Universidade de Aveiro
Ano 2014

Departamento de Economia, Gestão e Engenharia Industrial

Rui Pedro Bicho Beato

Lean aplicado no desenvolvimento de produtos – Proposta de um modelo

Lean Product Development – A framework proposal

Universidade de Aveiro
Ano 2014

Departamento de Economia, Gestão e Engenharia Industrial

Rui Pedro Bicho Beato

Lean aplicado no desenvolvimento de produtos – Proposta de um modelo

Lean Product Development – A framework proposal

Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia e Gestão Industrial, realizada sob a orientação científica do Professor Doutor Joaquim Borges Gouveia, Professor Catedrático e da coorientação do Professor Doutor Luís Miguel Ferreira, Professor Auxiliar, do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro

Dedico este trabalho a uma pessoa muito especial, Gonçalo Roberto Cruz.

Júri

Presidente	Prof. Doutora Maria João Machado Pires da Rosa Professora auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro
Arguente principal	Prof. Doutor António Carrizo Moreira Professor auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro
Orientador	Prof. Doutor Joaquim Borges Gouveia Professor catedrático do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro

acknowledgements I would like to publically express my appreciations and thankfulness to some persons who, directly and indirectly, made this internship possible and contributed towards the present document, namely:

Bosch Termotecnologia, in Aveiro, for the excellent learning opportunity it gave me. My sincere appreciation to all its associates for their support and to the Lean Management team members, especially Norbert Breuer, Carolina Mesquita and Anne Sauer.

Professor Joaquim Borges Gouveia, for sharing a knowledge of a lifetime and keep always challenging me to do better, for giving me the opportunity to do an amazing internship, and last but not least, for his friendship and support through my academic course.

Professor Luís Miguel Ferreira, for the support and availability during this amazing journey and and for his valuable inputs, which allowed me to enrich this document, both in structure and content.

My football teammates, for helping me to reinforce values such as: team spirit, sacrifice, fun and unity.

My close friends, who always supported me in good times, but especially in bad times, helping me to grow and exceed expectations.

Finally, my parents for the support, help, availability, affection and encouragement, essential conditions that enabled me to be the person I am today, my brother for being a role model and supporting me throughout life and Telma, for being my ultimate support, helping me to keep the pace and strive to be better, for the great moments and joys, friendship and love.

palavras-chave Lean Product Development, PDDIS framework, Product Development Measurement

resumo

O aumento da competição internacional tem pressionado as empresas a melhorarem a performance dos seus sistemas de desenvolvimento de produtos. De forma a manter e melhorar a quota de mercado, as empresas devem produzir produtos de elevada qualidade, numa perspetiva low-cost, disponíveis no mercado no menor tempo possível. Contudo, como a sobrevivência organizacional e o crescimento a longo-prazo dependem do desenvolvimento de produtos, as empresas necessitam de um modelo que ultrapasse o paradigma de Investigação & Desenvolvimento: standardização vs criatividade/inovação, para que seja possível assegurar uma transformação da organização, com o objetivo de obter maior competitividade e flexibilidade num mercado cada vez mais volátil e exigente.

Esta é a resposta às exigências de valor acrescentado, por parte dos clientes e do mercado, através de valores fundamentais como a eficiência, a sustentabilidade e a customização.

Esta tese apresenta uma proposta de um novo modelo de Lean Product Development, que esboça resultados da sua aplicação numa organização industrial, fornecendo uma melhor compreensão de como o Lean Thinking tem impacto no processo de desenvolvimento de produtos.

key words Lean Product Development, PDDIS framework, Product Development Measurement

abstract The increased international competition in the current global market is putting pressure on companies to improve the performance of their product development systems. To sustain and improve market share, companies must produce high quality products in a low-cost perspective and make them available in the market within the shortest time possible. However, because organizational survival and long-term growth depend upon the development of products, companies are in need of a new framework that goes beyond the Research & Development paradigm: standardization vs creativity/innovation, to ensure the transformation of the enterprise to become highly competitive and flexible in today's volatile and demanding marketplace. This is a response to customers and market demands of value creation, through efficiency, sustainability and customization.

This thesis presents a proposal of a new Lean Product Development framework, which outlines results in a manufacturing company, providing better understanding on how Lean Thinking application impacts product development processes.

List of Figures

Index of Tables

Index

1. Introduction

1.1 Aim and Motivation

Nowadays, companies are being pressured by economic crisis evolving market demands, stiff global competition and the need to improve time-to market (Khan et al, 2013). In order to gain competitive advantage, companies must invest in hiring excellent professionals, boosting a knowledge based environment and developing innovative products.

Product development has been seen as a reliable source for producing cash flow into firms and sustaining the company's growth. Taking into consideration the current global situation and the ultimate need for high quality and low-cost products, available in the market within the shortest time, companies struggle to achieve a high performance level, meeting customers' needs, building an efficient R&D process.

Known mainly for its good results in the manufacturing sector, Lean Thinking is widespread among many reference industrial organizations, such as: Toyota, Bosch, Boing, BMW, etc. However, there is a growing awareness that Lean Thinking can also be applied to great effect outside manufacturing operations, to other functions and sectors, such as: 'white-collar' activities (Engineering, Product Development), examples of application in service-based enterprises are relatively rare. Although waste is more visible in manufacturing processes, there is little doubt that application of Lean principles in the service sector represents an opportunity for improvements in competitiveness (Baines et al, 2006).

Companies are changing their way of thinking business and market competition. In the current conjuncture, engineering companies have changed their focus from great investments in new technologies to maximization of value creation through better performance rates, good practices, continuous improvement and waste elimination, with a low investment. Currently, new engineering products continue to under-perform in their lead times, cost and quality (Khan et al, 2013), which compels companies to improve efficiency and flexibility of product development processes, improve performance of product development systems and focus on sustainability and continuous improvement, e.g. obtaining more with less resources. But how can companies struggle against pressures, be more efficient and have higher performance rates regarding quality, cost and delivery?

This thesis provides an overview of how lean product development is being addressed by scholars, proposing a new lean product development framework, which provides cursory evidence for the plausibility of lean thinking application in R&D processes, in a practice based perspective.

1.2 Field of application

Nowadays the global society has understood the importance of saving resources, being sustainable, cutting costs and spending the money wisely. Lean Thinking is all about this and much more. Lean concepts were derived initially from studies of the Japanese automotive industry in the late 1980's, inspired by Toyota Motor Corporation, which has become the denomination for all things lean (Al-Ashaab and Sobek II, 2013). Mostly implemented in direct areas, Lean Thinking has its main application in the manufacturing field. While waste elimination and fast production lead times are good achievements, isolated success within a manufacturing company is not sufficient to ensure long-term survival in today's turbulent economy. What is needed is a new paradigm that will take lean thinking concepts from waste elimination into value creation. In order to make a significant change in enterprise performance and saving ultimate system costs, there is a need for the entire enterprise to undergo a lean transformation (Al-Ashaab and Sobek II, 2013), focusing not only on direct areas, but also in indirect areas, characterised by non-repetitive processes and highly qualified human resources.

This thesis focuses on the R&D department, as it represents the core process of a company, responsible for sustaining and improving market share by being able to produce high-quality and innovative products in a cost-effective manner in a shorter time (Al-Ashaab and Sobek II, 2013). Unfortunately, companies continue to have a bad performance rate concerning quality, cost and delivery of their products, which affects the company's success. For this reason, R&D processes must be studied and optimized to achieve an efficient process, based on value-added activities, meeting customers' requirements.

1.3 Objectives

The aim of this thesis is to propose a new Lean Product Development framework, presenting results in a case study company, which allow a better understanding about the way lean thinking implementation is able to impact product development processes, in a practice based perspective.

1.4 Thesis Structure

Chapter 2: In this chapter, an overview of existing literature will be provided. It will focus on definitions and practices regarding Lean Thinking, conceptualizing its evolution into indirect areas, namely Lean Product Development, in order to perceive the importance of product development (PD) in a company's success, considering barriers/challenges and benefits of Lean PD, as well as existing Lean PD models. To conclude, this chapter will focus on how companies should measure their performance in Product Development processes.

Chapter 3: A comprehensive methodology of the action research process is developed, providing insights into research context and goals and explaining the Data Collection procedure. In addition, a case study company is selected, setting a preliminary theory, with the aim of establishing the company's initial state.

Chapter 4: This chapter is dedicated to the proposal of a new Lean Product Development Framework, providing empirical results of its application in a Case Study Company.

Chapter 5: This chapter will be devoted to the conclusion of this thesis. In this chapter, the contribution of the new Lean Product Development framework will be argued; the research question will be addressed, in addition to the managerial implications. The chapter will end with suggestions for further studies and limitations which can help to address the lack of evidence of Lean Product Development in companies.

2. Literature Review

Lean thinking has been a subject of research for nearly two decades, the focus of which has been on improving manufacturing processes. However, there has been comparatively less research done to apply ‘lean’ to Product Development (PD): the design process, from the concept stage to the detailed development of products and their related manufacturing processes (Khan et al, 2013). In order to find relevant literature, a number of methods were employed.

The aim of the research is to investigate the impact of the application of Lean Thinking in the product development process, collecting information about existing Lean PD models and the resulting benefits and challenges. Thus, in order to circumscribe our collection of the articles that serve as theoretical framework, we define the following conditions, as depicted in Fig. 1:

1. Only articles that had been published in the Social and Physical Sciences, Engineering and Business Management-related fields were selected because such articles are in accordance with the focus of the thesis subject. The articles were searched and obtained from the academic database Scopus.
2. The Keywords of the research were “Lean Product Development”, “Lean Product Development models”.
3. Only literature published after 2000 was adopted. The option to base the research in a recent background has to do with a lack of existing literature related with Lean Product Development.

Another technique that was employed was backtracking through the references of the relevant papers.

Literature regarding Lean Product Development has been reviewed, providing a better understanding about the evolution of Lean Thinking from direct areas (Manufacturing processes) to indirect areas (R&D processes), existing Lean Product Development models, as well as literature about product development performance.

As can be observed, in Fig. 2, scholars have been increasingly interested in exploring Lean Thinking application in product development processes.

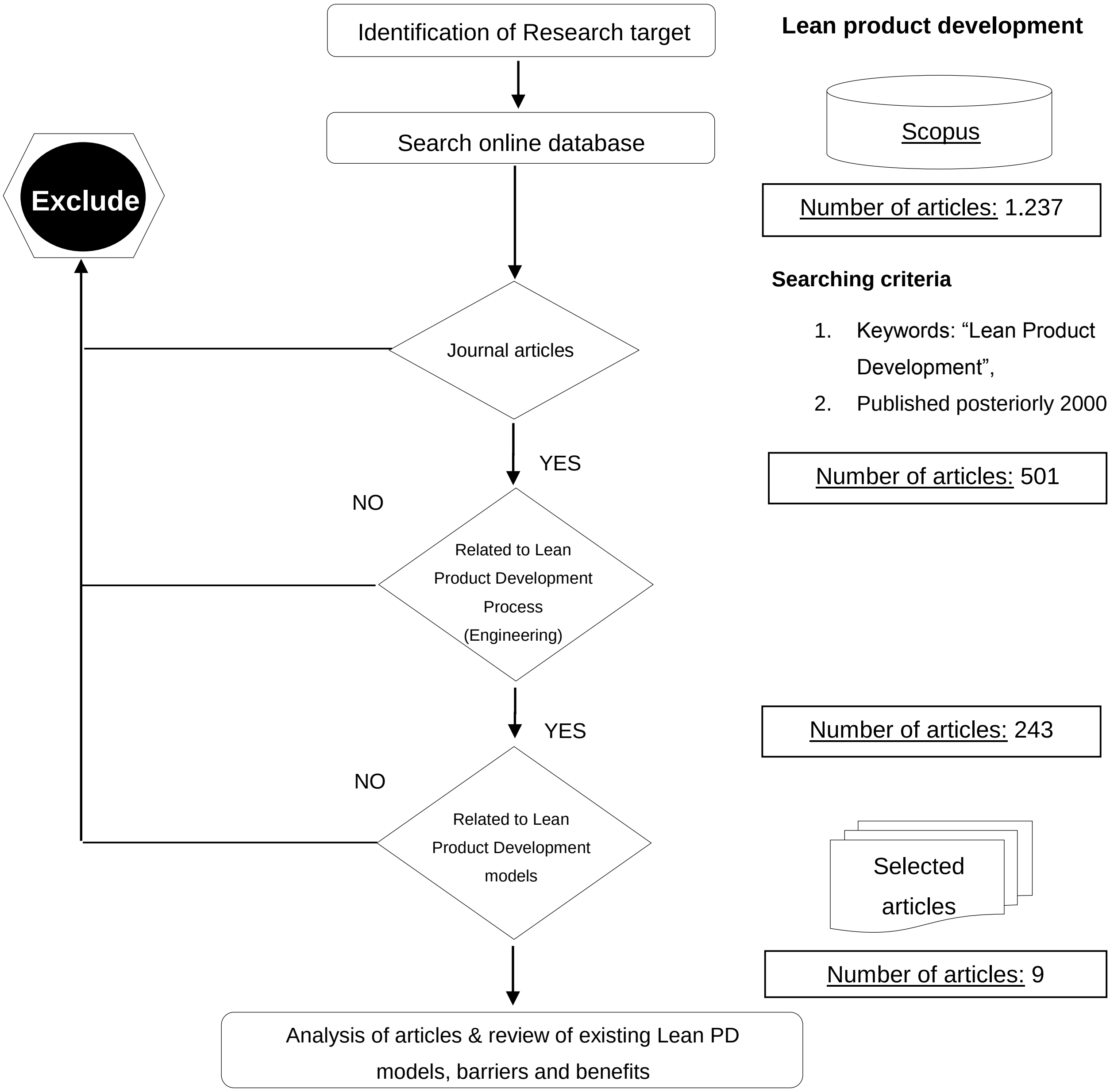


Figure 1 – Articles research methodology

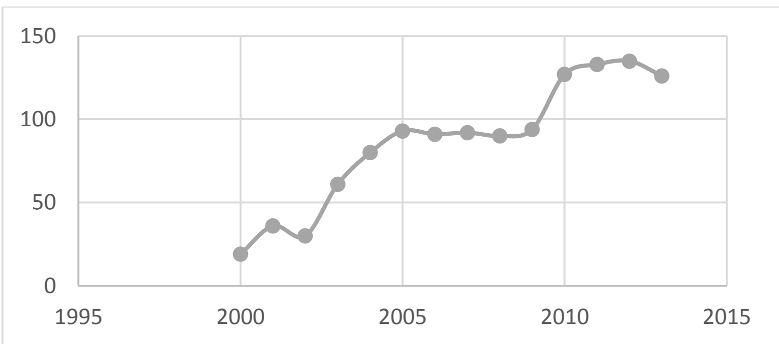


Figure 2 - Lean Product Development research evolution

2.1 Lean Thinking

Through the years, many industrialists (e.g. Henry Ford) and management thinkers (e.g. W. Edwards Deming) have been associated to the origin of the Lean Thinking concept, but only in Toyota's post Second World War manufacturing operations did it have its main impact, driven by the Japanese response to the oil crisis of 1973, where companies were compelled to use fewer resources to obtain the same or even higher quality products. Originally called "just-in-time production", Toyota Production System (TPS) was created by Toyota chief engineer, Taiichi Ohno, who introduced it first as a tool in the manufacturing process, in order to increase efficiency by reducing wastes. According to Liker and Morgan (2006), TPS is the foundation for what has become a global movement to "think lean", being represented as a house (see Fig. 3). It is represented in this way because a house is a system which is only as strong as the weakest part of the system. With a weak foundation or a weak pillar, the house is not stable, even if other parts are very strong. The parts work together to create the whole.

