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Lean implementation in product development processes: a framework proposal

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ABSTRACT

The implementation of lean principles in product development (PD) activities has been receiving increased attention lately. However, it is not clear how the application of these principles to PD activities enhances their effectiveness. Moreover, the implementation of lean principles is more difficult to achieve in PD activities than in the shop-floor context. The objective of this paper is to develop and implement a framework applying lean principles to the PD process. To that end, an action research project was conducted in the R&D department of an industrial company. This article presents and describes a six-step framework, its challenges, and main results. The implementation of the framework led to gains in the efficiency of the product development process through a 20% decrease in waste. Improvement measures such as standardisation, clear identification of roles, prioritisation of activities and improved efficiency of meetings were the main drivers for the gains in efficiency. Overall, three main contributions should be highlighted: the role a knowledgeable lean project leader can play; employee training focused on the implementation of lean-based product development activities; and team building and communication.

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Lean; product development; waste; framework; action research

1. Introduction

Lean manufacturing is one of the most widely accepted operational strategies used by companies to increase their performance and boost competitiveness (Antony et al. 2021). Although lean concepts originated in the manufacturing environment, their principles can have a universal application (Belvedere et al. 2019). The concept of lean thinking (LT), that was inspired by the Toyota Motor Corporation, focuses on examining organisations' value stream to eliminate all non-value adding activities and align required activities to external and internal customers (Hoppmann et al. 2011). There have been an increasing number of attempts to apply LT principles, tools and techniques to other processes such as product development (PD) activities (Salgado and Dekkers 2018). However, simply applying LT principles to PD activities does not necessarily lead to an effective PD process (León and Farris 2011). In fact, lean activities are more difficult to implement in PD than in production due to their specificities (Helander et al. 2015). For example, PD differs from repetitive production processes because its main input is information as opposed to materials (Morgan and Liker 2006; Belvedere et al. 2019). Further, PD has a higher degree of variability and uncertainty when compared to production processes which can prevent an effective identification of the waste in the delivery of value (Browning and Sanders 2012; Belvedere et al. 2019). Finally, PD is mainly based on intangible assets and on the flow of knowledge, information and ideas (Heinzen and Höflinger 2017).

The application of lean principles in PD processes is rare as these activities are not the traditional ones amenable to the disciplined cost focus of traditional lean manufacturing approaches (Tan et al. 2022). Additionally, there is still a lot of scepticism concerning the possibility of applying lean principles outside high volume manufacturing or stable contexts (Bevilacqua, Ciarapica, and De Sanctis 2017; Antony et al. 2021). In a similar fashion, Mund, Pieterse, and Cameron (2015) argue that the existing literature has failed to provide successful examples of the application of lean principles in PD activities. Furthermore, there are few empirical examples of applications of lean principles apart from the Toyota practices in the automotive industry in product development activities (Tortorella et al. 2016; Marodin et al. 2018; Hoppmann et al. 2011; León and Farris 2011; Letens, Farris, and van Aken 2011). Lean implementation is not just about the application of a set of tools, but it is also about the application of systematic methods and lean principles (Spear and Bowen 1999). Consequently, Karlsson and Ahlstrom (1996b) called for more in-depth case studies from sectors outside the automotive industry to fully understand the factors and contingencies that lead to a successful application of lean principles in PD processes.

Set against this background, this study poses two interrelated questions: (1) What are the opportunities to apply lean

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principles in PD? (2) How can lean principles be successfully implemented within PD activities?

To address these gaps, the present study adopts an action research (AR) approach to develop and implement a lean principle-based framework within PD process activities. In particular, this paper explores the adoption of lean principles in the early phase of PD execution, which occurs after the front-end process (Khurana and Rosenthal 1997). This point is particularly valid given the opportunities to apply lean principles to eliminate waste and non-added value activities in the PD process.

This study makes several contributions to the literature such as: assessing the feasibility of introducing lean principles in PD processes; reporting an example of how to successfully implement these lean principles (including the development of the conceptual framework, the selection of the various tools, techniques, and guidelines at each stage); and presents empirical evidence of the effective gains of deploying lean principles in support functions.

The article is structured as follows. After this introduction, Section 2 reviews the literature with a focus on LT and lean implementation in PD, while Section 3 presents the methodology adopted. Section 4 describes the development and implementation of the framework within PD activities. Section 5 provides a discussion of the results obtained while Section 6 offers concluding remarks, limitations, and avenues for future research.

2. Literature review

This section reviews the literature on lean in PD, characterising the notion of lean manufacturing, discussing the challenges of lean implementation in manufacturing shop floors and in PD contexts, and presenting the enablers and frameworks of lean application in PD in the automotive and other industries.

Following the world's exposure to the Toyota's production system and its associated set of principles, practices and techniques (Womack and Jones 1996), many companies have aimed at becoming lean by reducing waste and eliminating non-value-added activities from their operational processes (Hong and Leffakis 2017; Shah and Ward 2007). The main objective of lean production practices is to efficiently and effectively apply human and technical resources to improving product quality and delivery performance in the production system on a continuous basis (Holweg 2007; Hong and Leffakis 2017). Although originally conceived for the manufacturing environment, lean manufacturing has been described 'as an overall organisational philosophy, managerial approach, production system and a holistic set of internal operational practices and techniques' (Hong and Leffakis 2017, 1069). Lean thinking is about removing all non-value adding activities and aligning activities to external and internal customers to decrease lead-times and reduce the consumption of human and financial resources (Womack and Jones 1997). Because of its broad and holistic view, companies have seised the opportunity to apply lean practices to support functions rather than manufacturing, such as PD.

2.1. Lean for manufacturing and PD

Selecting the most appropriate practices and techniques to improve shop floor processes is a major responsibility for production managers (Marodin et al. 2018). On shop floors, the implementation and execution of lean management practices, tools and techniques seek to stabilise the daily production processes (through reduced operational variability) and reliability (ensuring each job task is executed consistently) (El-Khalil, Leffakis, and Hong 2020). Thus, a major emphasis of lean manufacturing process improvement practices, tools, and techniques is to continually reinforce and stress the importance of executing a job task continuously and repetitively to increase quality performance (El-Khalil, Leffakis, and Hong 2020). However, shop floor activities differ from PD processes as the latter are not repetitive and may be highly variable and uncertain.

PD is a complex adaptive system of decisions (McCarthy et al. 2006) to create new products by linking upstream (R&D, marketing, design and engineering) and downstream activities (operations, manufacturing engineering, quality control) (Hong, Nahm, and Doll 2004). There are several approaches that explain how the organisation and the management of PD are related to lead times and due dates. Perhaps the most well-known is Cooper's (1990) stage gate framework – representing PD processes as an ordered, sequential and predictable system of activities. Accordingly, ideas and market needs represent inputs, engineers and marketeers' resources, and the outputs are the new products (Clark and Wheelwright 1993). However, a major limitation of linear frameworks (as the one from Cooper) is that they ignore factors such as flexibility, informality, feedback and autonomy (Griffin 1997). PD processes are often complex, chaotic and recursive processes of decisions in which a poor control may lead to planning and coordination issues (McCarthy et al. 2006). Against this background, removing all non-value adding activities and aligning activities can contribute to decreasing lead-times and reducing human and financial waste, thus improving the PD performance.

Lean for PD is thus a cross-functional design practice, comprising techniques and tools that are driven by a philosophical foundation in LT. The notion is that lean principles can be applied to support functions (Salgado and Dekkers 2018). Applying LT to PD can lead to improved productivity, better product design, shorter development time and reduced engineering efforts for each product (Karlsson and Ahlstrom 1996a; León and Farris 2011; Morgan and Liker 2006; Womack, Jones, and Roos 1990). However, lean principles need to be translated into the specific context of PD so that they maximise value and eliminate waste in PD activities (Karlsson and Ahlstrom 1996a; León and Farris 2011). Lean implementation is more difficult in PD activities since it is based on emerging targets (compared to pre-specified ones as occurs in manufacturing), the flow is based on information and knowledge (rather than on parts and materials), the interactions are usually beneficial (instead of being considered a waste), and the process allows innovation and reduces cycle time (rather than being repeatable and seeking to be error-free) (Tortorella et al. 2016). Thus, while most companies have adopted LT in manufacturing operations (Baines et al. 2006; Khalil and Stockton 2010), it has less often been applied to PD processes (Al-Ashaab and Sobek 2013; Vinodh and Chethan Kumar 2015).

