes. With these results, the company strengthens its capacity for innovation and product quality, ensuring effective management of all its resources.

Thus, additional validation across other machines showed improvements exceeding 50%, supported by employee training, task standardization, and a targeted action plan. These outcomes contributed to improved flexibility, reduced downtime, and enhanced collaboration on the shop floor.

From an academic perspective, the case study contributes to Lean operations literature by demonstrating how a structured, team-based learning process on SMED leads to efficiency and efficacy improvements during its implementation. This aligns with socio-technical approaches in Lean transformation and highlights the value of cross-functional involvement, standardized work, and PDCA-driven continuous improvement.

Despite the limitation to a single industrial case, the findings highlight a replicable framework for organizations aiming to embed SMED into broader Lean philosophy applications. The defined workshop methodology, combined with low-cost implementation and demonstrable gains, offers a scalable model for further academic research. Future research should involve the SMED workshop methodology implementation in the remaining production areas, enabling process standardization and expansion of the operational gains achieved; cross-industry case studies to assess generalization; explore the integration of Industry 4.0 technologies, such as digital setup monitoring, AI-driven predictive changeovers, or augmented reality guides, to further enhance SMED efficiency and operator learning; and evaluate long-term sustainability of standard work adherence over time. By advancing both practical outcomes and theoretical understanding, this study can contribute to Lean transformation in modern manufacturing systems.