Figure 3 - The house of Toyota Production System (TPS)
Source: Liker and Morgan (2006)

The benefits of Lean system on performance are remarkable, in improving quality, reducing cost and expediting delivery (Lander and Liker, 2007). The term 'lean' was popularised in the seminal book 'The Machine that Changed the World' (Womack, Jones and Roos, 1990), which clearly illustrated - for the first time - the significant performance gap between the Japanese and western automotive industries. It described the key elements accounting for this superior performance as lean production - 'lean' because Japanese business methods used less of everything - human effort, capital investment, facilities, inventories and time - in manufacturing, product development, parts supply and customer relations.

Lean Thinking is an improvement philosophy which focuses on the creation of value and the elimination of waste (Khan et al, 2013). Taiichi Ohno was the first person to recognize the enormous amount of *muda* that exists in the *Gemba*, as well as recognizing that only a small portion of the daily activities can be really considered as value (Imai, 2012).
Work is a series of processes or steps starting with various inputs and raw materials and ending in a final product or service. At each process, value is added to the product (or, in the service sector, to the document or other piece of information), and then the product/service is sent to the next process. The resources at each process (people and machines), either do or do not add value. *Muda* refers to waste, any activity that does not add value. Ohno classified *muda* in the *Gemba* according to the following seven categories (Imai, 2012), represented in Fig. 4.

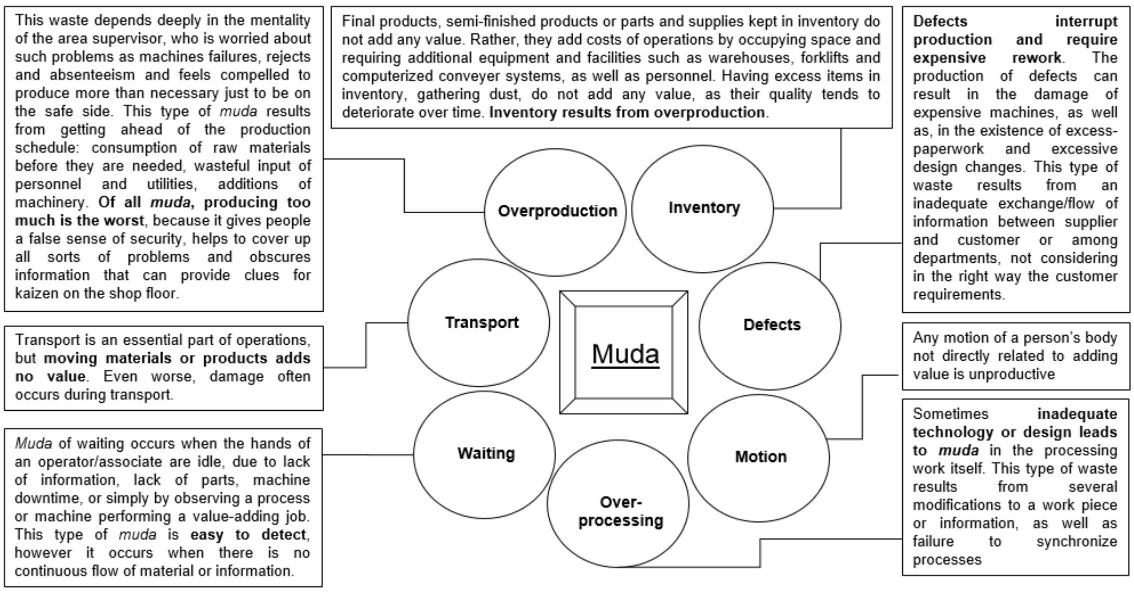


Figure 4 – 7 types of Waste

In 'Lean Thinking' (Womack and Jones, 1996), five lean principles were put forward as a framework to be used by an organization to implement lean thinking. A key initial premise is to recognize that only a small fraction of the total time and effort when producing a product or delivering a service actually adds value for the end customer. It is therefore critical to clearly define value for a specific product or service from the end customer's perspective, so that all the non-value activities - or waste - can be targeted for removal step by step (see Fig. 5).

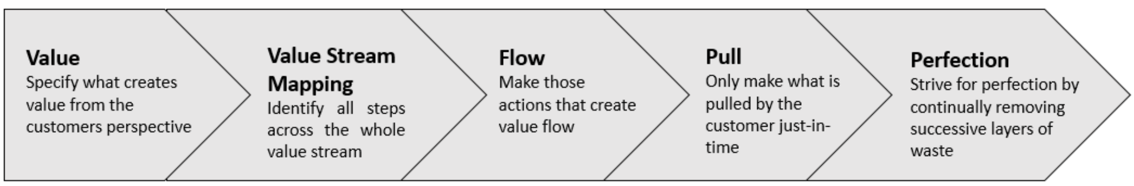


Figure 5 - The Key Lean Thinking Principles

Lean is usually understood to be relevant to the ‘operations’ of a manufacturing enterprise, meaning those processes associated with material supply, component production, and the delivery of products and services to the customer. Womack and Jones (1996) see that Lean Thinking can also be applied to great effect outside manufacturing operations. Although waste is more visible in factories, there is no doubt that the application of Lean principles in the services sector represents an opportunity for improvements in competitiveness (Baines et al, 2006).
In order to remain competitive, companies perceived the importance of ensuring an optimal transformation to a lean environment, across all areas and departments. This ‘lean initiative’ has been adopted by most manufacturing companies. Nowadays, lean thinking is spreading to a diverse range of organizations, including services (banking, marketing and insurance), healthcare, laboratories and construction. From all these sectors, knowledge-based activities such as Design, Engineering and Product Development (PD) are the areas within a company where the potential benefits from the adoption of lean principles may be significant (Baines et al, 2006).

2.2 Product Development Process

The increase in international competition in the current open global market is putting pressure on companies to improve the performance of their product development systems. To sustain and improve market share, companies must produce high-quality products in a cost-effective manner, in a shorter time period. However, because organizational survival and long-term growth increasingly depend upon the introduction and development of new products (Al-shaab and Sobek II, 2013), it is fundamental to comprehend all the stages of the Product Development process, depicted in Fig. 6.

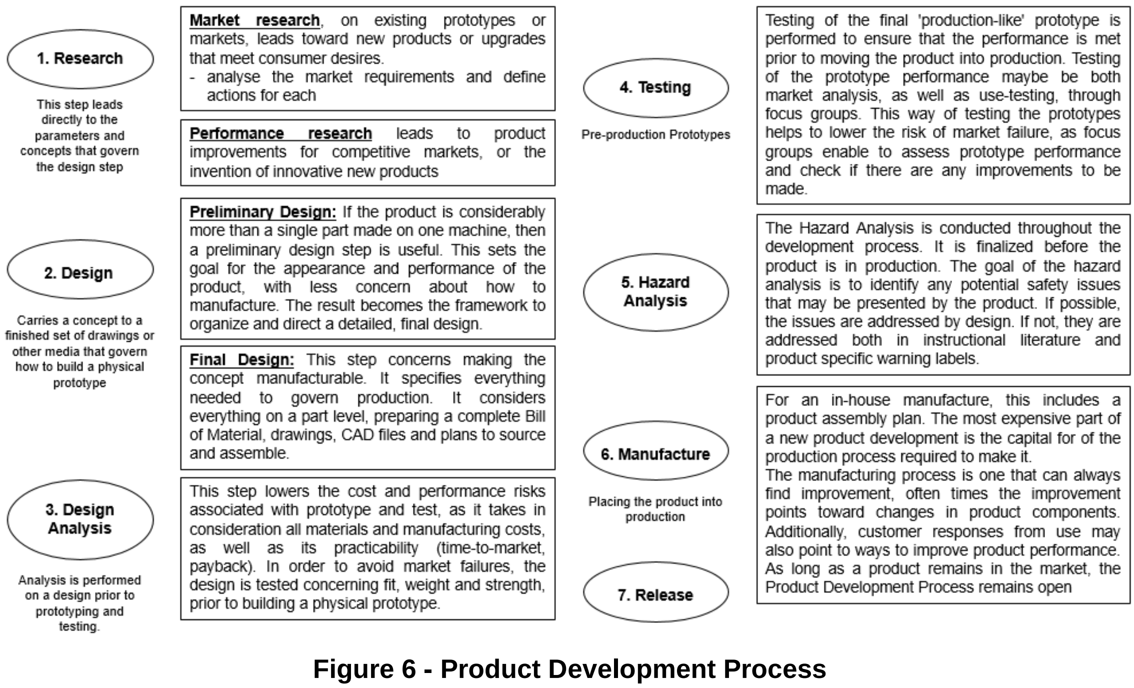


Figure 6 - Product Development Process
Source: http://www.kridleytech.com/Prodev.htm

2.3 Lean Product Development Definition

Lean Product Development (PD) is an emerging topic (Baines et al, 2006), which appeared from companies' needs to struggle against fierce competition and uncertainty. Nowadays, new product introduction and development is the most critical activity for a firm to achieve in order to sustain competitive advantage. Therefore, the interest in achieving improvements in the product design and development process has considerably increased in the last decade (Sorli et al, 2010). Because there are differences in culture and philosophy among enterprises, as well as product and branch specific peculiarities, it is not practical to define a universal Lean PD concept to fit every enterprise (Dombrowski and Zahn, 2011), as shown in Table 1.

Author	Definition
Al-shaab and Sobek II, 2013	Lean Product Development concerns the application of Lean Thinking to the early stages of the product life cycle, from initial concept through start of full production or delivery to the client
Khan et al, 2013	The term lean product development (PD) has been understood to mean lean manufacturing applied to PD, while the roots of lean PD – just like lean manufacturing – go back to Toyota.
Liker and Morgan, 2006	A knowledge work job-shop, which a company can continuously improve by using adapted tools used in repetitive manufacturing processes to eliminate waste and synchronize cross-functional activities
Ringen and Holtskog, 2011	Lean Product Development is the collective activities, or system, that a company uses to convert its technology and ideas into a stream of products that meet the needs of customers and the strategic goals of the company, it clearly includes motivation among the people involved to fully achieve ambitions
Sorli et al, 2010	Application of lean thinking concepts in all the stages of new product design and development, in order to enhance process's performance and subsequently, provide efficiency in the new product introduction.

Table 1 - Lean Product Development definitions

Regarding the definitions presented in table 1, it is possible to delineate a common conducting definition of Lean Product Development. This new concept has its roots in Toyota Production System (TPS), like Lean Thinking and Lean Manufacturing. This common route and principles are adapted to all stages of the product development process, from design to full production or delivery to end-customer, in order to convert creativity, innovation, technology and ideas into an efficient stream of products that meet customers' needs and the company's strategy, by standardizing processes, eliminating wastes and maximizing people's contributions. Although Lean Product Development seems easy to implement in a random product development process by copying Lean Thinking principles successfully applied to manufacturing processes, both are very different, which makes it fundamental to identify differences between Lean PD and Lean Manufacturing.

2.4 Lean manufacturing vs Lean Product Development

Nowadays, regardless of the origin, the value of the Lean paradigm (focus on activities that are of service to the customer and, whenever possible, reduce waste of materials, time and motion) to the success of manufacturing is now unquestionable (Baines et al, 2006). On the contrary, Lean Product Development is now being addressed as a common topic among all companies, in an attempt to strive against market pressures and customers' demands for high quality, low-cost and innovative products. In order to differentiate both paradigms, Table 2 represents a summary of Lean PD and Lean Manufacturing differences.

Topic	Lean Manufacturing	Lean Product Development
Implementation in companies	Spread among companies around the world	R&D Lean is now taking its first "baby steps", without many onsite research applications
People	Low qualified people (workforce)	High qualified people (engineers)
Variability	Must be eliminated in the manufacturing processes, because it leads to deviations and quality issues	Is a key concept, as it is the driving force in developing new products; The focus in PD is all about distinguishing bad (standardize) and good variability (added-value)
Area of application	Direct areas (repetitive processes)	Indirect areas (non-repetitive processes)
Standardization	Manufacturing processes must be repeated exhaustively/standardized, without any deviations, creating value and eliminating wastes	Developing a new product is a conjunct of processes that can be either variable or standard (creativity vs standardization)
Time-bounded	Bounded rigorously by a defined start and finish line	Not time-bounded, which means there is always a constant interaction with the customers, in order to meet their needs.
Types of waste	Over production: consumption of raw materials before they are needed, wasteful input of personnel and utilities Transportation: all sorts of transport (trucks, forklifts, conveyers) Waiting: when the hands of an operator are idle Inventory: stocking items not immediately needed Motion: any motion of a person's body not directly related to adding value, not working according to work standards Over processing: inadequate technology, design leads, unproductive striking, deburring Defects: rework, machine rejects, damage of expensive jigs or machines **Imai (2012)**	Over production: extra analysis and studies, too much information, unnecessary stages such as prototypes Transportation: flow of information and information sharing, ineffective communication Waiting: delay due to approval or testing Inventory: redundant, stoppage in information and data system Motion: wrong flow of information to people, seeking for unessential approval Over processing: unnecessary analysis and circulation of wrong decisions and out of place information Defects: failure in tests, inaccurate data and warranty costs **Womack and Jones (2003)**

Table 2- Lean Manufacturing vs Lean Product Development

In presenting the differences between Lean Product Development and Lean Manufacturing, it is possible to conclude that both are almost each other's opposite, since Lean PD is characterised by a non-repetitive and non-sequential processes, where variability (creativity) and standardization must be coordinated, in order to build an efficient process of innovative product development into effect. On the contrary, Lean Manufacturing considers repetitive processes, which must be standardized and performed exhaustively, without deviations and subsequent quality issues. Lean Manufacturing can be defined in simple terms as producing exactly what is needed, when it is needed, with the minimum amount of resource and space (Al-Shaab and Sobek II, 2013). As it is possible to perceive in Table 2, waste is more visible in factories, rather than in R&D, which enables an easier implementation of Lean Thinking principles. Although there are many differences, both paradigms derive from Lean Thinking, which is applied in different contexts and sectors, focusing on the creation of value and waste elimination.

2.5 Lean PD models

Even though Lean thinking application in product development processes is taking its first 'baby steps', some scholars have proposed Lean Product Development models that go beyond lean manufacturing, in an attempt to ensure a lean design and development, transposing the enterprise culture to a lean environment, based on a "LeanPPD paradigm". This paradigm proposes the move from waste elimination to value creation, which is the result of the application of lean thinking in product design and development, by providing knowledge based user-centric design and a development environment to support value creation for the customers, in terms of innovation, customization and quality, creating sustainable and affordable products (Sorli et al, 2010).

To enrich this thesis, literature about existing Lean Product Development models has been reviewed, as well as Toyota Product Development System (TPDS), in this way generating the creation of background awareness, by presenting interesting research papers that contribute to the understanding of Lean PD.

Sorli et al (2010): 'Applying Lean Thinking concepts to New Product Development'

According to Sorli et al (2010), new product introduction and development is the most critical activity for the firm to achieve and to sustain a competitive advantage in the current environment of continuous change and uncertainty. The authors provide some insights about new emerging trends such as: Lean Design and Development and Lean Innovation. In order to produce affordable and sustainable products,   effective lean design and engineering is required. The reason why products continue to under-perform is raised by the authors as the lack of a framework, which ensures the adoption of lean thinking throughout the entire product life cycle, right from the design and development stage. Thus, the authors of this research paper propose a new model that goes beyond lean manufacturing to ensure a lean design and development transposing the enterprise to a lean environment. To this end, in Fig. 7, the research steps to implement the proposed model are presented.