2.2. Framework for lean implementation in PD

Lean implementation in PD activities differs from traditional PD, as lean principles are applied to the PD process, creating flow, supporting the acceleration of the development process, and improving the reactivity of the company in a dynamic market (Kumar et al. 2016). Compared to traditional PD, lean implementation favours cross-functional teams, integrative meetings, simultaneous development phases, strong managerial importance, and early supplier involvement since the beginning of projects (Karlsson and Ahlstrom 1996a; Tortorella et al. 2016). When applied to PD, the lean approach contributes to a higher flexibility, dynamism, and interaction between teams, as well as shorter development lead times (Marodin et al. 2018).

Most research concentrated on developing frameworks for a leaner PD is grounded on practical applications in the automotive industry. Sobek II, Liker, and Ward's (1998) model focuses on how to create value (rather than on managing waste), emphasising the understanding of key elements of lean and the interactions and relationships between these elements' characteristics, introducing the concepts of set-based concurrent engineering (SBCE) and concurrent engineering (CE) to their PD system. Morgan and Liker (2006) carried out their research at Toyota and proposed a framework inspired by the Toyota Product Development System (TPDS) based on three key systems: people, process and tools, and technology. Ward (2007) conducted a study based on observations of, and practical consulting experience in, Toyota and American companies, basing their framework on five building blocks of value streams and knowledge creation cycles, namely: a focus on value; entrepreneurial system designers; teams of responsible experts; SBCE; and cadence (i.e. pull and flow). Liker and Morgan (2011) draw on their previous framework (see Morgan and Liker [2006] work on this subject) to argue that the TPDS framework is broad enough to be applied across companies and industries. Dombrowski and Zahn (2011) reviewed lean development concepts and, based on the TPDS and lean principles, summarised the concepts in a framework composed of seven principles: kaizen; standardisation; visualisation; flow and pull; zero defects; frontloading and employees; and leadership – testing them in the automotive industry.

Other research focussed on developing approaches to make PD processes leaner is grounded on previous studies. Hoppmann et al. (2011) conducted a survey of the literature on lean factors for PD and identified 11 enablers including: strong project managers; specialist career paths; workload levelling; responsibility-based planning and control; cross-project knowledge transfer; simultaneous engineering; supplier integration; product variety management; rapid prototyping, simulation and testing; process standardisation; and set-based engineering. Wang et al. (2011) derived a model from the literature by identifying three families of enablers that involve: the collection of information and the provision of feedback for the design process; the support of product design and development core activities; and the provision of administrative support to chief engineers and staff. However, both Hoppmann et al. (2011) and Wang et al. (2011) focus more on the identification of the enablers than on the challenges of the implementation of lean processes.

Finally, lean applications can also be found in industries other than the automotive sector. Karlsson and Ahlstrom (1996a) studied the PD system of a mechanical and electrical equipment manufacturer, focussing on the factors that enable or prevent a successful transition to lean production. They identified six elements to implement lean principles: supplier involvement; simultaneous engineering; cross-functional teams; integration of teams rather than coordination; heavyweight team structure; and strategic management of projects. However, this framework does not consider the concepts of waste elimination and the creation of a value stream. Letens, Farris, and van Aken (2011) conducted a longitudinal case study in an engineering PD department of the Belgian Armed Forces, proposing a framework based on the product portfolio, project and function, which stresses value definition, workflow optimisation and lean system dynamics at various organisational levels. Al-Ashaab et al. (2013) conducted a case study of a PD project for a helicopter engine in the aerospace industry splitting their model into two design stages: integrating the principles of SBCE; and implementing the framework. Khan et al. (2013) identified the enablers influencing the PD in five engineering companies from the automotive, aerospace and home appliances industries, discovering five main drivers: SBCE processes; chief engineer (i.e. entrepreneurial) technical leadership; value-focussed planning and development; a knowledge-based environment; and a continuous improvement culture. Lermen et al. (2018) conducted a real case application within a fruit processing company to increase fruit preservation and eliminate waste during PD processes proposing various tools and practices including: strategies and portfolio; project management; needs and requirements; concept system; detailed project; testing and validation; the launch of the manufacturing product; monitoring; and discontinuity. More recently, Marodin et al. (2018) used a survey to explore the moderating role of lean principles in PD and LM concerning quality and inventory performance, concluding that the joint implementation of lean principles in PD and LM yields a better result concerning quality improvement than the implementation of LM alone, advising managers to follow a cross-functional approach to lean implementation (lean should not be exclusive to the shop floor).

While each framework is unique, some factors are emphasised throughout all of them such as the importance of people and leadership (Hoppmann et al. 2011; Dombrowski and Zahn 2011; Khan et al. 2013; Tortorella et al. 2016), visualisation (Dombrowski and Zahn 2011), tools, technology (Morgan and Liker 2006) and a culture of continuous improvement (Khan et al. 2013; Tortorella et al.

2016). However, and perhaps more importantly, León and Farris (2011, 45) argue that the literature on lean principles in PD has 'focused mostly on the types of things that should be done to improve PD rather than on how recommendations should be implemented'. The same notion is shared by Lermen et al. (2018), who argue that companies still struggle to adapt the principles originally designed for manufacturing companies. Considering that lean can be understood as an internal set of operational practices and techniques, its underlying philosophy may be applied in distinct settings such as PD processes. However, PD processes hold inherent challenges such as being highly variable and based on a flow of information rather than materials. This increases the difficulties of applying more systematic approaches and identifying waste in variable and non-tangible tasks. In what follows, we examine how lean, as a philosophy, can be applied in such settings and how to embed it in PD routines successfully.

3. Research method

This section describes the company featured, its motivation to undertake the research project and details the AR protocol.

3.1. Research context

The manufacturing company, which is located in Portugal, has around 1,200 employees and produces a wide range of water heaters, boilers, and heat pumps. The business strategy relies on the development of innovative products to increase sales and reinforce brand awareness as a high-tech, innovation-led company.

Although the company was familiarised with lean practices in manufacturing activities, it did not have prior experience concerning the implementation of lean principles and practices in support functions. The company felt the need to improve its PD process by overcoming several operational shortcomings, for example: the difficulties related to complying with product development milestones; employee complaints concerning an administrative work overload; and work imbalance, among other issues. Moreover, the company was facing emerging challenges: low growth due to the stagnation of the main European markets; an increasing number of low-cost competitors; and intense international competition due to competing developing countries with lower wages.

Due to previous collaboration between the company and university experts, the company decided to contact the latter to develop a pilot study to improve the company's PD execution process. Moreover, the company is used to working with external teams of experts to provide technical advice, training, and support during the implementation of innovative solutions. This research project took place in the heat pump development department of the R&D corporate centre, involving the head of the R&D department, the team leader of the heat pump development department and six full-time PD engineers. The company was willing to extend the implementation of the new solution to the entire R&D department, contingent on the success of the pilot project.

It should be noted that, firstly, the company had previous and significant experience in the implementation of lean manufacturing, which facilitates the diffusion of lean principles and practices to other functions within the company. Secondly, the company is engaged in a highly competitive industrial sector in which product and process innovation is of utmost importance for its competitiveness. Finally, as lean implementation occurs concurrently with the research process allowing the researchers to intervene in the events as they unfold (and not just observe the outcome), AR is of added value to this highly specific, real situation context which has managerial relevance for the company and for operations management research (Coughlan and Coghlan 2016).

3.2. Research approach

AR is a common approach in operations management research (Silva et al. 2016; Kharlamov, Ferreira, and Godsell 2020) and is designed to establish a close association between actions and problem solving, involving researchers and participants in a cooperative and participatory way (Coughlan and Coghlan 2016). Furthermore, the aim of AR is to generate knowledge both from studying the theory before implementing actions and through the process of inquiry (Coughlan and Coghlan 2016). As such, AR supports the contribution of the research to solving practical problems and the generation of knowledge while dealing with the problem (Wagner et al. 2021).

The application of AR is based on four assumptions. First, it uses an empirical approach to study the resolution of an organisation's issues together with the actors who experience these issues directly. Second, it implies that the members of the system being studied participate in the research process, thereby establishing a link between the companies and researchers. Third, the aim of AR is to make the company's actions more effective while simultaneously creating empirical knowledge. Last, it is both a sequence of events and an approach to problem-solving (Coughlan and Coghlan 2016). Two further conditions had to be fulfilled so that this project could be considered AR. The research objective was determined by the researchers and the project plan was driven by the need to improve the company's PD process performance (rather than by the goal of transforming the entire PD process).