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References

1. Silva, A.; Sá, J.C.; Santos, G.; Silva, F.J.G.; Ferreira, L.P.; Pereira, M.T. Implementation of SMED in a cutting line. *Procedia Manuf.* **2020**, *51*, 1355–1362. [CrossRef]
2. Díaz-Reza, J.R.; García-Alcaraz, J.L.; Gil-López, A.J.; Realyvasquez-Vargas, A. Lean manufacturing tools as drivers of social sustainability in the Mexican maquiladora industry. *Comput. Ind. Eng.* **2024**, *196*, 110516. [CrossRef]
3. Costa, F.; Alemsan, N.; Bilancia, A.; Tortorella, G.L.; Staudacher, A.P. Integrating industry 4.0 and lean manufacturing for a sustainable green transition: A comprehensive model. *J. Clean. Prod.* **2024**, *465*, 142728. [CrossRef]
4. Monteiro, C.; Ferreira, L.P.; Fernandes, N.O.; Sá, J.C.; Ribeiro, M.T.; Silva, F.J.G. Improving the Machining Process of the Metalworking Industry Using the Lean Tool SMED. *Procedia Manuf.* **2019**, *41*, 555–562. [CrossRef]
5. Vieira, T.; Sá, J.C.; Lopes, M.P.; Santos, G.; Félix, M.J.; Ferreira, L.P.; Silva, F.J.G.; Pereira, M.T. Optimization of the cold profiling process through SMED. *Procedia Manuf.* **2019**, *38*, 892–899. [CrossRef]
6. Aljuwaied, M.; Almani, M.; Litos, L.; Salonitis, K. Lean Thinking and Resource Efficiency in the Design of Public Services. *Procedia CIRP* **2024**, *128*, 894–899. [CrossRef]
7. Deshmukh, M.; Gangele, A.; Gope, D.K.; Dewangan, S. Study and implementation of lean manufacturing strategies: A literature review. *Mater. Today Proc.* **2022**, *62*, 1489–1495. [CrossRef]
8. Tetteh, M.G.; Gupta, S.; Kumar, M.; Trollman, H.; Salonitis, K.; Jagtap, S. Pharma 4.0: A deep dive top management commitment to successful Lean 4.0 implementation in Ghanaian pharma manufacturing sector. *Heliyon* **2024**, *10*, e36677. [CrossRef]
9. Wang, P.; Wu, P.; Chi, H.L.; Li, X. Adopting lean thinking in virtual reality-based personalized operation training using value stream mapping. *Autom. Constr.* **2020**, *119*, 103355. [CrossRef]
10. Sivaraman, P.; Nithyanandhan, T.; Lakshminarasimhan, S.; Manikandan, S.; Saifudheen, M. Productivity enhancement in engine assembly using lean tools and techniques. *Mater. Today Proc.* **2020**, *33*, 201–207. [CrossRef]
11. Nandini, T.S.; MohanRam, M.; Shekar, G.L. Modeling 4Ps of Toyota way principles in MSMEs supply Chain-an empirical approach. *Mater. Today Proc.* **2023**, *92*, 284–290. [CrossRef]
12. Martins, M.; Godina, R.; Pimentel, C.; Silva, F.J.G.; Matias, J.C.O. A Practical Study of the Application of SMED to Electron-beam Machining in Automotive Industry. *Procedia Manuf.* **2018**, *17*, 647–654. [CrossRef]
13. Afonso, M.; Gabriel, A.T.; Godina, R. Proposal of an innovative ergonomic SMED model in an automotive steel springs industrial unit. *Adv. Ind. Manuf. Eng.* **2022**, *4*, 100075. [CrossRef]
14. Naciri, L.; Mouhib, Z.; Gallab, M.; Nali, M.; Abbou, R.; Kebe, A. Lean and industry 4.0: A leading harmony. *Procedia Comput. Sci.* **2022**, *200*, 394–406. [CrossRef]
15. Reke, E.; Powell, D.; Mogos, M.F. Applying the fundamentals of TPS to realize a resilient and responsive manufacturing system. *Procedia CIRP* **2022**, *107*, 1221–1225. [CrossRef]
16. Frédéric, R.; Florian, M.; Laurent, J.; Forget, P.; Pellerin, R.; Samir, L. Lean 4.0: Typology of scenarios and case studies to characterize Industry 4.0 autonomy model. *IFAC-PapersOnLine* **2022**, *55*, 2073–2078. [CrossRef]
17. Toyota. Visão e Filosofia da Toyota. Toyota Portugal. Available online: <https://www.toyota.pt/mundo-toyota/sobre-a-toyota/visao-e-filosofia> (accessed on 29 November 2024).
18. Bizuneh, B.; Omer, R. Lean waste prioritisation and reduction in the apparel industry: Application of waste assessment model and value stream mapping. *Cogent Eng.* **2024**, *11*, 2341538. [CrossRef]
19. Rodrigues, I.; Alves, W. Integrating Lean Thinking into Project Management: A Conceptual Model for the IT Sector. *Procedia Comput. Sci.* **2024**, *239*, 1604–1611. [CrossRef]
20. Kurganov, V.; Sai, V.; Gryaznov, M.; Dorofeev, A. The Emergence and Development of Lean Thinking in Transport Services. *Transp. Res. Procedia* **2021**, *54*, 309–319. [CrossRef]
21. Habib, M.A.; Rizvan, R.; Ahmed, S. Implementing lean manufacturing for improvement of operational performance in a labeling and packaging plant: A case study in Bangladesh. *Results Eng.* **2023**, *17*, 100818. [CrossRef]
22. Yeh, S.T.; Arthaud-Day, M.; Turvey-Welch, M. Propagation of lean thinking in academic libraries. *J. Acad. Libr.* **2021**, *47*, 102357. [CrossRef]
23. Maraqa, M.J.; Sacks, R.; Spatari, S. Strategies for reducing construction waste using lean principles. *Resour. Conserv. Recycl. Adv.* **2023**, *19*, 200180. [CrossRef]
24. Raza, M.; Malik, A.A.; Bilberg, A. PDCA integrated simulations enable effective deployment of collaborative robots: Case of a manufacturing SME. *Procedia CIRP* **2021**, *104*, 1518–1522. [CrossRef]
25. Gautam, A.; Khan, Z.A.; Gani, A.; Asjad, M. Identification, ranking and prioritization of Key Performance Indicators for evaluating greenness of manufactured products. *Green Technol. Sustain.* **2025**, *3*, 100114. [CrossRef]
26. Vieira, M.; Silva, F.J.G.; Campilho, R.D.S.G.; Ferreira, L.P.; Sá, J.C.; Pereira, T. SMED methodology applied to the deep drawing process in the automotive industry. *Procedia Manuf.* **2020**, *51*, 1416–1422. [CrossRef]
27. Bhade, S.; Hegde, S. Improvement of Overall Equipment Efficiency of Machine by SMED. *Mater. Today Proc.* **2020**, *24*, 463–472. [CrossRef]