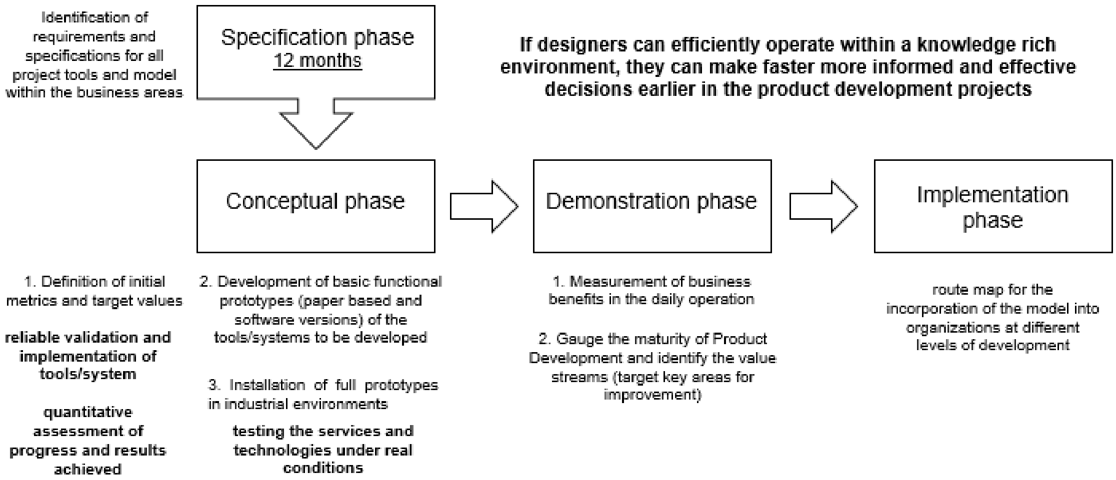


Figure 7 - Lean PD model stages

Additionally, Sorli et al (2006) describe four main tools: lean self-assessment tool, product development value mapping tool, knowledge-based engineering tool and set-based lean design tool, applied along the stages of the proposed model (Fig. 7), described below.

Lean PPD Self-Assessment Tool

Represents a method that provides a picture of current industry practices concerning lean application in the Product Development process and that is capable of guiding it towards the desired maturity level. This tool helps managers to track and measure the lean implementation progress in the product development process.

Lean PPD Value mapping tool

Represents a process-architecture able to provide an opportunity for assessing and managing relationships between individual processes, as well as searching for value activities and types of waste.

Lean PPD Knowledge Based Engineering Tool

Lean Product Development takes place in a knowledge-based (KB) environment. Product development activities must be formalised and structured in such a way that any engineering decisions taken are based on proven knowledge and experience. This tool represents a knowledge-based engineering architecture, to support the development of two knowledge-based systems:

- a System Architecture Reference Model (KB Eng), which enables a lean development process and lean product designs, in order to support a range of product life cycle engineering applications such as costing Design for Manufacture and Assembly (DFMA)
- a Knowledge-based environment (KB Env), which will capture previous projects to be one of the main sources of knowledge to define a set of conceptual designs of a new product.

The aim is to identify the wastes within the above mentioned activities and enhance the value adding elements, which will aid value creation in product design.

Set-Based Lean Design Tool

This tool aims to integrate the Set-Based Concurrent Engineering (SBCE) principles, in order to trade-off among the different concept designs based on the value of lean principles. These lean features are to be identified, extracted and inspired from lean tools, e.g. Poka-Yoka, Single-Minute Exchange of Die (SMED), Quality Cost Operations (QCO) and others, adopted from lean manufacturing applications.

Finally, according to the authors, research has made little progress in addressing lean aspects of the product and process development, not focusing on topics such as: applications of knowledge-based engineering, solutions of product development value mapping and definition of a route by which lean thinking could be incorporated into existing product design and development in different sectors.

Dombrowski and Zahn (2011): 'Design of a Lean Development Framework'

With this research, the authors aim to present a framework, which can be used as a basis to develop enterprise-specific Lean Development-concept. According to Dombrowski and Zahn (2011), in today's business environment, many enterprises react to changing conditions by implementing Lean development (LD), which offers an approach to eliminate waste, achieve high quality, and reduce the time-to-market.

In order to support the comprehension of the framework proposed, the authors provide the structure of the framework (see Fig. 8), which is grouped into seven principles.

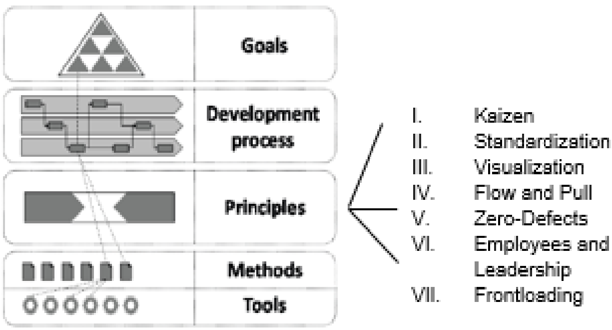


Figure 8 - Lean Development framework structure

Lean Development Framework Principles

I. Kaizen

The core concept of Lean Development is the continuous improvement process (CIP) to pursue perfection and is conveyed in the constant “change for the better”. Kaizen is used to systematically detect and eliminate waste according to the Plan-Do-Check-Act cycle (or PDCA).

II. Standardization

Ambiguous definitions of processes, responsibilities, and working methods lead to improvisation and ineffective actions. Standardization reduces these discrepancies, makes work easier and provides security. Standards should always be seen as temporary rule, which is the basis for Kaizen.

Process standardization requires the description of the phases and tasks of the development processes, as well as standardized procedures for each phase and task, defining roles and responsibilities.

III. Visualization

Visualization makes information about work flow and work outcome visible. The objective of visualization is to create transparency regarding goals, processes and performances, to enable employees and managers to observe the status from current processes easily (e.g., Key Performance Indicators, Andon-Boards, Whiteboards, etc) and to make problems noticeable (e.g. Value-Stream Mapping).

IV. Flow and Pull

The goal of the flow and pull principle is to create a process with a fast, continuous, and steady flow of information across all value streams, without waste, costumer-oriented, which means to deliver only what the internal customer orders (Pull). To achieve this, and to continuously reduce the time-to-market, the development process must be synchronized. Therefore each step in the development process needs to be scheduled and the whole process needs to be divided into uniform working phases (rhythm, ‘takt’ time). Afterwards, the working contents should be harmonized (workload levelling), so that every working phase has the same working content. In this way the duration of working phases will be continuously reduced without altering the working contents (One-Piece-Flow). Project teams and departments meet after every working phase for horizontal and vertical communication and to review completed contents and discuss upcoming phases (scrum/agile). If it becomes apparent that a working phase cannot be completed on time, actions will be taken immediately to mediate the problem. To do this, multi-project monitoring, which controls the progress, capacity, and timing of projects is approved.

V. Zero-Defects

Errors happen in every working process. However, it is important to deal with them, in order to avoid project-aborts or any unplanned rework. To achieve this, a requirements engineering (RE) is recommended. RE transfers the positive and negative responses of external and internal customers into requirements and manages them in the entire development process. Methods of the RE can be the Kano-Model, Quality Function Deployment, Target Definition Matrix, Design for Assembly, Design for Logistics, and Design for Lean Production. Besides the RE, employees should be enabled to identify and eliminate errors by themselves (decentralized quality assurance measures). To achieve this, quality assurance methods, e.g. Failure Model and Effects Analysis (FMEA) and Design Review Based on Failure Mode (DRBFM) are embedded in the standard development process and a rapid prototyping (e.g. with computer models, digital mock ups) and early testing are strongly recommended. This encompasses testing of unfinished products in early stages with digital media, simulations, testing programs, and the testing of the production processes with cardboard engineering. Furthermore, to enable a self-control mechanism, employees are provided with tools (e.g. check lists, questionnaires, trade-off-curves) that reflect specific customer needs concerning the employees' specific jobs.

Finally, another objective of the zero defect principle is preventing the transfer of errors to subsequent process steps or projects, through enterprise-specific procedures that systematically identify the source of errors.

VI. Employees and Leadership

The goal of the employees and leadership principle is to increase motivation and qualification of all employees. To participate in the motivation and qualification, a lean-culture is recommended. Cultural aspects include:

- A problem-solving-culture where employees are encouraged to identify errors;
- A no-blame-culture which assumes that mistakes occur because of systematic error and not intentionally;
- A culture of a serving-leadership, which includes the understanding that employees spend the most time with their work, so they know best how to improve it.

The duty of managers is to set targets, support and motivate employees to reach the targets, not to solve the problems.

This principle also includes methods of employee qualification. The bases for this are job descriptions and employee qualification profiles (e.g. skills matrix). From the comparison of both, substitute-rules and training-programs (e.g. job-rotation, education course) are deduced. In addition, workshops to get a better understanding of the customer needs or to do Kaizen activities, as well as trainings in state of the art technology are regulated.

New employees should receive theoretical and practical training (on the job training) as well as internships in production, sales and with some customers, to get a deep understanding of the customer needs. Along with lean-culture and qualifications, employee motivation is vital in Lean Product Development. This motivation leads to optimal usage and the enhancement of abilities and productivity of employees. Flexible work times or management-standards are one means of increasing employee motivation, as long as the management sticks to their own rules. These standards can include scheduled feedback meetings, a code of conduct for meetings, or a code of conduct for the flow of information (e.g. handling emails).

VII. <u>Frontloading</u>

The frontloading principle addresses the circumstance that in development, as opposed to production, individual solutions are required. The frontloading principle describes the effort to think through the process as far as possible in the very early stages, in order to avoid problems or rework. Frontloading happens at the beginning of the design phase, before expensive industrial engineering takes place. In order to think through problems in the early stages, a very detailed product concept (e.g. technology, interfaces, carry-over parts), as well as a product vision (e.g. patent planning, product specifications, design, technical properties, release engineering) are developed. The objective of the documents is to define all relevant customer needs (but not give any solution) and also to be the basis for every discussion during the development process. While working on parallel design-sets, decisions are delayed until they are necessary for the next process step ("delay decision") and will be made when objective data are available to support the decision ("decision on facts"). Once made, decisions may not be revised.

Another part of frontloading is complexity management. Complexity management encompasses the reuse of modules and parts in order to reduce complexity. For new products, standardized methods should be used to avoid complexity (e.g. predetermined reuse-KPI, postponement strategy, variant modes and effects analysis, costs of variants, lifecycle analyses). For already completed products, the diversity of variants and their possible combinations are surveyed together with the marketing and sales.

The presented framework was validated in a project with an enterprise of the automotive industry. The framework and the detailed description of some methods gave the top-management an excellent and structured overview of the concept. Based on the framework, the enterprise developed their enterprise-specific Lean Design (LD)-concept. Although the LD-framework gives an answer to the possible content of LD, concepts for the configuration, planning, and controlling of the LD-implementation were lacking. Further research in these subjects is needed to support enterprises working to improve efficiency, effectiveness, and increase the capabilities of the employees and the organization with a LD-concept.

Khan et al (2013): 'Towards lean product and process development'

According to Khan et al (2013), 'room for creativity' has the greatest influence on the profitability of any product, by its subsequent unstructured approach in traditional product design. With this research, scholars have proposed a framework (Fig. 9), which provides a foundation for the building blocks of Lean PD, as well as providing understanding on how lean PD could help companies to improve their product development process. Then, the authors differentiate Lean PD from Toyota Product Development System (TPDS) and Lean Manufacturing, by saying *'when you try to apply manufacturing principles and mechanisms to PD, there are a number of inconsistencies: the output value is not a physical product received by a customer, eliminating* *waste does not identify poor quality, and value stream mapping (VSM) is based on the assumption that you have already got all the required value-adding steps in your process'*, providing a definition of Lean PD: It must be a dynamic system that is always improving and responding to the challenges PD faces, not constrained to Toyota practices.

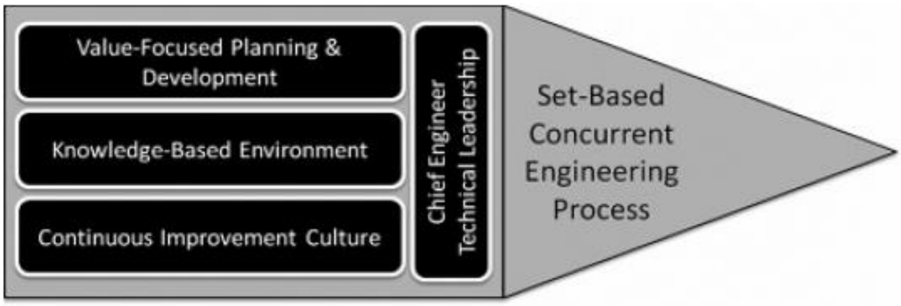


Figure 9 - The conceptual lean PPD model

1. Set-Based Concurrent Engineering process (SBCE)

Systems engineers and development managers are all too familiar with the frustration of seeing development teams revisit decisions made earlier in their projects and wincing at the ripple effects of violated assumptions, associated design changes, reworked plans, analyses and designs they know are coming as a result. To avoid rework, a new framework was developed: set-based concurrent engineering. This approach begins by considering 'sets of possible solutions' and then narrowing down the solutions by eliminating the weaker ones.

The SBCE process is practiced by designers by reasoning, developing and communicating about sets of solutions in parallel. As the design progresses, they gradually narrow their respective sets of solutions, based on the knowledge gained. As they narrow, they commit to staying within the sets so that others can rely on their communication.

This method comprises a number of characteristics such as exploring multiple alternatives, delaying specification, minimal constraint policy ('delayed commitment'), extensive prototyping (or simulation) and convergence upon the optimum design.

The Set-Based Concurrent Engineering process is characterised by many enablers such as: PD integration/target events (unique design reviews used to guide the set-based process), focus on inter-locking key suppliers (empowering suppliers to develop their own set-based approach can enable reduced supplier tracking and provide more room for innovation), mistake proofing (Poka Yoke), early problem solving (considering potential action scenarios to ensure conceptual robustness and designing in quality), design structures plan and test-to-failure (prototypes are tested to breaking point).

2. Chief engineer (entrepreneurial) technical leadership

In order to guarantee a lean transformation, it is fundamental to have a strong Chief Engineer technical leadership. The technical leader is involved prior to conception and remains at the helm throughout the entire PD process. The Chief Engineer (CE) follows a shared company vision and is responsible for the production of a design concept document, which is used to communicate the vision for the product system.

A successful CE is sometimes referred to as a 'heavyweight project manager' who has proven engineering excellence, leadership skills to control the programme, and who acts as the critical link between engineering and customer satisfaction (Liker and Morgan, 2006).

3. Value-focused planning and development

Understanding the concept of value-focused plan is very important, because customers are only willing to pay for the product itself. During all stages of product development there are many wastes that can be reduced or even eliminated if engineering teams use tools such as Value-Stream Mapping (VSM) or Value-Stream Design (VSD). Through these tools we can map all processes and find what brings added-value, what is support and what is considered waste and needs to be eliminated.

4. Knowledge-based environment

Product development activities must be formalised and structured in such a way that any engineering decisions taken are based on proven knowledge and experience. It is fundamental to create a knowledge-based environment, in order to ensure that knowledge flows and is received in the right place at the right time. Having a shared knowledge among the engineering teams allows a better focus on design alternatives, ensuring knowledge is pulled by upstream processes as opposed to pushed by downstream processes.

In order to capture, represent and communicate knowledge to support the KB environment, there are some important mechanisms/enablers that include: trade-off curves, check sheets, technical design standards and rules, and A3 single-sheet knowledge representations, which are primarily used for problem solving. These methods collectively provide a means for rapid communication and comprehension. Digital engineering including CAD, CAM, CAE and other simulation software also support the KB environment. A learning organization culture wherein employees are rewarded and appreciated for their technical contribution is another echoed enabler. Junior employees are mentored by senior employees who train their students on how to approach technical problems in addition to passing on a wealth of tacit knowledge. Learning cycles such as plan-do-check-act (PDCA) and look-ask-model-discuss-act (LAMDA) represent the general problem solving approach. This collaboration sustains an expert workforce which is empowered to make decisions and do their own responsibility-based planning.