An external team was created, composed of two senior researchers with previous AR experience and one junior researcher who worked along with the company's PD team developing and implementing a framework for applying lean principles to the PD process. Furthermore, a steering committee comprised by the two external senior researchers and the head of the R&D department, and the team leader of the heat pump development department was established to design and oversee the execution of the project.

The project lasted five months and, as suggested by AR, the researchers acted as external helpers and were directly involved with, and worked alongside, members of the company's R&D department to help the team leader and PD engineers to address the main intricacies of the PD process and to implement operational solutions. This ensured that any problems and resistance encountered while developing and implementing the framework proposed could be directly overcome with the help of the researchers through iterative feedback (Coughlan and Coghlan 2016) and that all relevant data could be easily accessed. As in all AR projects, the collaboration between researchers and practitioners played a fundamental role not only in achieving the desired goals but also in generating and improving the framework (Kocher, Kaudela-Baum, and Wolf 2011). The data for this study was collected through interviews, the company's internal documents and participative workshops and observation.

We followed Coughlan and Coghlan (2016), who defend the idea that AR can be compared to a 'spiral of steps each of which is composed of a circle of planning, action and fact-finding about the result of the action.'

4. Developing and implementing a framework within PD activities

This section indicates the starting point of the AR project and of the lean framework and describes its implementation and refinement (based on the difficulties faced and the lessons learned during the implementation).

A preliminary structure of the framework was initially drawn up. It was supported by the literature and discussed in successive rounds of data collection and validation with the steering committee. This preliminary version of the lean framework consisted of five steps as shown in Figure 1: preparation; awareness; tools; actions; and implementation. In the second cycle the framework was implemented and ratified to improve the preliminary version. Several work sessions were held during this second cycle that involved workshops, training, boot camp, and brainstorming sessions, which generated feedback during the whole process that fed follow-up/validation meetings. The external researchers were always present during these sessions.

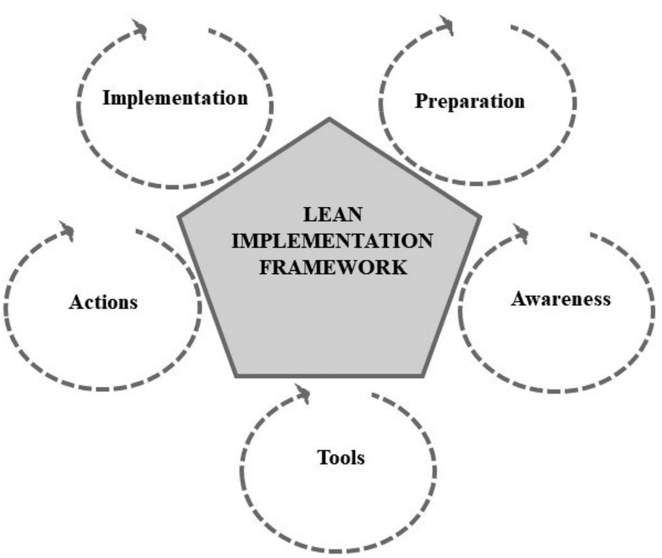

Figure 1. Lean Implementation five-step framework based on the principles of Action Research.

4.1. Preparation

The project started by setting-up the team, and during this stage, the research team identified the aspects for improvement, communication issues and the ability of the employees to react to performance and service level changes. Additionally, discussions were held regarding the communication of the evolution of the project, as well as more mundane questions related to the researchers' access to facilities, meetings rooms, materials and general conditions.

Data and information were collected through in loco observations, taking into consideration the organisation's chart, stakeholder analysis, project plan, scope and target. After analysing and discussing the information obtained, some areas for improvement were identified immediately: too much time was taken to answer e-mail requests; an imprecise understanding of a department's roles and targets; and a lack of employee support. The 'unexpected' conclusions of this preliminary analysis were presented to the head of the R&D department and to the Team Leader, in the context of the steering committee, and underpinned the subsequent actions supporting the project.

4.2. Awareness

According to Liker and Morgan (2011) and Morgan and Liker (2006), skilled and empowered employees are required to deploy lean activities effectively. Dombrowski and Zahn (2011) underline the importance of employee qualifications and motivations for such implementation, proposing activities such as workshops, kaizen activities and training in state-of-the-art technologies. Likewise, the TPDS also focus on human resources as 'knowledge workers who accumulate [...] the wisdom of experience' (Takeuchi, Osono, and Shimizu 2008, 2).

The organisation of a motivational boot camp can work as an integrator that guides the project team to a synergistic whole (Morgan and Liker 2006). This action also allows the leader to encourage employees to question the status quo (Takeuchi, Osono, and Shimizu 2008), to provide them with the resources they need, to guide them through problem-solving activities (Adler 1993). This activity is intended to develop background awareness and create a solid foundation for the project.

The motivational boot camp led by the two senior researchers was held involving all parties in the improvement process. During this two-day activity, participants were asked to discuss the core elements of lean management and the standardised methods for conducting a PD project. This activity allowed employees to develop insights into lean concepts and methodologies. One manager underlined the importance of this event as a way to become more familiar with lean concepts:

> This activity was fundamental. It represented a joint event in which we interacted and got to know each other, discussing the

> project's targets and plan. Because many concepts were unfamiliar, during those two days, it was possible to understand and become familiar with the main tools applied during the project. (Manager A)

The lean motivation boot camp proved to be a very important opportunity to interact with the project stakeholders as it enabled participants to increase their knowledge of lean through role playing and discussion sessions, which activated a better reaction to change during the development of the project on site in the following months.

4.3. Tools

Lean is closely related to learning and the various tools that transform learning processes into more efficient and effective ones (Solaimani et al. 2019). Lean philosophies are a way of thinking facilitated by practices for soft and cultural aspects, but also, for hard tools and processes (Bhasin and Burcher 2006). The contemporary lean approach implies a holistic view of people, technology and tools (Morgan and Liker 2006). The latter 'enable the people to execute and improve the process – no more and no less' (Liker and Morgan 2006, 9). Several tools can be used for individual and collective self-discovery and/or assessment (Dombrowski and Zahn 2011; Morgan and Liker 2006; Wang et al. 2011).

The literature presents a myriad of tools that can be employed for lean activities in PD (Mund, Pieterse, and Cameron 2015; Wang et al. 2011). The tools were originally presented by the research team based on an agreement between researchers, the project team leader and the R&D department manager: customers (e.g. Pareto analysis); process streamlining (e.g. capacity, value stream design and ideas workshops); performance management (e.g. cascade meetings); organisation and skills (e.g. productivity benchmarks and skills matrix); and mind-set-related behaviour (e.g. focus groups and employees' surveys). Figure 2 presents four of the tools used and some of the results obtained.

The application of these tools facilitated the analysis of aspects for improvement and the understanding of the PD process, its stages and existing wastes. This stage was a highly interactive process composed of several meetings and workshops. It started with individual meetings with each employee, in which his or her skills were assessed, and training needs identified. Next, a workshop was organised to present a tool to characterise the 'a week in the life of manager'. This tool allowed the research team to identify the time dedicated to the execution of the different daily activities carried out by each employee for one week. The results were analysed and presented to all participants. Other workshops were organised to draw the value stream maps for some of the main processes. This phase ended with a meeting between the researchers, the project team leader, and the R&D department manager to present the main outcomes and validate the results.