28. Rosa, C.; Silva, F.J.G.; Ferreira, L.P.; Campilho, R. SMED methodology: The reduction of setup times for Steel Wire-Rope assembly lines in the automotive industry. *Procedia Manuf.* **2017**, *13*, 1034–1042. [CrossRef]
29. Marcella, C.A.; Widjajati, K. Analysis of Lean Manufacturing Implementation through the Single Minute Exchange of Dies (SMED) Method to Reduce Setup Time in the Injection Molding Machine Process. *Adv. Sci. Comput. Intell.* **2024**, *5*, 87–95. [CrossRef]
30. Dora, M.; Kumar, M.; Goubergen, D.V.; Molnar, A.; Gellynck, X. Operational Performance and Critical Success Factors of Lean Manufacturing in European Food Processing SMEs. *Trends Food Sci. Technol.* **2013**, *31*, 156–164. [CrossRef]
31. McIntosh, R.I.; Culley, S.J.; Mileham, A.R.; Owen, G.W. A critical evaluation of Shingo's 'SMED' (Single Minute Exchange of Die) methodology. *Int. J. Prod. Res.* **2000**, *38*, 2377–2395. [CrossRef]
32. Shah, R.; Ward, P.T. Defining and developing measures of lean production. *J. Oper. Manag.* **2007**, *25*, 785–805. [CrossRef]
33. Vinodh, S.; Joy, D. Structural Equation Modelling of lean manufacturing practices. *Int. J. Prod. Res.* **2011**, *50*, 1598–1607. [CrossRef]
34. Abdi, M.R.; Labib, A.W.; Delavari Edalat, F.; Abdi, A. RMS value chain architecture. In *Integrated Reconfigurable Manufacturing Systems and Smart Value Chain*; Springer: Cham, Germany, 2018. [CrossRef]
35. Cakmakci, M. Process improvement: Performance analysis of the setup time reduction-SMED in the automobile industry. *Int. J. Adv. Manuf. Technol.* **2009**, *41*, 168–179. [CrossRef]
36. Vieira, S.M.O.; Lopes, R.B. Improving Production Systems with Lean: A Case Study in a Medium-Sized Manufacturer. *J. Manuf. Technol. Manag.* **2019**, *33*, 162–180. [CrossRef]
37. Khakpour, R.; Ebrahimi, A.; Hosseini, S.; Mohammad, S. SMED 4.0: A development of single minute exchange of die in the era of Industry 4.0 technologies to improve sustainability. *J. Manuf. Technol. Manag.* **2024**, *35*, 568–589. Available online: https://search.lib.uiowa.edu/primo-explore/fulldisplay?docid=TN_cdi_emerald_primary_10_1108_JMTM-08-2023-0333&context=PC&vid=01IOWA&lang=en_US&search_scope=default_scope&adaptor=primo_central_multiple_fe&query=sub,exact,buro&facet=citedby,exact,cdi_FETCH-LOGICAL-c342t-e187c26e1ed269ada07993ee9875eb330b4934c34cf798eba07740f5b3a692633&offset=20 (accessed on 29 November 2024). [CrossRef]
38. Womack, J.P.; Jones, D.T. Lean Thinking: Banish Waste and Create Wealth in Your Corporation. *J. Oper. Res. Soc.* **1996**, *48*, 1148. [CrossRef]
39. Shingo, S. *A Revolution in Manufacturing: The SMED System*; Routledge: New York, NY, USA, 1985. [CrossRef]

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