Another enabler is a KB engineering system, also known as a 'know-how' database. The KB engineering system captures knowledge in a centralized database, with the capability to locate and extract required information easily. Finally, in order to keep the pace and continuously improve, another frequently employed technique is a lessons learnt process wherein experiences are reflected upon and captured in the KB engineering system.

5. Continuous improvement (Kaizen) culture

The dictionary defines kaizen as “continuous improvement of working practices, personal efficiency, as a business philosophy”. In Japanese, kaizen means “continuous improvement”. The word implies improvement that involves everyone (managers and workers) and entails relatively little expense.

A culture for continuous improvement (Kaizen) emphasizes human efforts, morale, communication, training, teamwork, involvement and self-discipline – a common-sense, low-cost approach used in the product development process to standardize processes, skills and design methods.

This article presents an investigation of five engineering enterprises undertaken to search for evidence of the implementation of Lean PD enablers through observation, document analysis and interviews. These included the following:

- One aerospace company that designs and makes engines for a number of sectors;
- One automotive original equipment manufacturer company;
- Two automotive first tier supplier companies;
- One home appliances original equipment manufacturer company.

All of the companies faced a variety of challenges in PD, including barriers to innovation, late design changes, communication issues and knowledge-related problems, as well as resource restrictions, mainly due to economical factors.

Initial interaction with industry involved various discussions, through virtual web-based meetings, face-to-face meetings and location visits, which allowed researchers to observe Product Development processes, in order to understand industrial needs and to ensure an industrial-driven approach to the research. To complement this interaction, a questionnaire was used to guide the explorative study through individual interviews, regarding the following topics: Role in organization, Years of experience and Incorrect responses. With this questionnaire, researchers asked some important questions regarding enablers' implementation, depicted below:

(1) Do you have flexibility in how you do your job?
(2) Is there a technical leader who is responsible for the entire development of a product from concept to launch?
(3) Every specification is a compromise between what customers want and what can be provided. How is a product specification stabilised in your PD process?
(4) How do you select the design solution that will be developed?
(5) How are your current processes and work methods reviewed/improved?
(6) Do manufacturing engineers play an active role in each stage of PD?
(7) Do your suppliers provide you with multiple alternatives for a single part?
(8) How projects are currently initiated, and does PD process flow?

From this research, it was possible to take some conclusions, regarding each building block, presented in table 3.

Lean PD building block	Observation	Conclusion
SBCE process	None of the companies intentionally delay their specification of products and tend to work in a constrained design space that limits their innovation and prevents convergence upon optimum designs.	SBCE process could be a significant contribution to each of the five companies.
Chief Engineer Technical Leadership	In majority, companies define a non-technical project manager. Other companies employ technical leaders, but either they are appointed after the concept stage or there are multiple leaders that lead different stages of PD.	Implies that the demonstration of consistent technical leadership for the full product life-cycle could yield significant results.
Knowledge-based Environment	Knowledge tends not to be pulled, rather it is pushed onto engineers. Most interviewees spend 80% of their time in routine tasks, with the exception of one company that puts special emphasis on innovation. None of the companies focus primarily on learning and increasing enterprise knowledge.	Most design problems would be solved if the correct knowledge was in the right place at the right time
Continuous improvement culture	A few companies use lessons learnt, A3 group problem solving and mistake proofing, but they are not used effectively, because the majority of interviewees stated that they are always overburdened by the quantity of work	A lessons learnt strategy must be defined in order to capture lessons from each project, by employees who are encouraged to make suggestions which are fed back into the processes.
Value-focused planning & development	Projects tend to run late, and activities are often sacrificed in order to meet launch dates. Only one company has a separate (dedicated) research department	Product development process must be planned and mapped to include only value-added activities

Table 3 - Results from a Lean PD study in five engineering companies

The authors conclude this research by stating that the area of research is fairly new and has been overshadowed by Lean Manufacturing and Lean Enterprise Research. There is also a cultural barrier that inhibits the ideas of ‘left-shifting work’ and developing multiple alternative designs instead of a single design. This shows there is a need to demonstrate the conceptual Lean PD model and assess its impact on PD, taking in consideration organizational, human resource and cultural factors, as processes are implemented by people.

Toyota Product Development System (TPDS)

Since the 1980s, companies throughout the world have been looking to Toyota as a model for manufacturing, striving for a competitive advantage, but not all have succeeded. Most of these companies have learned the hard way that the isolated application of lean tools and techniques does not lead to sustainable improvement. The broader organizational culture of the firm separates the short-term improvements from the long-term lean enterprises. And, to be effective, lean thinking cannot stop at the shop floor. Management principles must extend beyond the shop floor, as they do at Toyota, and be found in the boardroom, the sales offices, and quite clearly in the product development process.

Clearer lessons for lean services can be found not in the manufacturing side but by examining Toyota's Product Development System, which is thriving on lean principles that were derived separately from the manufacturing operation. Toyota has taken the same underlying principles of the Toyota Way and evolved a product development system. It is lean in the broadest sense—customer focused, continually improved through waste reduction, and tightly integrated with upstream and downstream processes as part of a lean value chain (Liker and Morgan, 2006). Toyota's Product Development System has enabled it to consistently develop higher quality vehicles faster, for less cost, and at a greater profit than their competitors. They also manage more new vehicle launches annually than most of their competitors, thus creating a steady flow of high quality new products to meet consumer demand. For example, Toyota was the first to produce an electric diesel hybrid using Lean in product development, a radically new product (Liker and Morgan, 2006).

Some experts believe Toyota engineers are four times more productive than other engineering teams (Kennedy, 2004). Some attribute it to the company's Lean Production fluid penchant for eliminating anything that does not add value to a product by the time it reaches a customer's hands. As a result, development at Toyota is largely free of wasted time, effort, and motion. As a matter of fact, Toyota engineers spend 80% of their time adding value to products they create. But eliminating waste falls far short of explaining Toyota's design engineers' productivity (Kennedy, 2004).

Normally, when engineers are developing products, they follow pretty much the same process. The design team first defines a few system concepts and selects the one thought to have the most promise. The team generates design specifications and partitions the product into subsystems. After each subsystem is developed, they are pulled together and a prototype is assembled and tested. If results are disappointing, the team doubles back to an earlier point in the process and starts over. This approach leads to highly structured work environments and, in fact, most companies have somewhat rigid product development processes. They emphasize particular activities, procedures and controls. Progress is usually measured by how many tasks are completed. The Toyota system, on the other hand, is non-linear and represents a totally different approach. The goal is not to complete a certain number of tasks or maintain a specific production rate, but to generate a constant flow of new products. So, instead of focusing on developing one particular device, the company tries to create a steady value stream of new products. In practice, this means many possibilities are generated from every perspective such as software, hardware, suppliers, and manufacturing, then evaluated at the subsystem level against broadly defined targets. If a newly developed subsystem proves unworkable, a proven subsystem is always available. Most importantly, all of the knowledge even that which didn't work, is captured and reused for immature projects.

Essentially, Toyota engineers search for and converge upon a solution. Unlike the traditional, linear approach, where success of individual engineers is measured by how many tasks they complete, at Toyota, an engineer's success is based on how he or she contributes to the success of the end product. This spreads responsibility across the entire team (Kennedy, 2004).

Morgan, conducted a two-and-a-half-year, in-depth study of Toyota's automotive body development, as compared to one of the American "Big 3" automakers, regarding body engineering, manufacturing engineering, prototype development, die manufacture, and die and stamping approval. This in-depth study of Toyota's approach to product-process development led to the identification of a set of 13 management principles that can be considered a foundation for lean product development (Liker and Morgan, 2006). These principles were organized in a framework of process, people, and tools/technology, which can be applied to service industries and professional operations. The important lesson to note is that it is a systems model.

TPDS framework and 13 Lean PD management principles

What makes it work at Toyota is that all the pieces fit together and support each other. Pull out a piece of the system and it collapses (Liker and Morgan, 2006). The Toyota Product Development System framework proposed is based on three fundamental pillars/subsystems: process, people and tools/technology, each one characterized by fundamental Lean PD principles.

Process. When thinking of process improvement, we often think of simple repetitive processes. In manufacturing, we can watch a worker do a job and time it several times and try to 'kaizen out' seconds of work. This is obviously not the case with product development. Toyota views product development as a process, less precise than most short-cycle manufacturing jobs, but able to be standardized, as well as eliminating waste and continually reducing both lead time and cost from program to program. The process starts with specific stretch objectives for each program and the teams virtually always achieve the targets.

At Toyota there is a philosophy of having a good process. It is as much a philosophical issue as a technical issue. There are a set of beliefs about what makes up a good process. A good process is not defined by technology but by good process principles and then people create and improve the process according to these principles. A summary of the process principles of lean product development is provided in Table 4.

Principle	Description
1. Establish customer-defined value to separate value added from waste.	Lean is a never ending journey of waste elimination. Waste is non-value added defined by first defining customer value.
2. Front load the product development process to thoroughly explore alternative Solutions while there is Maximum Design Space.	Defining the wrong problem or premature convergence on the wrong solution will have costs throughout the product life cycle. Taking time to thoroughly explore alternatives and solve anticipated problems at the root cause has exponential benefits.
3. Create a leveled Product Development Process Flow.	Leveling the flow starts with stabilizing the process so it can be predicted and appropriately planned. This allows product planning to reduce wild swings in work load. Predictable work load swings can be staffed through flexible labor pools.
4. Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes.	Standardization is the basis for continuous improvement. Standardization of the product and process is a foundation for all the other process principles.

Table 4 - Process principles of Lean Product Development
Source: Liker and Morgan (2006)

People. People are the core element to drive the lean process and achieve a rigorous standardization, working as a team to achieve common objectives. They not only do the work with high levels of skill and discipline but also reflect on the process and work to improve it. This activity happens on a continuing basis (continuous improvement). To do this, people with "towering technical competence" are required, who learn the specific technology and also learn through intense mentoring in the "Toyota Way" of identifying problems, analysing them, developing countermeasures, communicating and improving. The deep technical knowledge is the baseline skill and the Toyota Way is the higher level meta-improvement method that is part of the culture of the company.

People provide the intelligence and energy for any lean system. People Systems includes the recruitment and selection of engineers, training and professional development, leadership styles, organizational structure, institutional learning and memory as well as creating an organizational culture. Culture refers to shared language, symbols, beliefs, and values. While many companies are attempting to reduce reliance on people to cut costs through methods like automation or by shipping out engineering work to low-wage engineering service firms, Toyota's system is built around people who are thoroughly immersed in the Toyota Way. The principles of people systems are all about developing people who challenge, think, and continuously improve the product and process (see Table 5).

Principle	Description
5. Develop a "Chief Engineer System" to Integrate Development from start to finish.	The chief engineer is the master architect with final authority and responsibility for the entire product development process. The chief engineer is the overarching source of product and process integration.
6. Organize to balance Functional Expertise and Cross-functional Integration.	Deep functional expertise combined with superordinate goals and the chief engineer system provides the balance sought by matrix organization.
7. Develop Towering Technical Competence in all Engineers.	Engineers must have deep specialized knowledge of the product and process that comes from direct experience at the *gemba*.
8. Fully Integrate Suppliers into the Product Development System.	Suppliers of components must be seamlessly integrated into the development process with compatible capabilities and culture.
9. Build in Learning and Continuous Improvement.	Organizational learning is a necessary condition for continuous improvement and builds on all of the other principles.
10. Build a Culture to Support Excellence and Relentless Improvement.	Excellence and *kaizen* in the final analysis reflect the organizational culture.

Table 5 - People principles of Lean Product Development
Source: Liker and Morgan (2006)

Tools. Technology, to Toyota, is a set of tools to enable the people to execute and improve the process. As one Toyota Vice President explained, "Computer technology does not change the way we work. It simply helps us do what we do faster." Doing wasteful work such as rework faster is still waste. If you cannot do a good job of defining the project, identifying problems, developing appropriate solutions, communicating effectively to the right people, and meeting deadlines, then technology will not solve your problem. It may even mask the problems. Toyota does not subordinate good thinking to technology.

The third subsystem involves the tools and technologies employed to develop and build the product. This subsystem not only includes CAD systems, machine technology, and digital manufacturing and testing technologies, but all the "soft" tools that support the effort of the people involved in the development project whether it be for problem solving, learning, or standardizing best practices (see Table 6).

Principle	Description
11. Adapt Technology to Fit your People and Process.	Technology must be customized and always subordinated to the people and process.
12. Align your Organization through Simple, Visual Communication.	Aligned goals must be cascaded down and joint problem solving is enabled by simple, visual communication.
13. Use Powerful Tools for Standardization and Organizational Learning.	Powerful tools can be simple. Their power comes from enabling standardization which is necessary for organizational learning.

Table 6 - Tools/Technology principles of Lean Product Development
Source: Liker and Morgan (2006)

Although Lean PD is an emerging topic, all scholars state companies are in need of a new framework which is able to address customer volatile demands and under-performance of new engineering products and are unable to create a competitive advantage in relation to global competitors. Lean PD models were proposed by different scholars; however, there is a common conducting line, which links five fundamental enablers to apply Lean Thinking principles to R&D processes: Set-Based Concurrent Engineering, Value-focused planning and development, Chief Engineer Technical Leadership, Knowledge-based Environment and Continuous Improvement Culture. From this research, it is also possible to perceive Lean Product Development is difficult to apply randomly in a company, because companies must be able to optimize processes, motivate people to continuously improve and solve problems in a sustainable way and adapt tools/technology to fit people and existing processes, in order to build an efficient and flexible product development process, which is able to react rapidly to unexpected changes in customers' requirements or expectations. These conditions are only possible if organization and people accept to undergo a lean transformation, boosting performance and saving costs.

Lean thinking has been successfully applied along the last two decades in many companies, regarding manufacturing processes. In today's turbulent market, customers are not only interested in low-cost products; rather they are driven by fundamental factors, such as: innovation, quality, customization and delivery. In order to ensure survival and long-term growth, companies have perceived the importance of extending lean concepts to different sectors and areas, such as: New Product Development, Engineering, Product Development, among other ‘white-collar’ areas. The proposed Lean PD models in literature presented some empirical results of lean thinking application in product development processes in companies from a large variety of sectors, namely automotive, aerospace and home appliances.

To conclude, scholars address the lack of a framework able to empower people and focus on building an efficient and effective product development process, based on a roadmap of value-added activities, knowledge sharing and high capacity to react to changes and solve problems. In addition, researchers assume that engineers are not capable to measure performance and define efficiency gains, because there is no concrete definition of value and which processes are absolutely variable (creativity) or able to be standardized.

2.6 Challenges

Even though Lean Thinking is being applied with great success in almost all companies in the world, regarding the manufacturing processes, not all companies succeed in applying lean concepts to indirect areas, such as product development (PD). Thus, Table 7 provides a set of Lean Product Development challenges identified in literature.