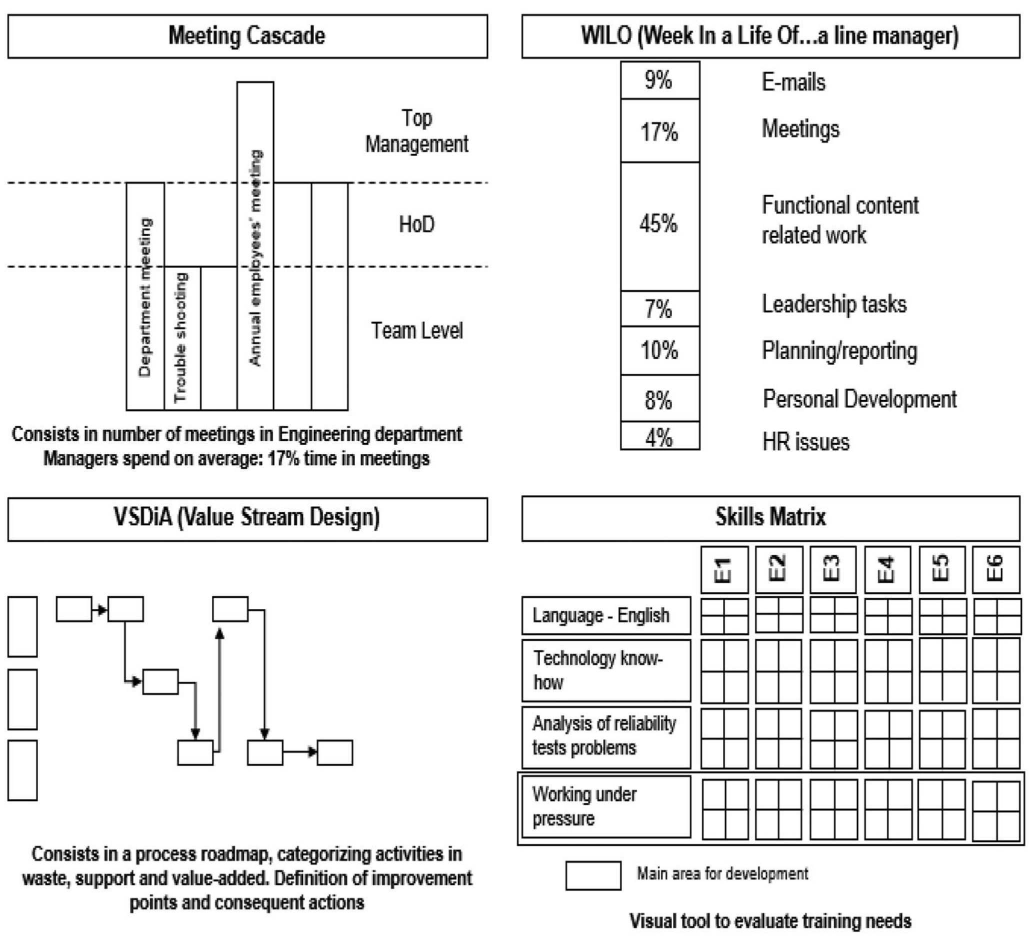

Figure 2. Tools adopted for lean activities in PD.

Table 1. Main levers (improvement points) for the R&D department.

Main lever	Negative impact	Main Results
Poor cooperation	Inefficiencies in the Engineering Department.	Low level of customer satisfaction
Incomplete tasks and work handed over incomplete	Daily tasks are not allocated based on available capacity and prioritisation.	Daily demand not fulfilled; Capacity management not in place
No control of PD projects	Inadequate key performance indicators (KPI) and lack of project control.	Delays in project delivery
Wrong allocation of capacities and lack of dialogue	Engineers performance only measured at the mid and/or long-term and no daily KPI system	Low performance; low level of employee satisfaction
Existing standards are not fully implemented or non-existent for some procedures.	Additional rework and time wasted	Capacity management not in place; low performance;
Inefficient meetings and reporting routines	Failure to achieve objectives	Capacity management not in place

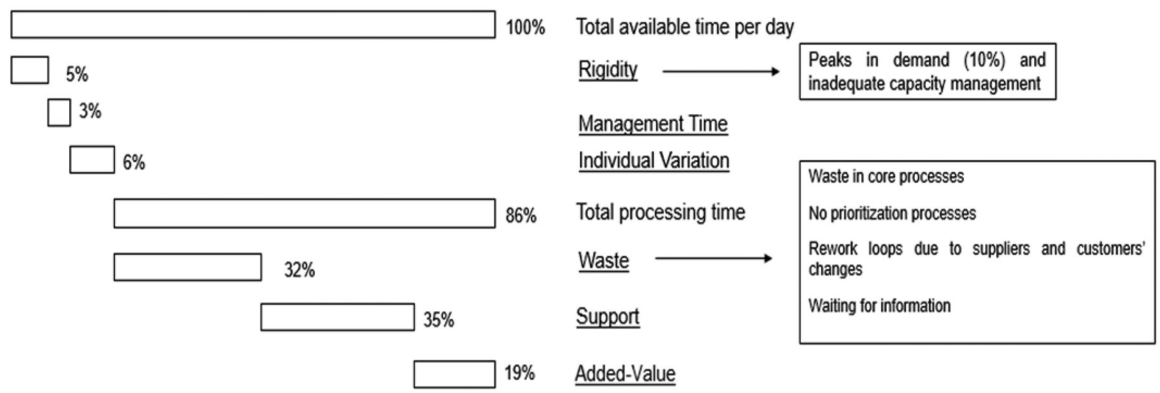

Figure 3. Employee overall efficiency.
Note: Percentage of hours devoted to each process (8h total time per day).

The application of these tools proved to be one of the most important stages in the implementation of the framework and led to the identification of the R&D department's main levers (see Table 1). This is in line with the literature as the process and tools significantly define any PD process (Varl, Duhovnik, and Tavčar 2020).

The simultaneous application of this set of lean tools also contributed to a better understanding of the inefficiencies of the PD process at that time, helping to define improvement actions. Although PD is a support functional area in which waste is not easily identified – at least, when compared to manufacturing processes – the tools used made it possible to identify several examples of existing waste. For instance, we found: overproduction (i.e. reports with too much information), unnecessary waiting (time wasted while waiting for data needed to begin and/or continue existing work), motion (time wasted going to meetings in different buildings), inventory (producing too many prototypes), defects (rework) and over-processing (detailed simulations instead of simple estimates).

This stage ended with an examination of the employee overall process efficiency (see Figure 3). An analysis of this figure shows that the waste was the result of inefficient core processes, no prioritisation of activities, rework loops due to supplier and customer changes in design and information delays – accounting for 32% of the total time available. This value exceeded the percentage of value-added time (19%). Clearly, there was room to improve added-value time and to increase the efficiency of the PD process.

4.4. Actions

Once waste and non-value-added activities were identified, the next step was to design and create an inspiring vision of a future state by planning the measures required. The focus was on defining steps for improvement and to determine who was responsible for their implementation. In lean philosophies, employees enjoy a fair amount of room for decision-making (Solaimani et al. 2019) and objectives are often organised into specific milestones, which are agreed on and their deadlines with the employees (Karlsson and Ahlstrom 1996a; Morgan and Liker 2006).

Based on the areas for improvement identified and the diagnostic tools applied, efficiency gains for each activity were established regarding each main lever, as recommended by Dombrowski and Zahn (2011). During this stage, the researchers, together with the R&D engineers, defined the layout of whiteboards (WBs), the KPIs, the tactical implementation plan (TIP) and the cascade meetings to discuss the department's future state in order to create transparency in goals, processes and performance. This enabled the team leader and the six engineers to understand the current status of the processes and identify problems easily. Throughout this activity, the researchers and team leader defined the improvement measures, and the team leader was trained by the researchers for two weeks to act as role model. Once again, the team leader had an important responsibility for the entire PD process as he is not only the project manager, but also a guide to the group of engineers and the bond that holds their activities altogether (Varl, Duhovnik, and Tavčar 2020). At the end of this stage, a meeting was held between researchers and top management to present the WB layout and define KPIs and the TIP. This ensured the commitment of the top management to the implementation of the framework within the company.

4.5. Implementation

The following stage was to develop the actions needed to achieve the desired results. The employees were given the opportunity (a) to internalise the new way of working with the researchers' support and (b) to raise their awareness on the importance of the TIP and its improvement actions to ensure gains in efficiency.

One of the researchers was systematically present working in the company's premises. The usual workday started with a whiteboard meeting (WB), during which: daily deliverables (important added-value tasks that needed to be accomplished) were analysed; an assessment of individuals' daily capacity was presented using a colour scheme (green – available; yellow – okay; red – completely full/unavailable); the team's mood was evaluated; and the difficulties in achieving the previous day's objectives were discussed. This meeting usually lasted for 15 to 30 minutes and was chaired by the researcher. It was chaired by the PD manager, at a later stage.

The researchers also participated in the sessions analysing the department's current state and in designing the desired future state. The improvement actions, organised in accordance with the key levers (see Table 2), were conducted with the researchers' support. This took place over time, in which the 'Meetings' and 'E-mail' key-levers took place in the first week to define the compliance rules for the meetings and e-mails. Afterwards, the 'Communication' key-levers were settled to define and communicate roles and responsibilities among the employees and create an R&D front helpdesk; this implementation lasted two weeks. The implementation of the remaining actions took place during the entire time span of the project. Based on the employees', managers' and researchers' joint efforts, the lean principles, methods, and tools allowed them to achieve efficiency gains as presented in Table 2, in which 'Performance management' and 'Standardisation' achieved the largest efficiency gains, 7% and 6% respectively.

At this point, the first issues regarding the implementation of the framework began to emerge. These were mostly due to the employees' difficulties in understanding the importance of prioritising and breaking down deliverables to properly plan activities in advance. The employees were very sceptical concerning the impact of the standardisation of activities, on the elimination of non-value added activities and the enforcement of standards. Other difficulties were: the mismatch between KPIs and management evaluations; the perception that lean practices require extra time and increase the workload; problems while mapping large processes; and difficulties in measuring efficiency. Two engineers initially reported:

Table 2. Improvement actions.

							Timespan (weeks)					
Key levers	Efficiency loss driver	Improvement action	Efficiency gains (%)	Total effort (h)	Responsible	Completed (y/n)	Week 1	Week 2	Week 3	Week 4	Week …	Week 20
Performance management	Lack of a daily KPI system	Define KPIs	7%									
Capacity management	Tasks not allocated based on available capacities and clear prioritisation	• Make WB six-week plan • Prioritise tasks • - Breakdown of deliverables	4%									
Communication	Inefficiencies in R&D department (i.e. capacity to react to and solve problems)	• Define and communicate roles and responsibilities • Create an R&D front help desk	3%									
Meetings	Lack of efficiency and effectiveness	Define meeting rules	2%									
E-mails	Lack of efficiency and effectiveness	Define e-mail rules	2%									
Standardisation	Existing standards not fully implemented or non-existent for some procedures	• Enforce standards • Standardise activities • Track and eliminate non-core activities	6%									

Figure 4. R&D department white board.

> Lean activities do not have an instantaneous impact on my daily work, and I do not have the capacity to plan my daily deliverables ahead of time because when I am developing a new product, most of the processes are not standardised and do not have a specific time assigned. Furthermore, KPIs do not have a direct impact on management perceptions. (Engineer A)

> Lean activities require a large chunk of my time, which makes me work extra hours to meet daily targets. Product development processes are too broad to map, and I have difficulty measuring the efficiency gains of the improvement actions or finding suitable KPIs. (Engineer B)

These issues required constant communication between engineers and managers to find a consensus. One tool that contributed to overcoming the lack of communication and time to discuss problems was the implementation of the daily WB meetings. During these meetings, the staff discussed topics such as: daily capacity, moods, current problems, KPI control, best practices, success stories and new ideas for improvements or products, increasing managers' awareness of engineers' lean implementation in PD difficulties. Figure 4 is an example of a WB showing the names of the collaborators, their daily status workload and their planned tasks for the day. Each square corresponds to a day of the week (plus an additional one for running tasks), with each task represented by a coloured post-it according to its periodicity (with task name and duration written on them).

Although the WBs were initially conducted inefficiently and with an unclear focus, they improved progressively and became a powerful tool. One engineer highlighted the WBs' importance in the implementation of the framework by saying:

> in whiteboard meetings and problem-solving sessions, we can structure our own topics and take the picture back home with us. (Engineer C)

To complement the WBs and meet the engineers' needs regarding job-related issues and inexperience or difficulties in performing tasks efficiently, several coaching sessions, sit-ins (i.e. observations of an engineer's daily process by a colleague or a researcher), training, workshops and problem-solving meetings were performed. These forms of assistance underlined how engineers had previously lacked adequate support or a willingness to discuss daily problems, shared the responsibility for functions, asked for help or planned deliverables in advance. The implementation of these improvement actions contributed actively to increasing cohesion within the R&D team. When talking about sit-ins and the coaching sessions' importance, one engineer said:

> we were not used to having sit-ins in indirect areas. Some lean tools are new for us, but they help to do more with less. (Engineer B)

Another engineer also said enthusiastically:

> I did not believe in it, but I tried it. After doing two rounds of coaching with my team members, I was converted. (Engineer E)

Several problem-solving meetings were held generating issue trees without an initial root cause. For example, during the project, the R&D department took on a new trainee,

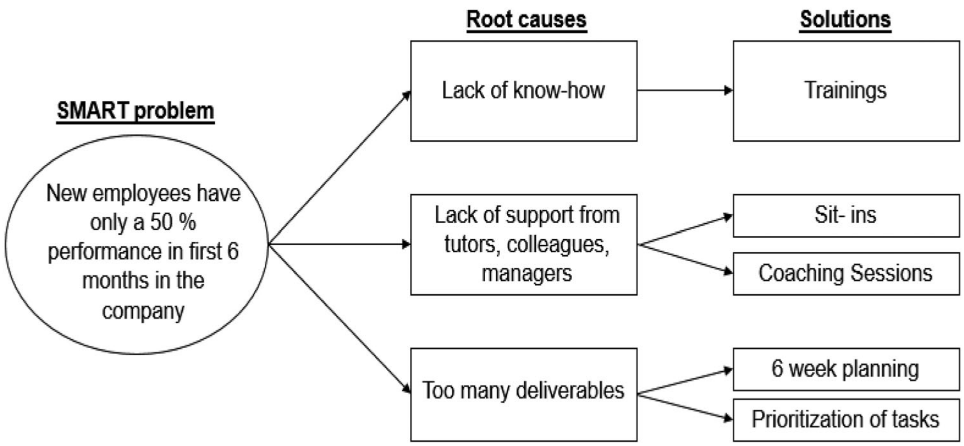

Figure 5. Issue tree of new employees' problems.

which constituted an opportunity to identify some causes of why trainees perform below expectations (see Figure 5 for the issue tree). Because problems were faced as improvement opportunities, previous issues were no longer disregarded and the problem-solving meetings contributed to finding solutions, focussing exclusively on identifying root causes and solutions. Overall, this approach meant problems were identified and discussed, resulting in a positive impact on overall efficiency and team performance.

Another tool used to implement lean in PD was a value stream design in administration (VSDiA), among several of the processes analysed. This tool helped to analyse the value flow and identify unnecessary waste. Then, the actions needed to eliminate that waste were formulated, and new value stream maps were implemented, making the processes leaner. Figure 6 gives an example of how VSDiA shortened the logistic process of the R&D samples, a process that describes the logistics involved in the sourcing of samples, from four days to one. The example below has the name of the departments involved, the tasks undertaken by each of them and the lead times from the time the sample is requested from the Production Department to its delivery to the Engineering Department.

A further important lever was the inability to react quickly to unforeseen problems. To overcome these issues, a front help desk was created, to solve communication issues and improve the speed with which requests got to the right person. This new system consisted of redirecting incoming phone calls and e-mails through a desk clerk, who had guidelines with information on engineers' products and/or appliance responsibilities. This led to faster problem solving as the technician responsible was easily identifiable.

The ineffectiveness of meetings and excessive volume of e-mails were also subjected to improvement actions to boost performance and increase the staff's focus on the PD process. A set of rules was developed for e-mail handling (e.g. determine subject, write short, well-structured emails, reread messages before sending and limit the number of receivers). Another set of guidelines was developed for meetings (e.g. invite only the relevant people, focus on the agenda, summarise decisions and distribute minutes as soon as possible). These guidelines were distributed among employees to resolve these issues, which contributed to diminishing the number of e-mails and time spent in meetings, leading simultaneously to an increased focus on development processes and face-to-face interactions. More efficient e-mail treatment and meeting management contributed to a decrease in the time wasted, leading to faster problem solving and to addressing the right people with the right information. Although these improvements may appear obvious, dealing with meetings and e-mails previously represented a large share of the total time available.

As a concluding step, a meeting was held between the researchers, team leaders, engineers and top management, to present and discuss the results achieved. The R&D team was asked to list the most important issues to be addressed. These were identified as the ability to delegate tasks, the WB as a fundamental tool to ensure lean sustainability and daily management and the changes in mindset leading to continuous improvement actions. Additional topics selected by the team were; commitment to lean transformation; cooperation with other departments; improved testing and standard operational procedures; and the implementation of a sort, set in order, shine, standardise and sustain (i.e. 5S) administrative layout.

The obstacles to the implementation of the framework in the R&D department were also discussed. The R&D team identified the need to improve the following aspects: lack of medium-to-long-term planning capacity; lack of a proper understanding of the market and customers' requirements; and the lack of shared PD success stories.