Scholar	Challenge
Sorli et al, 2010	Measure the readiness and level of adoption of lean thinking principles in current industrial practice of product design and development processes by using performance measurement that considers human resources, technology factors and processes of an enterprise; Understand how product and process development is structured and what is needed to streamline the process to maximize value creation; Ensure the concurrent generation of lean product and process design and consideration, as well as the design of its associated lean manufacturing system that is highly responsive to the changing market requirements and production technologies; Select Key Performance Indicators (KPI) to measure the progress made after implementing lean for product development Improve actual self-assessment tools that are not web based and do not provide functionalities to easily report the assessment results in an automatic way
Dombrowski and Zahn, 2011	Types of waste differ from the types of waste in production as defined by Taiichi Ohno
Khan et al, 2013	Barriers to innovation Late design changes Communication issues Knowledge-related problems Cultural and organizational barriers

Table 7 - Lean PD challenges

2.7 Benefits

Many factors have contributed to change Society's priorities in the world. Today, we live in the Technology and Information era. The Internet and Globalization contributed to worldwide trade, opening the markets, consequently increasing the competition between companies on a global scale and raising customers' awareness about products, services and new technologies. Due to these factors, organizations face disloyal customers, who are demanding and price-driven. This has forced them to adapt, with the aim of obtaining success: value-addition. To overcome the existing challenges, Lean Product Development is a powerful weapon to work in an efficient and effective way, achieving results in quality, as well as pledging budget and deadline compliance.

Lean adoption into the product development process enables the creation of competitive advantage in comparison with competitors, as it allows cost reduction, through waste elimination and value creation, through a perfect balance between standardization and creativity.

Lean PD model is able to gauge the maturity of product development and identify the value streams which will enable the company to target the key areas for improvement. As it contributes to a knowledge rich environment, engineers can make faster, more informed and effective decisions earlier in the product development projects. These earlier decisions significantly impact the efficiency and performance of the Product, Suppliers, Manufacturers and End-users in the product lifecycle.

The Lean PD approach provides a new concept of European knowledge-based factories that goes beyond the typical lean manufacturing paradigm of waste elimination to an environment that supports creativity and value creation (Sorli et al, 2010). This framework enhances the companies' opportunities to compete and grow in the global market place due to the high efficiency of the new Lean PD model in delivering products that meet customers' demands in terms of innovation, customization, quality and sustainability at a competitive price.

To conclude this section, it is important to clarify that Lean Product Development does not concern only the process improvement, as it contributes also towards the creation of a kaizen culture, affecting day to day activities of project members, what they view as relevant, problematic, and worth communicating, in other words, Lean PD efficacy increases by learning in action (Dutton, 2014). It represents a strategic approach that values employees' improvement and empowerment highly, in order to assure high quality and innovative products.

In sum, Lean Product Development has many benefits, regarding change of employees' mind-set and creates a value-focused and customer-oriented process capable of reacting to volatile demands and to facing an increased trend of customized products.

2.8 Performance Measurement in Product Development

There is an old saying “If you want to manage it, you have to measure it” (Driva et al, 2000). As mentioned by Cooper & Edgett (2008) and Reinerten & Schaeffer (2005), identifying right metrics and measuring performance of Product development processes play a key role in the success of Lean Product Development, since it will facilitate identifying improvement areas and will provide a road map.

Competitive business environments demand effective product development investment. Performance measurement can help to achieve these objectives by helping managers evaluate performances, identify improvement areas and define new development strategies.

Performance measurement in R&D activities, compared to other parts of the operation, is associated with more problems because of: a) high uncertainties in R&D processes and outcomes; b) complexity in following negative and positive effects of innovations; c) the close relationship between R&D processes which have many sources that can affect outcome; d) difficulties in measuring processes with quantitative indicators; e) claiming credit for different actors, after accomplishment, is a political problem (Geisler, 1994).

Geisler (1995) classified studies in R&D performance measurement into four streams. The first category considers economic impact of research and development. The second includes productivity of researchers and research teams. The third one measures performance of research activities with outcome indicators such as number of patents. The fourth one considers a subjective qualitative assessment by experts. These four streams can be classified in three general models of 1) performance (output) 2) cost (input) cost-performance models (Geisler, 1994). In a cost model, input of the R&D process which are considered as measures of investment in R&D and comparison with other input or output indicators. On the contrary, a performance model considers development of key output indexes for different stages of R&D processes (Geisler, 1994). Geisler (1995) categorized these outputs in four stages: a) immediate/direct; b) intermediate; c) preultimate and d) ultimate.

Chiesa et al (2007) identify the following objectives of a Performance Measurement system: Support decision making, Enhancing R&D performance, Motivating personnel, Supporting the incentive scheme, Fostering organizational learning, Enhancing communication and coordination and Reducing R&D risks. Considering the main objectives, managers should select suitable indicators.

Key performance indicators (KPI) are quantifiable measurements, agreed to beforehand, that reflect the critical success factors of an organization. They represent a set of measures focusing on aspects of organizational performance that are the most critical for the success of an organization and help companies define and measure progress toward organizational goals (Parmenter and Wiley, 2010). KPIs can be categorized considering a Quality, Delivery, Cost and Morale (QDCM) model. Assigning a suitable indicator to each category is essential. An effective performance measurement system must be linked with company strategy and include Specific, Measurable, Actionable, Result-oriented/Relevant and Time Constrained (SMART) Key Performance Indicators. Each Key Performance Indicator must have standard and understandable definitions, regarding KPI definition, Data source, Unit, Frequency of calculation, Sources of error (which can influence the information), Responsible process owner, level at which information is used and a defined target.

Performance measurement is increasingly gaining companies' interest, due to its capacity to help control processes performance and measure some existing wastes in the R&D process. Considering the Engineering department, many KPIs can be defined: number of patents, number of design changes to specification, number of defects detected in development stages, time spent in meetings, development cost of products which do not reach commercialization, number of prototypes, percentage of sales coming from new products, number of new products, success rate of products' tests, number of recurrences, among others (Mohammadi, 2010).

KPIs help managers to control if R&D activities are on track and to provide updates, regarding project transparency.

As has been mentioned in the Lean Product Development literature, changes in early stages are easier and less costly. Therefore, with the earlier application of a measurement system, there is higher possibility of correcting actions and controlling projects and guiding them in the right direction.

In conclusion, an integrated performance measurement system, which is able to evaluate R&D activities from start to finish is required in lean product development. An integrated system will garner know-how regarding waste elimination in the process and facilitate continuous improvement by identifying areas which require improvement and measuring the performance continuously.

Summary

This literature review provides a clear view of why Lean is so important to drive companies' performance and success, as well as their progress from mass production to indirect areas. Concerning this topic, Lean represents an improvement philosophy which focuses on the creation of value and the elimination of waste (Khan et al, 2013), in order to enhance process performance and efficiency. The term was initially used in reference to manufacturing operations, but now is being used across a spectrum of sectors.

Given the topic of Lean Product Development, there is less research done to apply lean in product development processes, due to its complexity and existing paradigm: standardization vs creativity/innovation. Although Lean Product Development is an emerging topic, there is still no evidence of lean impact on important factors such as quality, cost and delivery. Thus, a question arises: Why is it so difficult to apply lean to improve the process of developing products? Scholars have identified as main challenges the difficulty of measuring performance in an adequate way and of having a clear understanding of what can be considered as value in all stages of the process, as well as no existence of a kaizen culture, which would allow to identify improvement opportunities and solve problems in a sustainable way. In order to address this issue, many scholars have proposed Lean Product Development models and principles, to help companies to address their lack of knowledge about lean enablers and efficiency, in order to develop products with lower costs, higher quality and available on the market in half the time.

According to the literature, a successful implementation of Lean Product Development framework depends upon the combination of the following enablers: Set-Based Concurrent Engineering, Chief engineer (entrepreneurial) technical leadership, Value-focused planning and development, Knowledge-based environment and Continuous improvement (Kaizen) culture. Although there is some literature on the application of Lean Thinking in product development process, there is no conceptual model of Lean Product Development with proven results, which would contribute to the understanding of the impact of lean on non-repetitive processes, such as product development.

Ease of access to information has boosted customers' demands for product variety, innovation, low-cost products with higher quality and shorter lead times, forcing companies to adapt and focus on achieving competitive advantages. Thus, never before has Lean Product Development been more important to the success of the organization. Because not all companies are able to apply it successfully or do not know how to measure the performance of PD projects continuously, companies are in need of a new framework, that is easy to implement, able to build an efficient processes and a continuous improvement culture. Therefore, this thesis aims to answer the following research question: ***"****How can companies implement successfully a Lean Product Development framework, able to impact R&D processes' efficiency?".*

3. Research aims and methodology

3.1 The context and goals of the research

This project aims to understand how the successful implementation of a new Lean Product Development framework can positively impact the performance and efficiency of product development processes.

The research lasted 5 months, based on the evidence and extending concepts and theories from Lean Product Development literature. To be successful, a Lean PD framework preliminary theory (case study company initial state) needs to be developed and tested in the field study, through an Action Research (AR) approach. AR also aims to evaluate whether the directive approach is suited for the purpose of stimulating lean application to Product Development.

The present thesis is based on the AR process within a study of a Lean Product Development framework applied in a manufacturing company, focusing, in particular, on two issues:

- ❑ The organization, i.e. creating an organizational culture based on continuous improvement principles.
- ❑ The process, i.e. the various phases and steps the company goes through to develop products, according to customers' requirements

In particular, this paper aims at answering, through the AR empirical evidence, the following research question:

- "How can companies implement successfully a Lean Product Development framework, able to impact R&D processes' efficiency?"

3.2 Research methodology

To develop a structured research upon a real case scenario, in a manufacturing company, an AR methodology was used. Action Research process has been chosen as the best way to develop theory on a new approach, that does not yet exist in the company practice. The main characteristics of AR are the following (Cagliano et al, 2005):

- ❑ AR focuses on research in action, rather than research about action;
- ❑ AR is based on a preliminary theory that is tested and refined on the field;
- ❑ AR is a cyclical process of planning, taking action, evaluating the action, and leading to further planning and so on;
- ❑ Members of the system, which is being studied, participate actively in the cyclical process;
- ❑ Researchers participate actively in the process, purposefully influencing the system.

AR aims both at achieving practical results on the field as well as developing new knowledge. The AR process was performed during an internship in a manufacturing company in Aveiro, where it was possible to come into contact with Lean Management methodologies, concepts and tools applied in the Engineering department.

3.3 The action research process

The AR process was organized throughout a 5 month project that took place from November 2013 to April 2014, where researchers provided new contents, assignments were set, work was performed with the support of researchers and results were presented to top management. All the actions were performed by the employees and managers (members of the system), supported by the researchers. The researchers had both the role of supporting the activities and observing the process, in order to gather relevant information for the research.

The proposal of a new Lean Product Development framework is mainly to provide help to all companies to achieve success through fundamental stages and steps of a Lean Management philosophy, based on five dimensions, represented in Fig. 10.

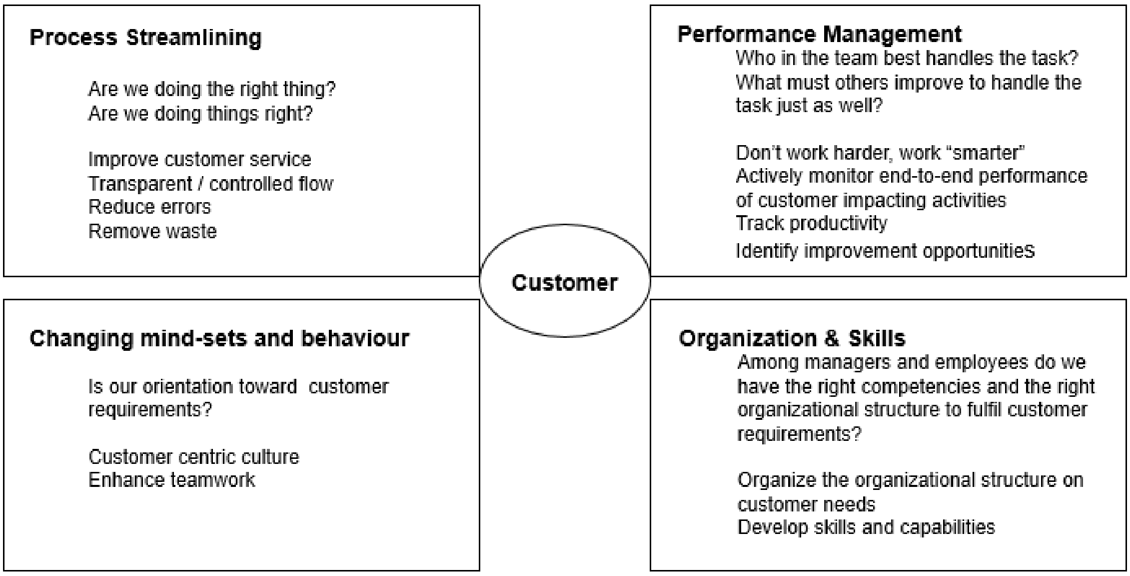


Figure 10 – Lean PD framework proposal: 5 dimensions

3.4 Case Study Company

This thesis reports on the AR performed in a manufacturing company, regarding a Lean Management Project focused in applying lean methodologies in the Engineering department.

The focal company was established in 1977. It is an international leader, manufacturing hot water and heating systems, whose core business is to produce solutions that are both energy efficient and environmental friendly. The Company's success deeply depends upon product performance, regarding innovation, quality, cost and delivery; essential conditions to conquer new markets and increase its market share.

The AR process was initiated in the focal company to fight against some emerging challenges, by establishing future goals to achieve a better definition of both organization and product development processes, resulting in an efficient and flexible flow of information, people and materials, represented in table 8.

Challenges	Goals
Focal company with flat or even no growth - Rising pressure on costs and structures to compensate cost increases and to reach result improvements	With Lean Management ithe aim is to support managers to establish a new culture of leading and collaboration and thereby focus on improving performance and solving problems in a sustainable way
Main markets in Europe showing an additional phase of stagnation as well as an increasing competitive situation - Increase of low-cost competitors	To reach the challenging targets, the effective assignment of existing resources and alignment on the customer' s benefit are important action fields
Further overall cost cutting and structural adaptations lead to a loss in company performance and overloading of associates - Emerging countries with lower average wages compared with Portugal	Lean Management will help to accomplish a platform for associates to address daily problems and solve them in a sustainable way; the daily routine allows to solve the problems on short notice and without time delay
How to further reduce cost of indirect functions without losing performance, people motivation and customer satisfaction?	By applying the balanced and holistic approach of Lean Management in Aveiro, it will be possible to achieve result improvements as well as improvement of both employee and customer satisfaction

Table 8 - Focal company challenges and goals

4. Lean PD framework proposal: PDDIS

Under the present global pressures that urge companies to do better with less from a short-term perspective, the long-term survival of organizations may very well depend on their ability to introduce new products, better, faster and customer-oriented, by multiple interactions between the engineering department and suppliers, customers, production and product management departments. This emerging need obliges companies to go under a lean transformation, able to achieve an efficient and flexible product development process. From this, we can highlight Lean Product Development (LPD) as being critical to the revival or survival of almost global companies. Despite two decades of research on LPD, it remains unclear what exactly Lean PD is (no universal definition), whether there is real empirical evidence of the success of LPD, and maybe even more importantly from a practitioner perspective, how to introduce LPD in environments that are non-repetitive and non-sequential.

In this chapter, a new Lean Product Development framework is proposed: PDDIS Framework. In order to initiate, perform and sustain Lean Product Development in R&D, companies need to go through a series of steps and undertake a sequence of actions, as represented in Fig. 11.

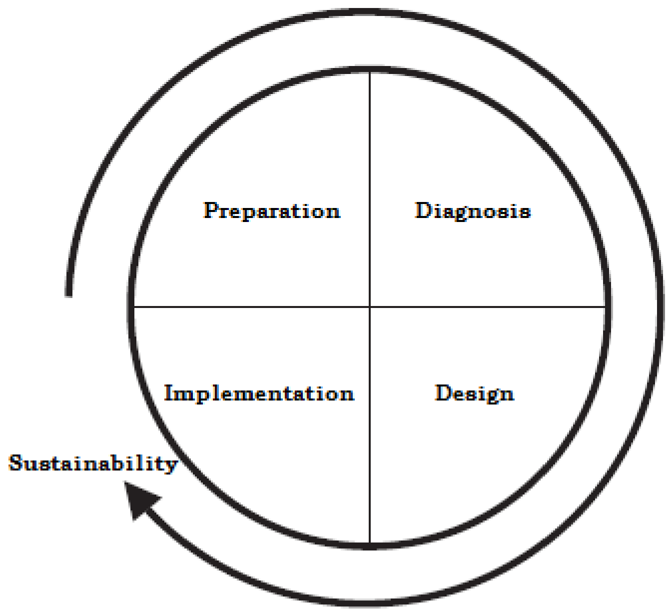


Figure 11 - PDDIS Framework

Designed to be user-friendly, the PDDIS framework aims to address companies' lack of knowledge applying lean product development philosophy to R&D processes.

First of all, it is fundamental to involve all different stakeholders, creating a kaizen culture, which means, suppliers and customers (internal and external) need to be carefully identified and assessed about current performance of the engineering department, concerning improvement points, communication, capability to react to changes, performance and service level. All stakeholders must participate actively and be involved in the process, in order to raise awareness about the topic and ensure sustainability of the methods, concepts and tools applied. PDDIS framework activities should be carried out daily, with a permanent interaction between Top Management, researchers, managers and associates.

The market is highly competitive, which implies companies have to seek a way to differentiate from competitors every day. PDDIS framework represents a competitive advantage as it acts as a system of highly interwoven components, which only in their concurrency will lead to an efficient and customer-oriented process, able to react to customers' demand changes. Thus, companies must take into consideration a real case scenario, with valuable tips about what to do in each phase, represented below, according to an Action Research process.

Phase 1: ***Preparation.*** This is the first stage of each new project. First of all, a research team must be set-up, as well as a project leader. Preparation is essential to perform an initial assessment about Engineering department, regarding product development process, specific functions, initial hypothesis (improvement points), through data and stakeholders analysis (skype and telephone calls, and emails). From this, researchers need to define targets and a roadmap. Broadly speaking, during this stage, you must create background awareness, in order to avoid misunderstandings or even mistakes.

Preparation is essential to create a solid backbone for the project. In order to collect and garner all the information needed there is a summary below of the topics that should be taken into consideration:

- ❑ Project Structure / Organization chart
- ❑ Scope of the project
- ❑ Stakeholders analysis (find hypothesis, collect observations)
    - Employee Survey
    - Needs
    - Objectives
- ❑ Communication Plan
- ❑ Checklists
    - On site logistics
    - Transformation Area
- ❑ Project Plan
- ❑ Initial position
- ❑ Program target

To end this phase, a Lean motivation boot camp must be organized between researchers and R&D managers, where PDDIS framework is presented and discussed, and both parties involved in the improvement process interact.

Phase 2: ***Diagnosis.*** After gathering all the necessary information away from the site, it is time to go to Gemba. This stage is characterised by great interaction between researchers and managers, as well as "in loco" observations, in order to find hypothesis (improvement points).
During this stage there are many tools that can be used for individual & collective self-discovery of current state of 5 dimensions and to describe current data (see Fig. 12). These are useful to create background awareness, understand the product development process, identify existing wastes and consequently identify improvement areas.

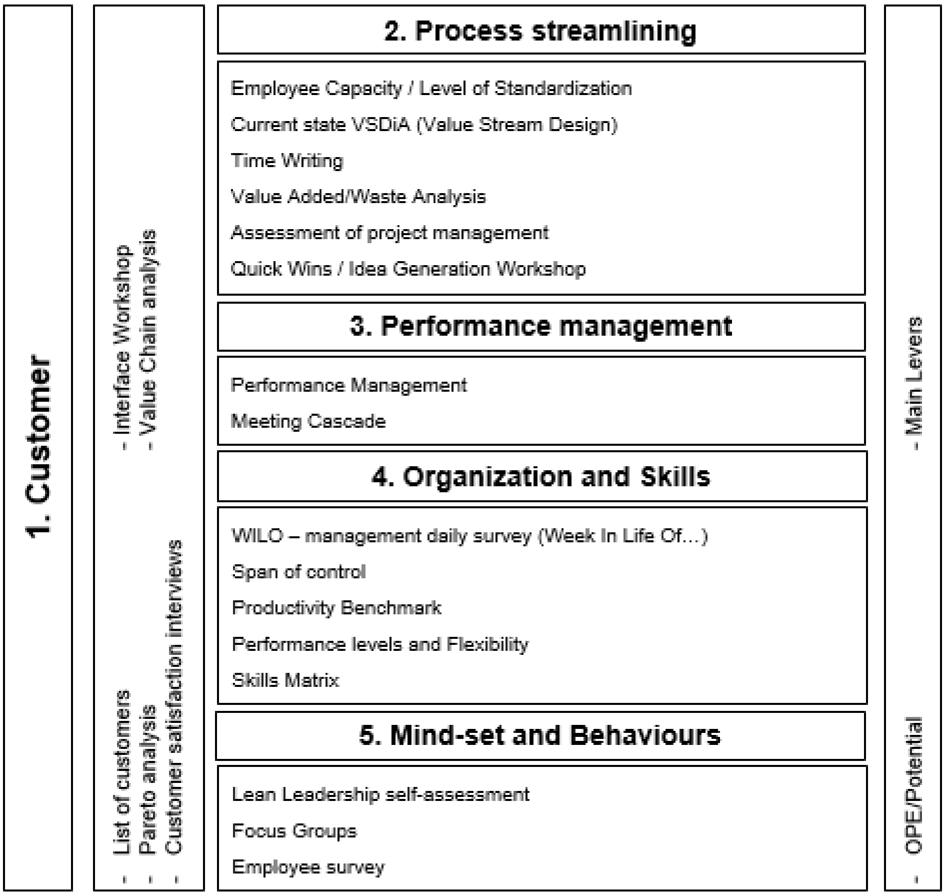


Figure 12 - Diagnosis Tools

Phase 3: ***Design.*** The diagnosis tools were applied and hypothesis identified, so it is time to design and create the inspiring future state. In this stage, it is mandatory to focus on planning the improvement actions and define responsibles, for the following stages: implementation and sustainability. According to the hypothesis and diagnostic tools, it is essential to define efficiency gains for each activity, concerning each main lever, in order to establish an efficiency target that is higher than 10%.
Sometimes, there are some barriers or lack of commitment from managers, which must be overtaken with a correct and wise plan of how to move from current state to future state and to commit collectively to the objectives and to the defined plan. This commitment should be ensured by top management.

During this stage, it is important to define the layout of whiteboards, to define Key Performance Indicators (KPIs), as well as to define a Tactical Implementation Plan (TIP), and a future state meeting cascade. In order to understand these tools, templates of each tool are represented in Fig. 13. Managers must implement these tools effectively, as they represent the difference between a successful and an unsuccessful project and must be used.

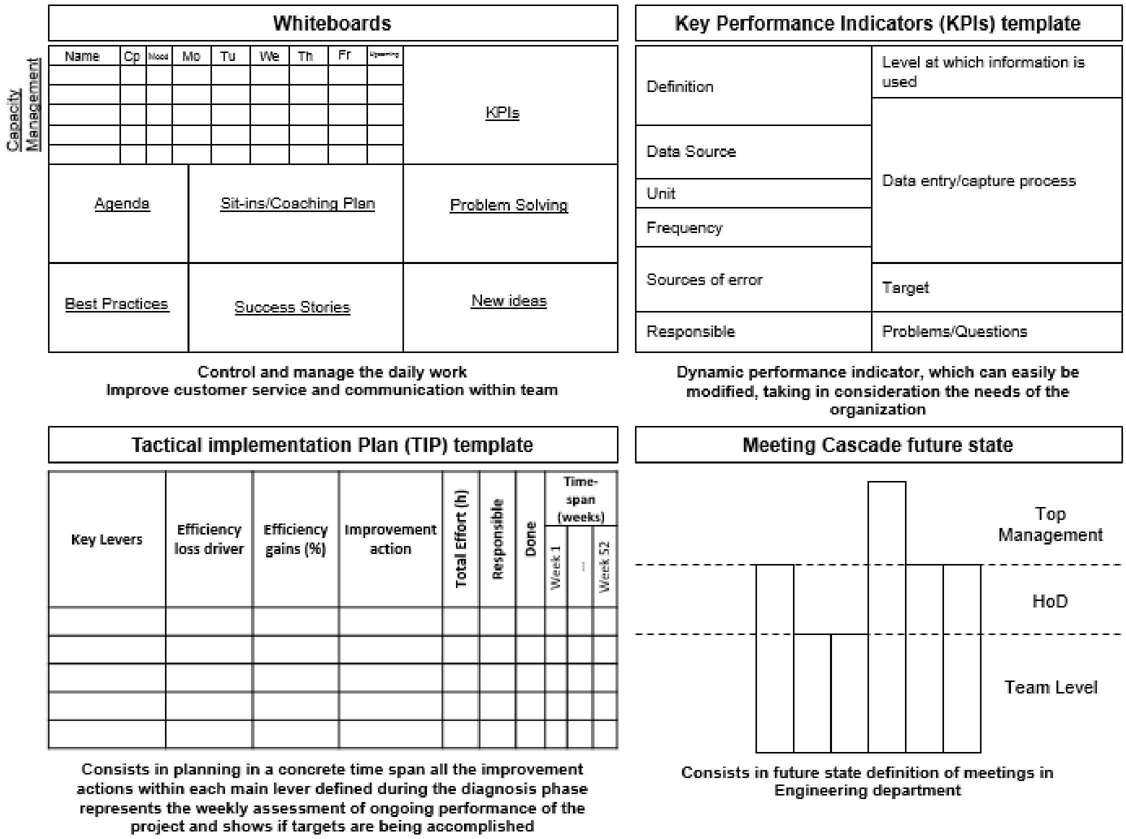


Figure 13 - Design tools

<u>Phase 4:</u> Implementation. The improvement activity is planned, allocating resources and defining the actions needed to achieve the desired results. The plan is then executed, through the development and implementation of the solutions that emerged. During this phase, employees try and learn the new way of working, with the support from researchers. All employees should be aware of the importance of the TIP and its improvement actions, in order to assure efficiency gains are achieved. At the end of this stage there should be a visible impact of Lean Product Development principles, methods and tools on teams, management and KPIs, resulting from a joint workforce: employees and managers. To achieve this knowledge, during the diagnosis, design and implementation phases, first managers and then employees attend workshops and trainings, performed by researchers about the 8 lean fundamental blocks (see Fig. 14). Managers and employees must, during this stage, delve deep into this knowledge and use these tools to achieve targets and perform improvement actions and at the end must be assessed about their maturity in each element, through a Maturity Assessment Tool (template presented in Appendix I).

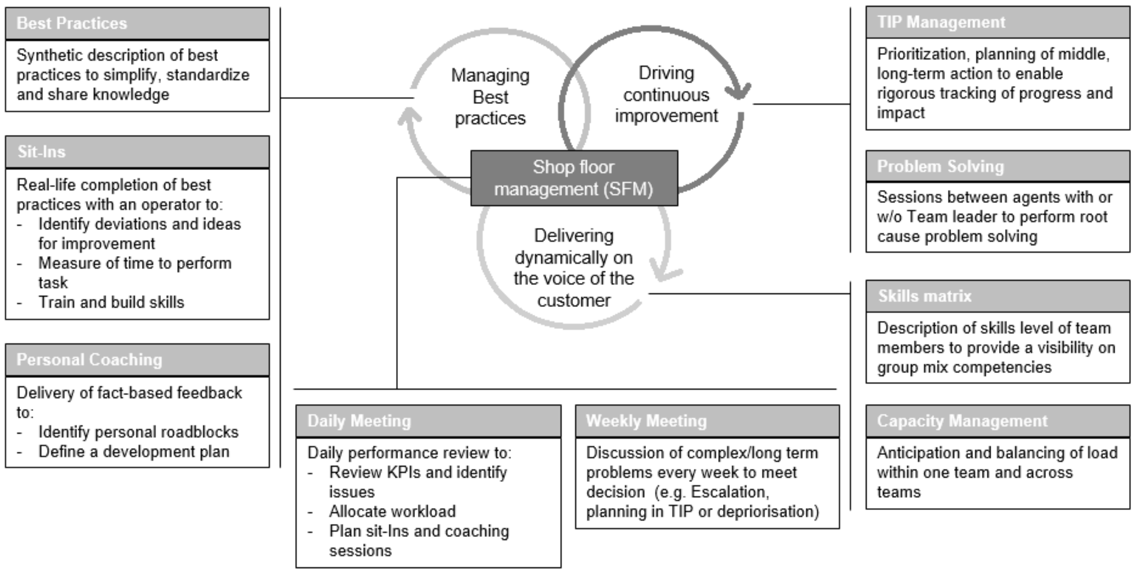


Figure 14 - 8 lean fundamental building blocks

<u>Phase 5:</u> Sustainability. This is the final stage of the PDDIS framework. Sustainability Phase is a cyclical phase, a review of all previous stages and aims to create a new working culture, based on changing habits. In order to ensure change and sustainability of the methods used, employees must act autonomously, carry on with improvements, measure gains, make reports, act according to a transparent, committed plan and improve maturity levels in each one of the 8 building blocks, taking the necessary measures to reach the target.

Sometimes Tactical Implementation Plans are too ambitious and many tasks need to be realized during the sustainability phase, so it is necessary to structure a new tactical plan: Sustainability TIP. This new plan should include unfinished tasks from the implementation phase and new improvement actions, with assigned gains and responsibles, as presented in Table 9.

List of Ideas or Problems					
Date raised	**Topic / Cluster**	**Topic / Problem Description**	**Benefit (0-10)**	**Effort (0-10)**	**Responsible**

Table 9 - Sustainability TIP template

Framework application

As perceived in the previous chapter, this framework was applied in a manufacturing company, through an Action Research process. AR allowed the testing of the organization suggested by the preliminary theory (case study company initial state), in order to identify strengths and weaknesses. The first important element is that the organization should work as one, which means every stakeholder must be committed with the targets and be involved in the process from the beginning, in order to build a collaborative and co-operative environment, otherwise, a continuous improvement culture will not be sustainable.

In this project, regarding Product Development Process, the Engineering department was divided into three divisions: ENG1 – Development of gas appliances (ENG1.1 – Fan-pressurized, ENG1.2 – Open-flow, DOC – Catalogues/Product manuals), ENG2: support to ENG1 (ENG2.1 – CAD design, ENG2.2 – Tests Laboratory) and ENG3.1 – Development of Heat Pumps and ENG3.2 – Electronic development, representing a total of 40 employees, 5 team leaders, 3 line managers and 1 Head of Department (HoD). The selected teams presented different degrees of and different attitudes towards collaboration, but in all cases there was a common commitment to improve the company's performance jointly and in a collaborative way. AR showed that, even though Lean methodologies and techniques are standard, each team must customize and use them in order to achieve team targets and to create a kaizen culture within the team.

The PDDIS framework was applied in the Engineering department. However, this thesis will focus on results of its application on one specific team: ENG3.1, concerning the development of Heat Pumps. This team is constituted by 1 team leader and 6 engineers.

When the project started, only the goal was defined: to reduce the waste in R&D. But a question emerged: How to achieve waste reduction, in order to create added-value to meet customers' requirements?

The PDDIS framework was applied during 5 months in the Engineering department, providing the following results for a specific team, ENG3.1, to whom each one of the stages of new Lean Product Development framework proposal was explained in detail.