Despite these obstacles, the implementation of the framework led to several improvements and effective efficiency gains in PD processes. This was achieved in three main areas: rigid planning, management and waste. Regarding rigidity, the implementation of WB and daily meetings contributed to both better daily capacity management and an improved ability to plan, which generated gains in efficiency. The engineers' ability to manage time was improved through training, coaching sessions and sit-ins. Waste reduction showed the biggest opportunity for improvement. The main issues were waste in core processes, lack of prioritisation, reworks and time spent waiting for information. Improvement actions such as standardisation, clear identification of roles, prioritisation of activities and improved meeting efficiency brought

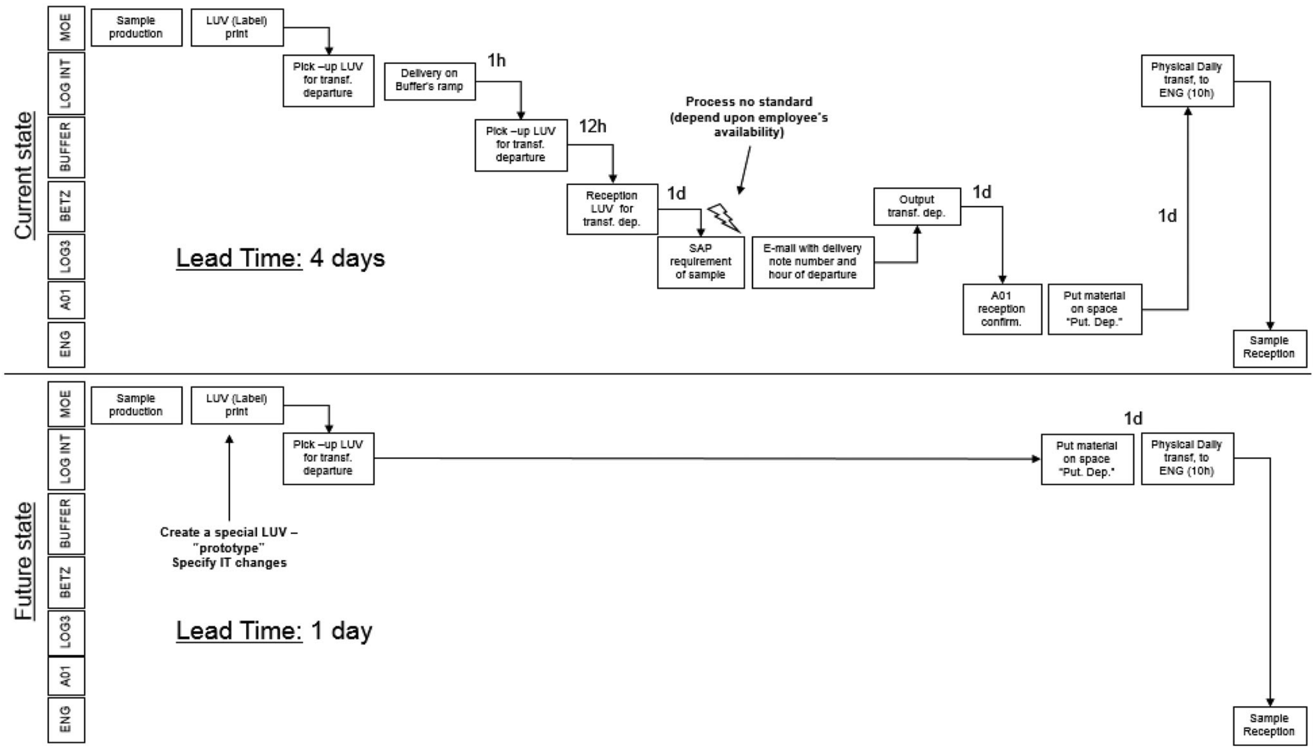

Figure 6. VSDiA example – R&D sample logistics.

important efficiency gains. Figure 7 details efficiency loss drivers, implemented solutions and the gains achieved.

Efficiency gains were achieved through a decrease of 2% in rigidity, 4% in time management and, most importantly, 20% in PD waste (i.e. process standardisation and clear roles and responsibilities).

4.6. Sustainability – a new step

After completing the implementation of the lean framework, which was mainly driven by managerial initiatives, the team started a new one. This new implementation sought to consolidate the previous results and extend the novel solutions to a wider set of products. Thus, employees were challenged to build a new TIP to address new improvement ideas or unsolved problems. During this step, employees played a new role as they were expected to act according to the new embedded lean culture, to increase performance, effectiveness, and the quality of the products.

However, it became clear to the research team that the efficiency gains were not enough to change the teamwork performance sustainably. As such, top management support and commitment was considered crucial to keep the pace of the lean transformation within the R&D team. It is necessary that both an active Kaizen culture and the presence of role models play fundamental roles in such a transformation process. The checklists presented in Table 3 were proposed by the researchers to ensure the sustainability of the framework over time. That checklist includes a description of lean activities to be conducted and their frequency.

The embodiment of the framework will only be realised when sustainability is attained, in other words, when lean practices become fully embedded in the R&D team and new work routines are created. It is expected that employees will: begin to act autonomously; carry on the improvements; measure gains; report developments; adopt a transparent and committed plan; demonstrate high levels of lean maturity; and perform the necessary actions to reach the targets. As the team leader manager claimed:

> the biggest challenge now is to continue sustaining all these initiatives as a pull system – but also to push them across the entire organisation. (Team Leader)

Managers and engineers deployed the new routines to disseminate the knowledge gathered and mature the lean elements to increase PD performance and effectiveness. Thus, the R&D staff continued to identify new ideas and opportunities. Existing processes were reviewed in the search for further improvements such as sample preparation, test plans, development of templates and other PD activities. These activities were aimed at both consolidating the results achieved and on extending the solutions to a wider set of products. The sustainability of using the new framework is about ensuring a continuous review of the methods and tools applied, motivating managers and employees to engage in a process of continuous improvement and change of mindset (striving for perfection).

5. Discussion

This section presents the discussion and improvement of the lean framework, the quality in the AR and the main conclusions of the research project from which future avenues of research are suggested.