Phase 1: ***Preparation.*** The project started with setting-up a team (a project leader and lean consultants). During this phase it is important to create background awareness. Therefore, researchers initiated this process with a stakeholder analysis, through emails and telephone calls, having found some hypothesis (improvement points), such as: too much time to answer an email, no clear understanding about department roles and targets, lack of support to employees. To complement this analysis, information about employees' performance and flexibility to perform tasks was gathered, employees' operating time, as well as employees' satisfaction, through a survey regarding direct management (see Fig. 15).

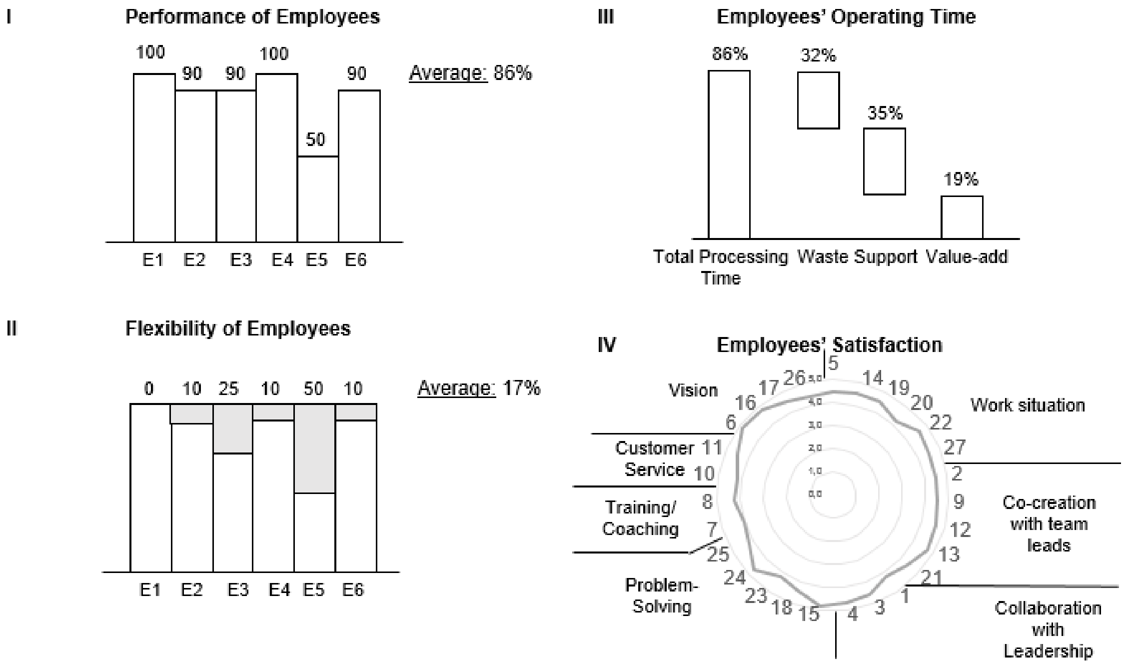
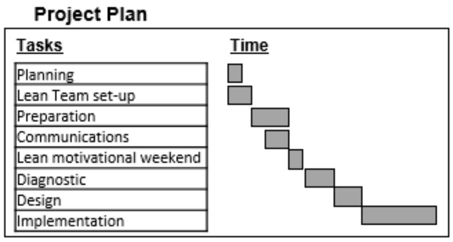


Figure 15 - Stakeholder analysis

After the stakeholders' analysis, the communication and the project plan were set, as well as the onsite logistics plan, regarding researchers' room (size, location), needed materials and general conditions (see Fig. 16).



Onsite Logistics

Lean Management project	Responsible	Due date	Status
Contact person for on site logistics, office material, etc			
Information about working time (location individual regulations)			
Project room (size) near Engineering department			
Access on site (badge)			
Workplaces (tables, chairs, etc)			
Printer			
Whiteboards			
Access to water, coffee machine			

Figure 16 - Preparation Phase logistics

Finally, in order to prepare the upcoming phases of the project, a Lean motivation boot camp was organized. This activity was held by lean specialists and it enjoyed the presence of the Engineering line managers and head of department (HoD), as well as the researchers involved in the project. During this 2-day activity all the participants were confronted with the core elements of Lean Management (8 fundamental building blocks), that became familiarized with the PDDIS framework tools and with a standardized method for conducting a lean project (project plan and targets for each phase, employees' benefits and a lean change model, based on four main categories: Insight, Skills, Systems and Culture/Role model). This activity was very important because it joined together managers and researchers, provided insights about lean concepts, principles and methodologies and the preliminary theory was presented and discussed with the participants. This initial phase impacts the overall perception of managers about lean and its importance to perform better in a continuous improving and sustainable way, as presented in table 10.

Participant	Comment
Researcher	Lean motivation boot camps are very important to interact with project stakeholders, as it also enables participants to increase their knowledge of lean tools, through role playing and discussion sessions, which activates a better reaction to change during the project on site.
Line manager	This activity before the official start of the project onsite is fundamental, as it represents a joint event, where both researchers and Engineering line managers interact and get to know each other, discussing project targets and plan. Because, many concepts were unfamiliar, during these 2 days it was possible to understand and become familiar with the main tools, applied during the project.

Table 10 - Lean motivation boot camp participants' feedback

<u>Phase 2:</u> Diagnosis. In order to initiate the project onsite, the first step towards a lean transformation was done by dedicating a first session/joint event to explain the meaning, importance, benefits and critical aspects of the lean concept and respective methodologies, in addition to the project scope.

This was a fundamental phase as it concerned the application of diagnosis tools, enabling initial hypothesis confirmation and the identification of new ones, as well as understanding the product development process, its stages and possible existing wastes.

This phase was highly interactive, composed of several meetings and workshops only between managers and researchers, to increase managers' knowledge about some important tools, depicted in table 11.

Problem Solving	Sit-ins	Trainings
Whiteboards	Lessons Learnt	Best Practice Exchange
TIP	Feedback	Meetings & E-mail efficiency and effectiveness
KPI definition	Top-down communication	Coaching

Table 11 - AR workshops

Every day, managers and researchers met for 15 minutes in Whiteboard meetings. This daily alignment concerned talking about daily deliverables (important tasks that must be done and add value), daily capacity (green – available; yellow – okay; red – completely full/unavailable), team mood, KPIs and existing problems. During the diagnosis phase, these daily meetings were important to perceive managers' availability for meetings and Gemba process observations, regarding improvement actions and waste identification.

Diagnosis represents one of the most important stages of the PDDIS framework, because it is characterised by the application of fundamental tools, presented before, in fig.12.

This phase ended with a regular meeting between researchers, managers and top management, which aimed to present the main results from diagnosis tools (see Fig. 17) and main levers identified within the project, for the ENG3.1 team (presented in table 12).

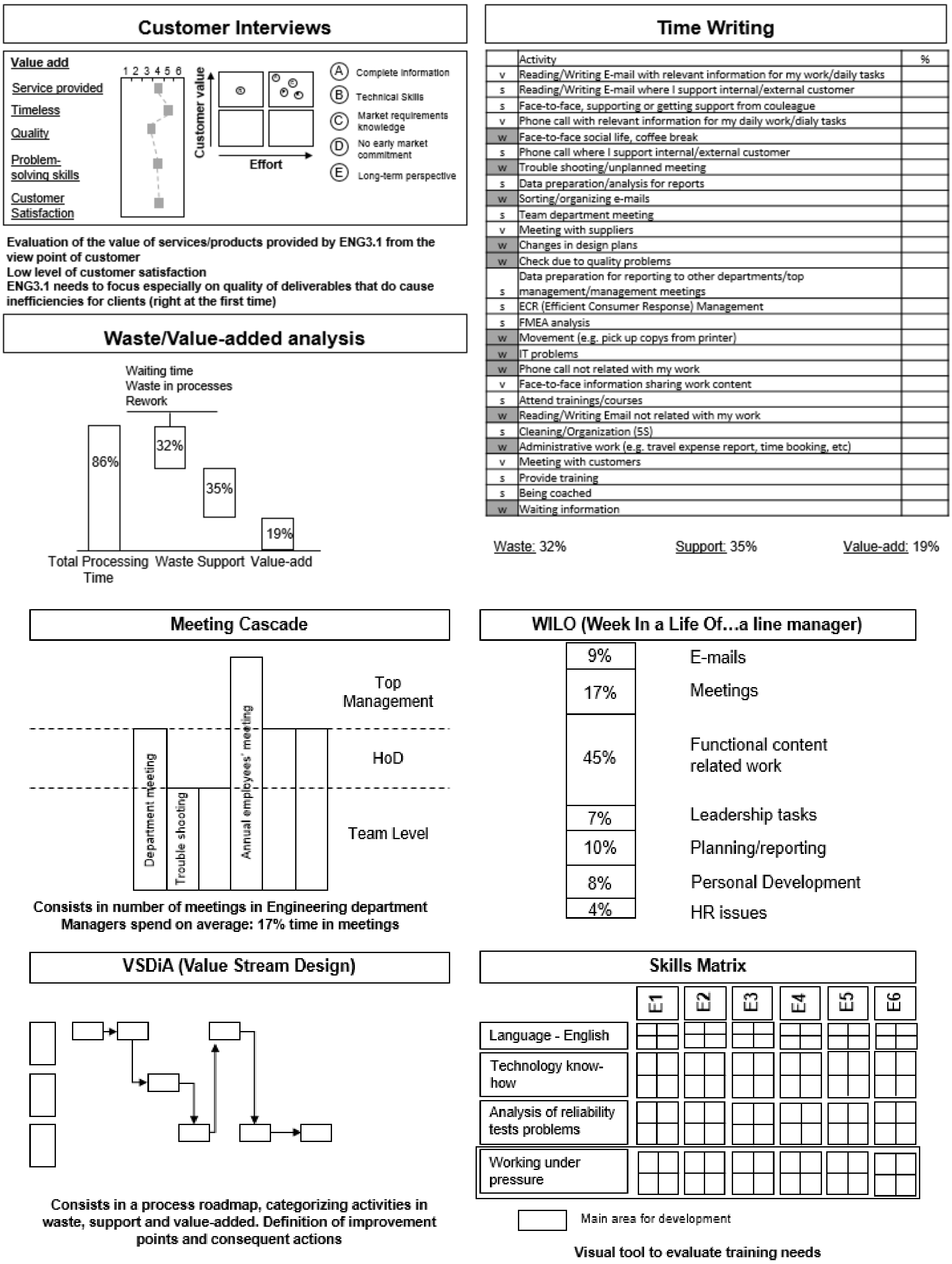


Figure 17 – PDDIS Framework: diagnosis tools results

Main Lever	Negative impact	Result
Low level of customers' satisfaction	Inefficiencies in the Engineering department	Bad cooperation with other departments
A daily demand and capacity management is not in place	Daily tasks are not allocated based on available capacities and clear prioritization	Unresolved tasks, work handed over incomplete and consequently a decrease in customer satisfaction
Insufficient daily performance management	Engineers were not aware of key performance indicators and its importance to control projects status continuously, delays or even the number of new ideas or patents.	No control of product development projects
Performance was only being measured on mid-/long term basis and lacked a daily KPI system	Customer satisfaction is decreased	Wrong allocation of capacities and lack of performance dialogues
Level of standardization in selected operational processes can be improved	Existing standards were not fully implemented or didn't exist for some procedures	Additional rework and waste of time, impacting performance and efficiency of the process
Meeting and reporting routines were not carried out efficiently (e.g. missing objectives)	A significant amount of time is spent on meetings, not providing value-added or on inefficient meeting/reporting routines	Lack of capacities for core activities

Table 12 - Diagnosis of main levers (improvement points)

Lean diagnosis tools have a clear impact on the process as they contribute to understanding the overall roadmap of the product development process, identifying existing problems and wastes and, consequently, defining improvement actions to meet team and company targets, aiming to develop products with higher quality, lower costs and available faster on the market.
Although Product Development concerns an indirect area, where waste is normally not so easily identified as in the manufacturing processes (repetitive processes), during the diagnosis phase it was possible to identify some examples of existing wastes (see Fig. 18).

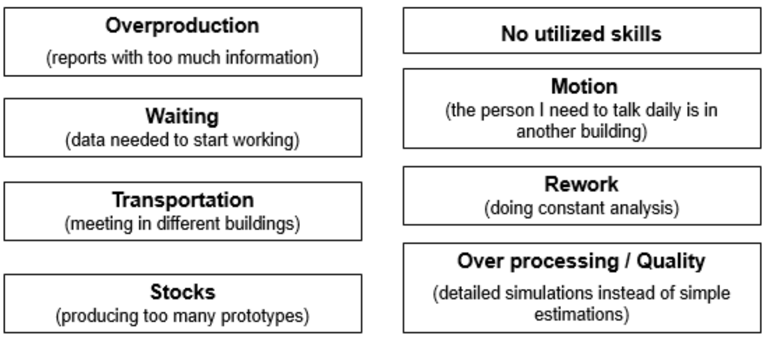


Figure 18 - Types of wastes (R&D department)

At the end of diagnosis phase, an Overall Process Efficiency (OPE) waterfall was disclosed, presented in fig. 19, where it is possible to see the deployment of the product development process, regarding important topics, such as: Rigidity, Management time, Individual variation, Total processing time, Waste, Support and Value-Add.

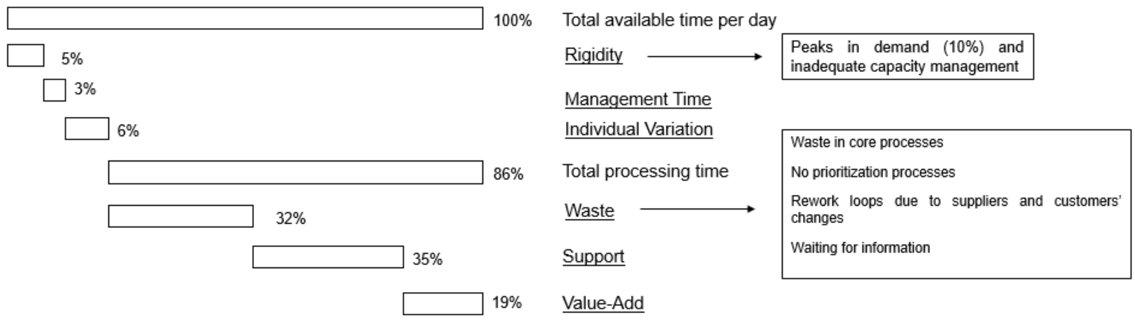


Figure 19 – Overall Process Efficiency waterfall

<u>Phase 3:</u> Design. In the third phase of the project, researchers and managers defined all improvement actions. Design represents a 2 week phase, in which managers are prepared by researchers to act as role models. Broadly speaking, the design phase represents an ultimate stage before implementation, in which the future state of the department is set, regarding improvements, the definition of a tailored KPI system, meeting cascade future state, design of whiteboards and the development of future state skills matrix, with desired levels of skills for each employee.

The whiteboard is considered the driving force of lean ongoing application, because it represents both a daily regular meeting, where managers and team members meet together to talk about daily capacity, problems, performance update and new ideas, and a management board, where all important topics are covered, providing a general overview of team performance and projects status, to control and to better manage the daily work. On the other hand, making a Tactical Implementation Plan (TIP) represents a commitment to improvement actions and future efficiency gains from managers and team members. This tool is an ongoing control tool, where it is possible to identify back spikes (delays) to the plan and actions implemented with success and represents a summary of all actions needed to be implemented, along the project, during the implementation phase. It must be reviewed on a weekly basis, checking if planned actions are being done and implemented with success.

Finally, in this phase, KPIs were set and its frequency of measurement defined, because performance indicators represent the only way to assess the team's growth and development (see Table 13).