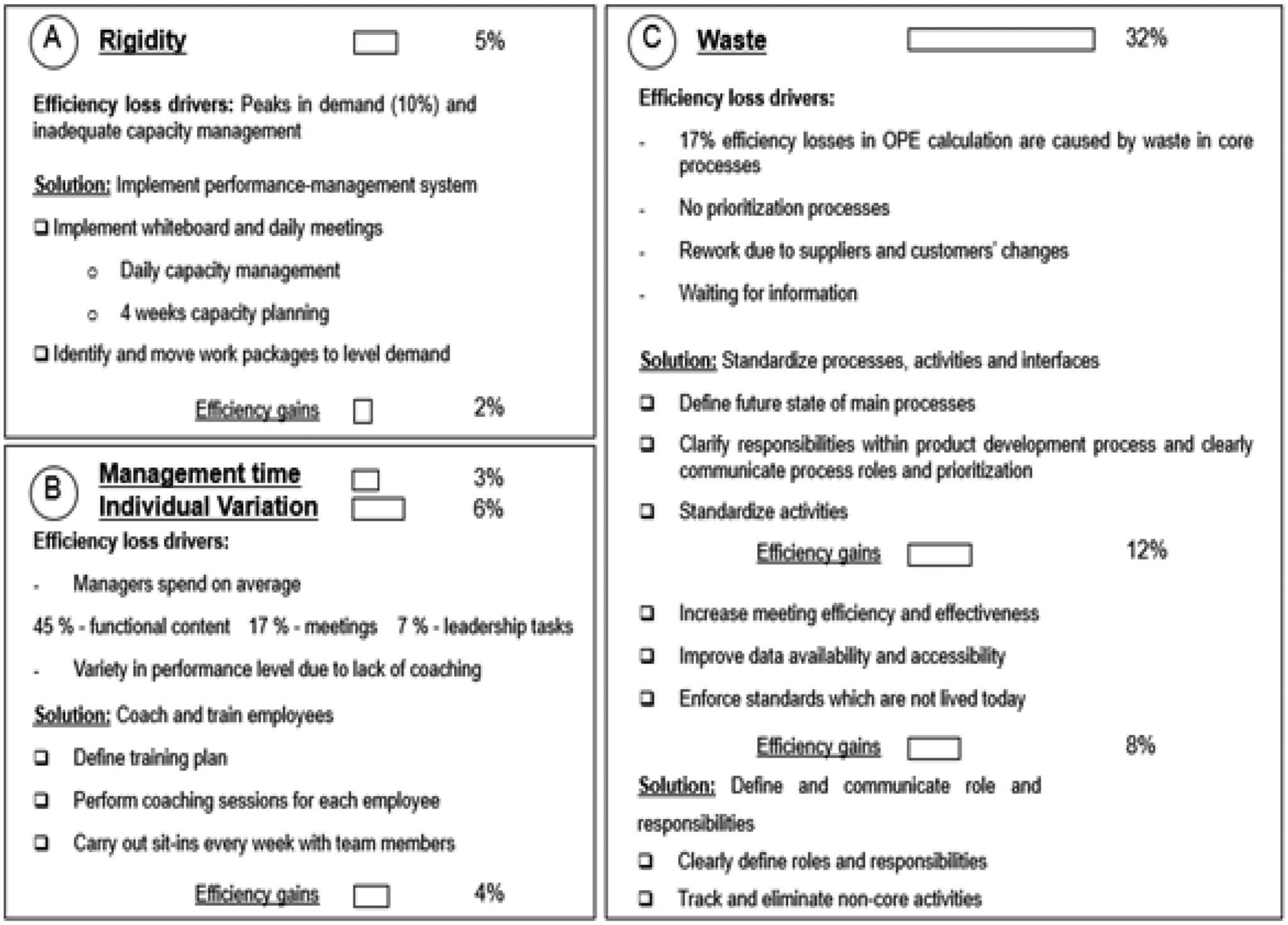

Figure 7. Framework implementation – efficiency gains and improvement actions.

Table 3. lean implementation sustainability checklist.

Lean activity	Frequency of activity
One-to-one coaching session	Weekly
Definition of targets and reports	Weekly
Performance discussions – follow up to problem-solving sessions	Bi-weekly
Gemba – attend WB meetings/sit-ins and provide feedback	Weekly
Attend problem solving meetings	Weekly
Communication about the lean management deployment within the team/department	Monthly

5.1. The importance of AR in in PD activities

The spiral of the five steps referred to above – preparation, awareness, tools, actions and implementation, which originated from the literature, led to the co-development of the framework discussed with the steering committee and the AR activities themselves. The researchers always led the AR process. The implementation of the micro-initiatives included tasks such as developing guidelines for e-mails and daily whiteboard meetings, which proved to be of highly added value regarding the implementation of the framework. Moreover, those micro-initiatives reinforced the involvement of all those who participated in the activities, contributing to the deployment of the lean principles within the R&D team. The activities that promoted this were the result of the managerial team's push for commitment to the implementation process.

After concluding the implementation of the preliminary lean framework, the researchers (as well as the R&D team) realised that although top management support was important to change the level of the team's performance sustainably, the active participation and commitment of the employees was also crucial to keep the pace of the lean transformation in the R&D team. As a result, a new step for the framework was proposed – sustainability – to guarantee that lean principles were properly internalised by the R&D team and the new work routines embodied. This reflection, stepping back from the experience already gained, supported the perspective of planning further actions to enable this action research to be much more than an everyday problem-solving approach. Therefore, we revised the original framework by proposing six steps: preparation; awareness; tools; actions; implementation; and sustainability. Figure 8 presents an overview of the framework.

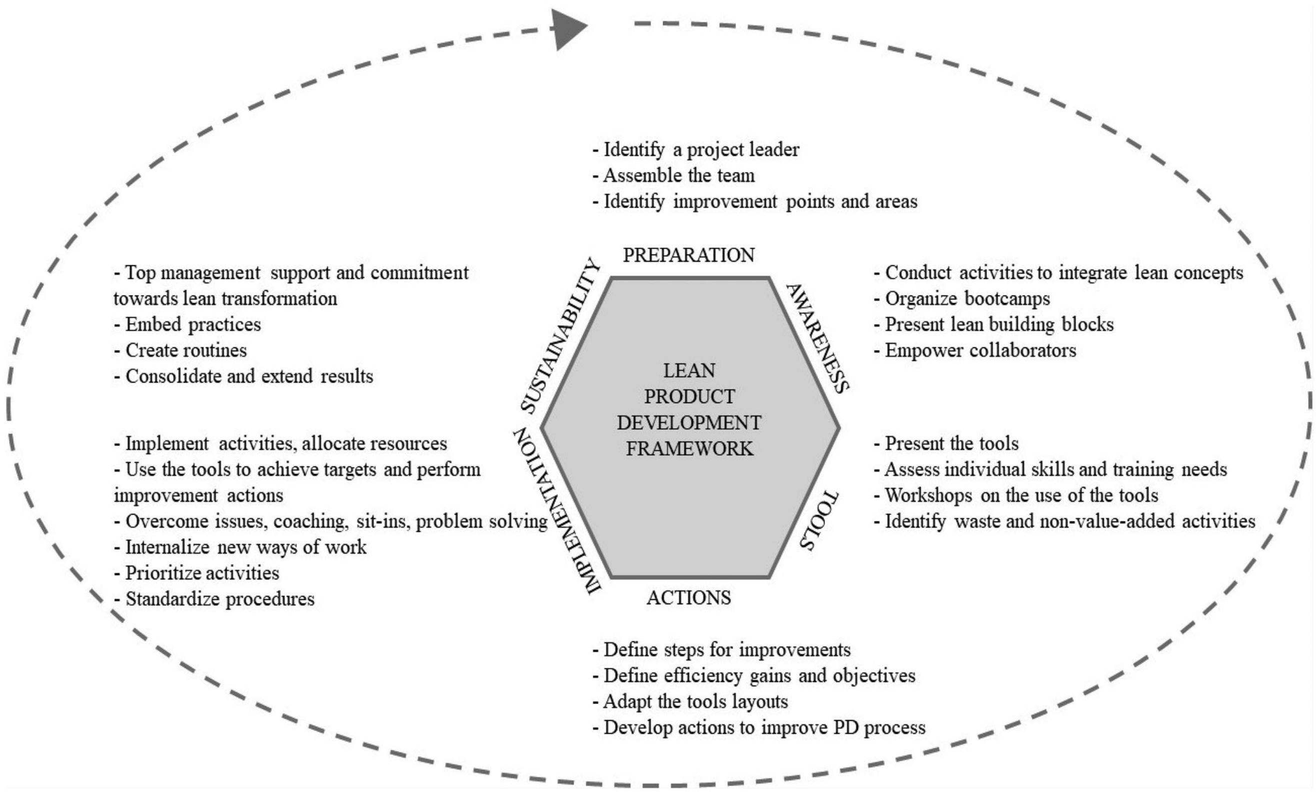

Figure 8. Framework for the application of lean principles in PD activities.

The existing literature provides descriptions of several implementation frameworks that have mostly been applied in an automotive setting. In contrast, the present framework was developed outside the context of the automotive industry, in a heating and hot water appliances company that was already familiar with lean implementation in the manufacturing shop floor. Another characteristic of previous research is that it focuses more on what should be done rather than on how to implement it (León and Farris 2011; Lermen et al. 2018).

Our results highlight three important aspects of the implementation of lean principles in product development activities: the role of lean leadership; the role of training and the implementation of lean principles adjusted to PD activities; and the importance of team building and communication.

Although not all companies have succeeded in implementing lean principles within PD activities, as previously stated, this may be due to an inadequately adapted approach, for instance, treating support PD areas as if they were manufacturing areas. In the present study, the process-based standardisation nature of LT clearly resulted in the PD professionals' initial hesitance to adopt LT. For example, an important challenge was to achieve a level of standardisation that allows engineers to eliminate waste and non-added value activities without hindering innovation.

The deployment of lean principles in PD activities was not achieved without problems. In our case, the staff's resistance to change was based on deep-rooted routines and procedures and a misconception of lean practices. Furthermore, during the implementation of the framework, employees also complained about the lack of time to plan work ahead of time and the difficulties in identifying improvement actions and obtaining short-term results. Staff also experienced difficulties reconciling lean activities with daily work, which jeopardised defining targets and efficiency gains. This is in line with Tzortzopoulos and Formoso (1999) who identified topics such as: poor communication; lack of documentation; deficient or missing information; unbalanced resource allocation; or erratic decision making as the main problems for development management.

These hurdles were overcome with the support of the researchers and increased interaction among the members of the PD team. The first challenge concerning the implementation of the framework lies in finding a project leader (Lermen et al. 2018; Boehm 2012). The team leader, with the right authority, extensive experience in PD activities and supported by the research team, played a key role in the implementation of the framework. A crucial factor was that managers with technical knowledge acted as role models by identifying priorities and problems and committing to a culture that favours change. This is in line with the literature, as leaders obtain respect by practicing what they preach (Adler 1993; Solaimani et al. 2019) and is also aligned with the literature that refers to the importance of role models and inspirational leaders (Boehm 2012; Solaimani et al. 2019).

Like the TPDS and other frameworks (Dombrowski and Zahn 2011; Liker and Morgan 2006; Morgan and Liker 2006; Wang et al. 2011), ours also highlights the role of lean tools. As such, a phase was dedicated to promoting employee knowledge of lean principles and tools adjusted to the context of PD. This resulted in an increased awareness of the principles and tools, which complemented the previous stage, and enabled the self-assessment of the PD process, leading to the identification of waste.

Previously, daily routines and problems causing inefficiencies were not discussed systematically, and best practices were not shared or implemented as standards. The daily WB meetings were crucial for engineers to gain a clear perspective on the daily deliverables expected. During these meetings, the previous day was reviewed, and issues impacting on efficiency were identified, which served as a background for future improvements. When problems were not solved promptly, they were discussed in detail later during the problem solving meetings. Another example was the regular sit-ins, which allowed for better practices to be defined and improvements in each process to be identified. During the research project a set of guidelines was developed to manage e-mails and meetings, and gains were achieved through an organisation-wide adhesion to those rules.

These are examples on how administrative tasks can be improved when standardised (Solaimani et al. 2019). The results achieved reinforce the importance of managing moving away from the 'work harder' perspective and developing the capability of 'working smarter' successfully, just as Repenning and Sterman (2001) argue. This is in line with Womack, Jones, and Roos (1990) who argue that lean tools and practices can be considered as process capability boosters as they underpin the identification and elimination of waste or non-value-added activities.

Unlike most lean implementation frameworks, we included a stage exclusively focussed on increasing LT awareness, as lean implementation is about people (Varl, Duhovnik, and Tavčar 2020). The project not only needed skilled employees but also employees willing to embrace lean practices. The lean boot camp, which contributed to teambuilding and its familiarisation with lean concepts, was recognised as being an important activity as only after a change in mind-set were the employees willing to change pre-established habits and routines (Takeuchi, Osono, and Shimizu 2008). The boot camp played a key role in the implementation of the framework as it helped to explain the meaning, importance, benefits, and critical aspects of lean principles and respective methodologies, as well as the scope of the project. Moreover, the boot camp simultaneously increased the cooperation and flow of knowledge between employees, contributing to the acceptance of lean practices. In the early stages, increased transparency was clearly the basis for improved communication among employees facilitating group discussions, which enabled more cooperation among team members (Bouas and Komorita 1996).

This framework, as with other frameworks (Karlsson and Ahlstrom 1996a; León and Farris 2011; Liker and Morgan 2006; Ward 2007; Womack, Jones, and Roos 1990), highlights the importance of leadership, tools, and communication. This is reflected on the need to have a lean leadership, supported on the concept of 'working smarter' and training, which strengthens team bonds and communication that create lean awareness, appropriately supported on the use of lean tools. This new way of working supported the employees' change of mind and behaviour that drove a momentum of continuous improvement and change, which supported not only the implementation of each step of the framework, but also self-supported the sustainability of the framework as a whole. As such, it was possible to move away from a 'working harder' principle to a 'working smarter' perspective. The eclectic and comprehensive nature of this framework provides the building blocks to improve the performance of the PD process.

5.2. Research quality in AR

Although AR is commonly used by researchers and practitioners, it has failed to generate new valid knowledge since there is a lack of reflection on the choices that are made, in relation to: contextual analysis, design, purposes, degrees of collaboration, planning, implementation, review, reflection on theory and extrapolation to a broader context (Coghlan and Shani 2005). Instead, as Coghlan and Shani (2014) argued, AR should be judged on its rigour, reflection, and relevance. Therefore, the research quality of our study is based on the following criteria (Coghlan and Shani 2014):

- The purpose and rationale – The rational for the project came from the need felt by the company to improve the PD process. The literature lacks 'recommendations' on how lean PD should be 'implemented'. The implementation of the framework can bring new and useful insights about how a manufacturing company can extend lean principles to other industrial management support functions.
- Context: This University-Industry joint project took place in an R&D department of a highly competitive international manufacturing company. Starting from the challenges the company faced, the aim of the project was to gain deeper insights about lean PD activities and how they can be implemented successfully.
- Methodology and method of inquiry: the development and implementation of the framework followed a collaborative stance during the whole project and was described in detail for each stage. Several round-up meetings were organised throughout the project to promote a common ground for all the participants concerning lean concepts and methodologies. Additionally, a steering committee was created to validate the tools implemented, and the new solution that empowered the diffusion of the lean principles within the PD activities.
- Design: The gathering and analysis of data was carried out collaboratively throughout the AR project. The research team guided the project and criteria for data collection, the analysis and interpretation were agreed upon with the head of the R&D department, and the team leader of the heat pump development department. The researchers' presence and follow-up of daily activities during the AR project contributed significantly to improving the quality of the relationships within the PD team.
- Narrative and outcomes: the story of developing and implementing the framework is told with an appropriate level of details highlighting its collaborative nature. The objective of the story presented is to capture what

happened, and the emerging need felt by the AR team to add an additional step to the lean framework.

- Reflection on the narrative in the light of the experience and the theory: the lean framework was developed collaboratively, involving the researchers, the head of the R&D department, the team leader of the heat pump development department and six full-time PD engineers. This reflection led to the recognition that persistent top management support and commitment was crucial to keep the pace of the lean transformation. The outcomes of the project were to implement lean principles within PD activities successfully, and to produce valuable and publishable academic knowledge about how they were implemented.
- Extrapolation to a broader context and the articulation of practical knowing: the outcome of the process generated insights about how to help industrial organisations implement lean principles within PD activities. The importance of relationships and their continuous improvement has been clearly described showing that the study meets action research quality criteria. The project's return on investment for the company is positive, leading to gains in the efficiency of the product development process. For the researchers, the collaboration led to good prospects of an academic publication (diffusion of knowledge).

6. Conclusions, limitations, and directions for future research

This article describes the development and implementation of a framework to apply lean principles in PD activities. An AR approach was used to co-develop the framework in product development related activities in the R&D department of an industrial company. The final version of the framework proposed is organised in six steps: preparation; awareness; tools; actions; implementation; and sustainability. The implementation of the framework led to a 20% decrease in product development waste. Additional efficiency gains were also achieved through the reduction of rigid planning and time management activities, 2% and 4%, respectively.

The main contribution of this study is that it demonstrates that lean implementation in PD activities is supported by: the role played by a knowledgeable lean project leader; employee training focussed on the implementation of lean-based product development activities; and team building and communication. Successfully implementing a lean philosophy in a product development department constitutes an exercise that should go beyond learning 'hard' lean routines (i.e. technical, and analytical tools) by also developing 'soft' routines (i.e. concerning the people and their relations, collaborative structures, lean awareness, and commitment to learning) in order to nurture the development of an appropriate lean culture, moving away from a 'working harder' to embracing a 'working smarter' perspective. The framework proposed could help companies to reach a balanced alignment between lean techniques and soft routines that are both intertwined. Additionally, the framework was developed in a context of an AR project in an industrial hot-water and heating-systems company, thereby contributing to both, first the application of AR in the field of PD management and secondly, to an extension of the application of lean principles to PD activities outside the automotive industry.

A limitation of this research is that the results were only concern this specific project. As we developed and tested the framework only in the area of heat pumps, more empirical research is required to examine its viability in different business areas and different industries. It should also be noted that our framework was implemented in a relatively small team, which favoured a close interaction with the researchers and within the team. Implementation of the framework in larger or cross-functional teams in which communication, proximity and close interactivity is not a given may pose additional challenges due to the difficulties of addressing the collaborators' needs effectively and in a timely fashion. In addition, given the eclecticism of our framework that proved that working smarter is more important than working harder, it could be adapted for use in other functional areas, such as logistics, quality or purchasing management.

Future studies could examine how the framework may be similarly adapted to the service industry. Given the present results, future studies should examine how different organisational cultural settings can affect lean implementation in product/service development activities. Furthermore, another important challenge is to assess whether the implementation of lean methodologies in product development activities can improve PD performance indicators, such as the speed to market, cost of developing the product or launching the product on time.

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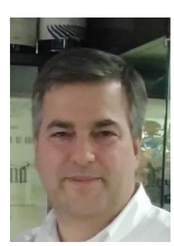

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