KPI	Frequency	KPI	Frequency
Number of tasks left to be completed	Daily	Number of new problems	Daily
Number of improvements	Weekly	Number of new ideas	Weekly
Number of coachings performed	Weekly	Number of failures in testing chambers	Daily
Team barometer (team satisfaction)	Weekly	Number of patents	Monthly
Number of feedbacks given in formal way	Weekly	Number of prototypes	Weekly
Time of deliverables (Real vs Planned)	Daily	Number of changes in products' design	Daily
Number of ad-hocs (unfinished tasks)	Daily	Number of new products	Weekly
Number of hours available	Monthly	Success rate of products' tests	Daily
Meetings Efficiency	Weekly	Percentage of sales coming from new products	Monthly
Number of best practices	Weekly		

Table 13 - PDDIS framework: KPI definition

All these tools were designed jointly by researchers and managers, to better address team needs. At the end of this phase a regular meeting between researchers, managers and top management was organized, which aimed to present the Whiteboards layout, Tactical Implementation Plans and main KPIs defined. This meeting was very important, because it represented a commitment from managers to top management towards the hypothesis identified during the diagnosis phase, and consequent improvement actions and efficiency gains. During this meeting the results of maturity assessment of lean elements of ENG3.1 line manager were also shown, as represented in Fig. 20.

Figure 20 - PDDIS Framework: Maturity of lean elements (Design Phase)

Design tools make a great contribution to design the future state of the Engineering department, defining clear targets for the implementation phase and addressing the way wastes and problems are being reduced as well as enhancing a commitment to invest in an organizational culture, set on fundamental pillars: continuous improvement, problem identification and resolution, performance measurement, collaboration and communication, knowledge and sharing success stories, capacity management and personal and team planning.

Phase 4: ***Implementation.*** After observing the current state and designing the desired future state, managers started implementing improvement actions, with the researchers' support, according to TIP, represented in table 14.

Key Levers	**Efficiency loss driver**	**Improvement action**	**Efficiency gains (%)**	**Total Effort (h)**	**Responsible**	**Done**	**Time-span (weeks)**					
							Week 1	Week 2	Week 3	Week 4	...	Week 52
Performance Management	Lack of a daily KPI system	Definition of KPIs	7%									
Capacity Management	Tasks not allocated based on available capacities and clear prioritization	Whiteboard 6 weeks plan Prioritization of tasks Deliverables breakdown	4%									
Communication	Inefficiencies in Engineering department (capacity to react and solve problems)	Define and communicate role and responsibilities Creation of an ENG help front-desk	3%									
Meetings	Lack of efficiency and effectiveness	Definition of Meeting rules	2%									
E-mails	Lack of efficiency and effectiveness	Definition of E-mail rules	2%									
Standardization	Existing standards not fully implemented or don't exist for some procedures	Enforce standards which are not lived today Standardize activities Track and eliminate non-core activities	6%									

Table 14 - PDDIS Framework: Improvement actions (TIP)

Engineers had a critical role in generating improvement actions and then implementing them, but during this phase the problems started to appear, due to two main factors: resistance of employees to change and to cooperate, and lack of time to coordinate lean activities and development of products (see table 15).

Participant	Comment
Researcher	Managers faced many problems to implement lean methodologies, because engineers didn't understand the importance of planning activities in advance, were not transparent, were not able to express their daily problems and were always reluctant to changes regarding product development process, due to lack of repetitive processes, able to be standardized.
Engineer	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, because when I am developing a new product most of the actions are variable and without a specific time assigned. In addition, KPIs do not have a direct impact on management.
ENG3.1 line manager	Lean activities occupy a large time slot, which obliges me to work extra hours to meet daily targets. Product development processes are too big to map and I have many difficulties in measuring efficiency gains of improvement actions, and find suitable KPIs

Table 15 - PDDIS framework: Implementation problems

This phase required strong communication and collaboration between employees and the team leader. In order to overcome this lack of communication and time to share problems, the ENG3.1 team started performing daily Whiteboard meetings, addressing topics such as: daily capacity, team mood of each participant in the meeting, existing problems, control of KPIs and sharing of best practices and success stories, as well as new ideas concerning improvements or products (see an example, in Fig. 21).

Figure 21 - ENG3.1 Whiteboard

Due to initial employees' mind-set, whiteboards were performed inefficiently with low focus, being improved along time, during the implementation phase. To complement whiteboards and to meet employees' needs regarding job related problems, inexperience and some difficulties to perform in an efficient and effective way, several coachings, sit-ins, trainings, workshops and problem solving sessions were performed.

Applying these tools showed how engineers were lacking support and openness to share daily problems, share functions responsibility, ask for help and plan and slice/break down deliverables in advance.

The implementation of improvement actions that contribute actively to creating a kaizen culture is the focus of the implementation phase. During this phase many problem solving sessions were held, generating issue trees (see an example, in Fig. 22), with a Mutually Exclusive, Collectively Exhaustive (MECE) description of defined Specific, Measurable, Action-oriented, Relevant and Time bounded (SMART) problems, without an initial root cause. Because problems must be faced as improvement opportunities, problem solving sessions contributed actively to reach solutions together, without blaming anyone, only focusing in identifying root causes and possible solutions. Although not all solutions were implemented, in all cases it was possible to identify root causes and raise awareness about the problem, which will impact on efficiency and team performance.

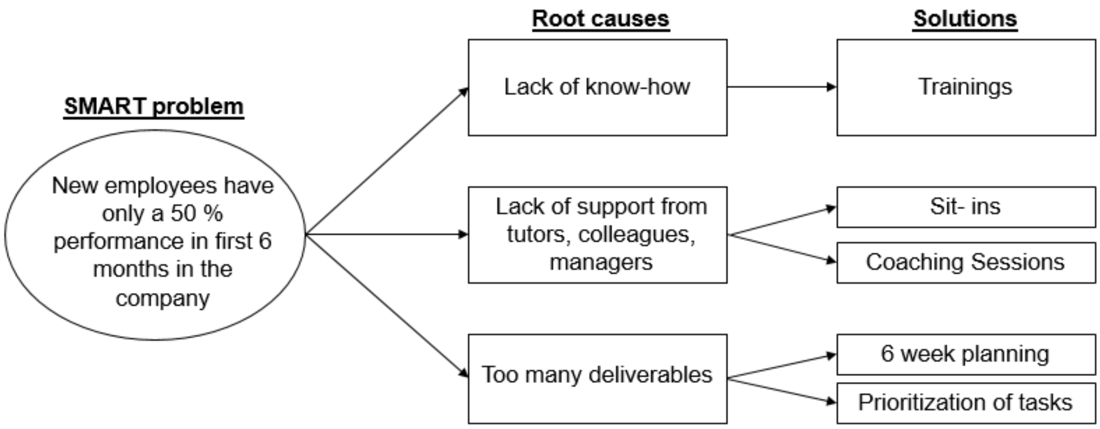


Figure 22 - Issue Tree example

The issue tree, depicted in fig. 22, helped to understand the reasons behind the low performance of new employees, when they arrive for the first time in the company. From the deployment of this problem, it was possible to define improvement actions/solutions to surpass this recurrent situation and address problems like: lack of know-how, lack of support and existence of too many deliverables (daily activities).

Implementation phase is all about applying the knowledge provided by researchers, focusing on ensuring standardization of procedures, daily whiteboard meetings, weekly problem solving sessions, coachings and trainings done on a weekly basis, regular VSDiAs to 'attack' obstacles and problems affecting the efficiency of the product development process (see an example, in Fig. 23).

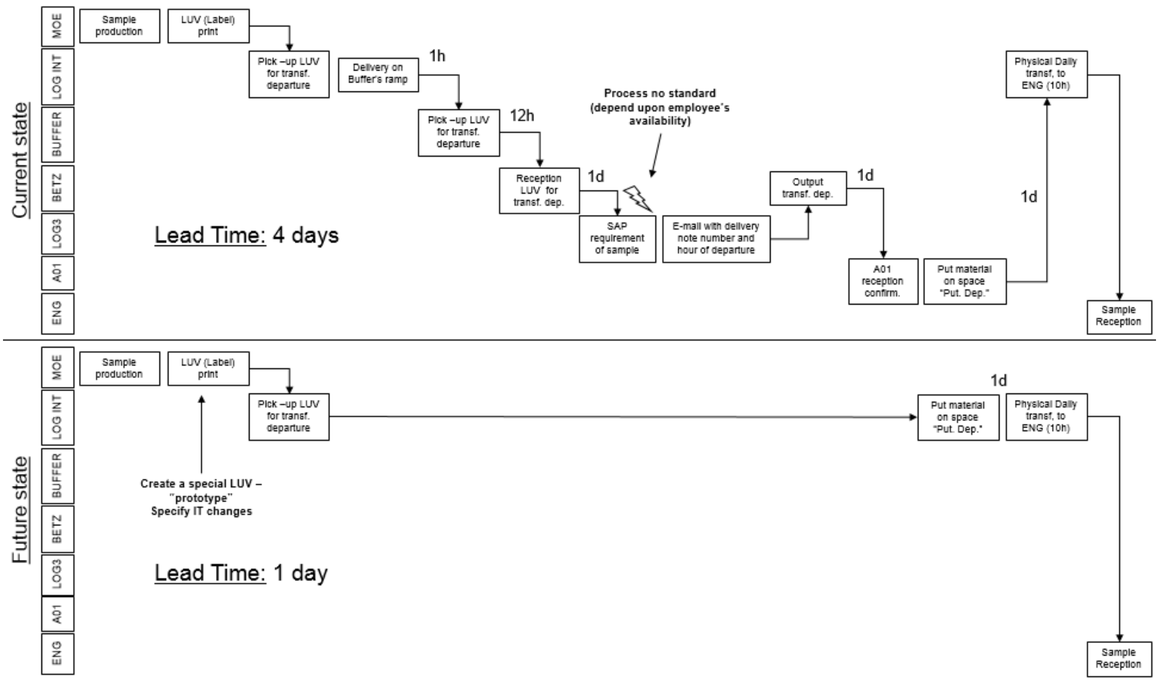


Figure 23 – VSDiA example: ENG samples logistics

One of the main levers identified during the diagnosis phase was the lack of capacity to react to and solve problems. To surpass this issue, an ENG help front-desk was created, which enabled resolution of communication problems and to better route requests to the right person. This new interactive system consists of redirecting incoming phone calls and e-mails, through a secretary, who has a guideline with information on the people responsible for gas/water appliances. This allowed solve problems faster, because the people responsible were found efficiently and effectively, without much delay.

Another hypothesis found concerned the lack of efficiency and effectiveness of meetings and emails. Apart from the fact that both are fundamental to help management, they need to be reduced, in order to boost performance and focus on the product development process. To ensure a common-sense approach, rules for email handling and meeting organization and participation were created and these were spread among employees (see Fig. 24 and 25).

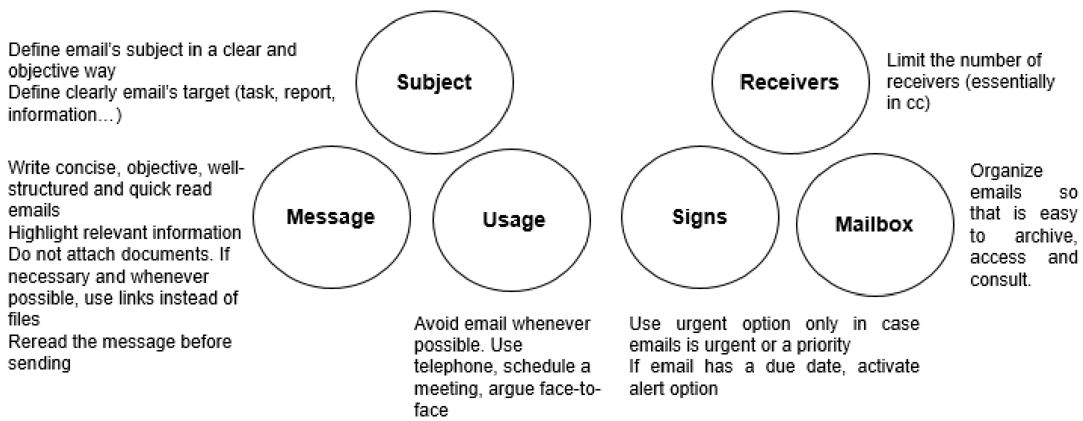


Figure 24 - Email Rules

- Make clear if meeting request is accepted or rejected
- Do not be late! Meetings start and end at defined time
- Focus on agenda and meeting objectives
- Do not send emails and/or answer telephone calls during meetings

Meeting Organizer/Moderator:

- Invite only the necessary people
- Define and share agenda and meeting objectives in advance
- Define roles
- Keep focus on agenda and time (avoid deviations)
- Address important topics such as bad behaviour
- Observe and summarize decisions; Attribute responsibles (tasks and deadlines)
- Distribute minutes at earliest after meeting

Meeting leader check-list

1. Start on time
2. Review meeting agenda
3. Define roles (Facilitator, Scribe, Timekeeper, Observer)
4. Agree on ground rules
5. Steer the conversation
6. Review and summarize actions
7. Evaluate meeting
8. Finish on time

Figure 25 - Meeting Rules

These rules were created, through internet research and employee's assessment (workshop) about improvement points regarding e-mail and meetings. This was considered an important topic, because by reducing the number of emails sent and time spent in meetings engineers were enabled to focus on the development process and increase face-to-face interaction within the team and at the departmental level. Efficient and effective emails and meetings contribute actively to reducing waste of time, activate faster resolution of problems and target the right people, with the right amount of information needed to perform better, without doubts or deviations. Although it seems obvious and necessary, meetings and e-mail represent a large share of time in a work day. In order to decrease the time spent every day writing, reading, sorting, organizing e-mails and participating in meetings, rules were spread across all the departments, through the following means:

- ❑ Top management e-mail to the whole organization
- ❑ Posters placed in 'traffic areas' (canteen, social area)
- ❑ Article in the company magazine
- ❑ Flyers distributed to all employees (available on each desk)
- ❑ Engineering department meeting (Communication)
- ❑ Workshops

The critical aspect of this phase was related to introduce lean fundamental blocks to employees, and to create a sustainable and interactive culture, giving the 1st step towards excellence. Because being excellent or even making every day better than the previous day is a never-ending road, maturity of lean elements was assessed. This assessment allowed for the understanding of the maturity level of each manager, regarding lean fundamental blocks, creating awareness about level of implementation of lean methodologies and concepts (see Fig. 26).

Figure 26 - PDDIS Framework: Maturity of lean elements (Implementation Phase)

Like the previous phases, at the end of this phase a regular meeting between researchers, managers and top management was organized, with the aim of presenting the achieved results during implementation phase. Managers presented an update of the Tactical Implementation Plan (TIP) and defined a sustainability TIP, to continue improvement actions during the sustainability phase. During this meeting, managers were asked to raise main topics (focus) and weak points. In sum, managers identified as main topics the capability to delegate tasks, Whiteboard as a fundamental tool to ensure lean sustainability and daily management, the change of the mind-set, resulting in continuous improvement actions, implementing 5S in the department (secretaries, drawers, shelves, closets), commitment towards lean transformation, cooperation and collaboration with other departments, improved testing and investing in guidelines and SOP (Standard Operational Procedures). However, lean implementation in the Engineering department had some difficulties. Managers pointed out as weak points: the need to improve performance dialogues, lack of capability to plan ahead (3 months planning), to understand market and customers' requirements, no sharing of knowledge and success stories within the department teams, lack of coaching/training/skills regarding RASIC tool (an example presented in Fig. 27) and skills matrix and finally, no visible impact of lean appliance in the short-term.

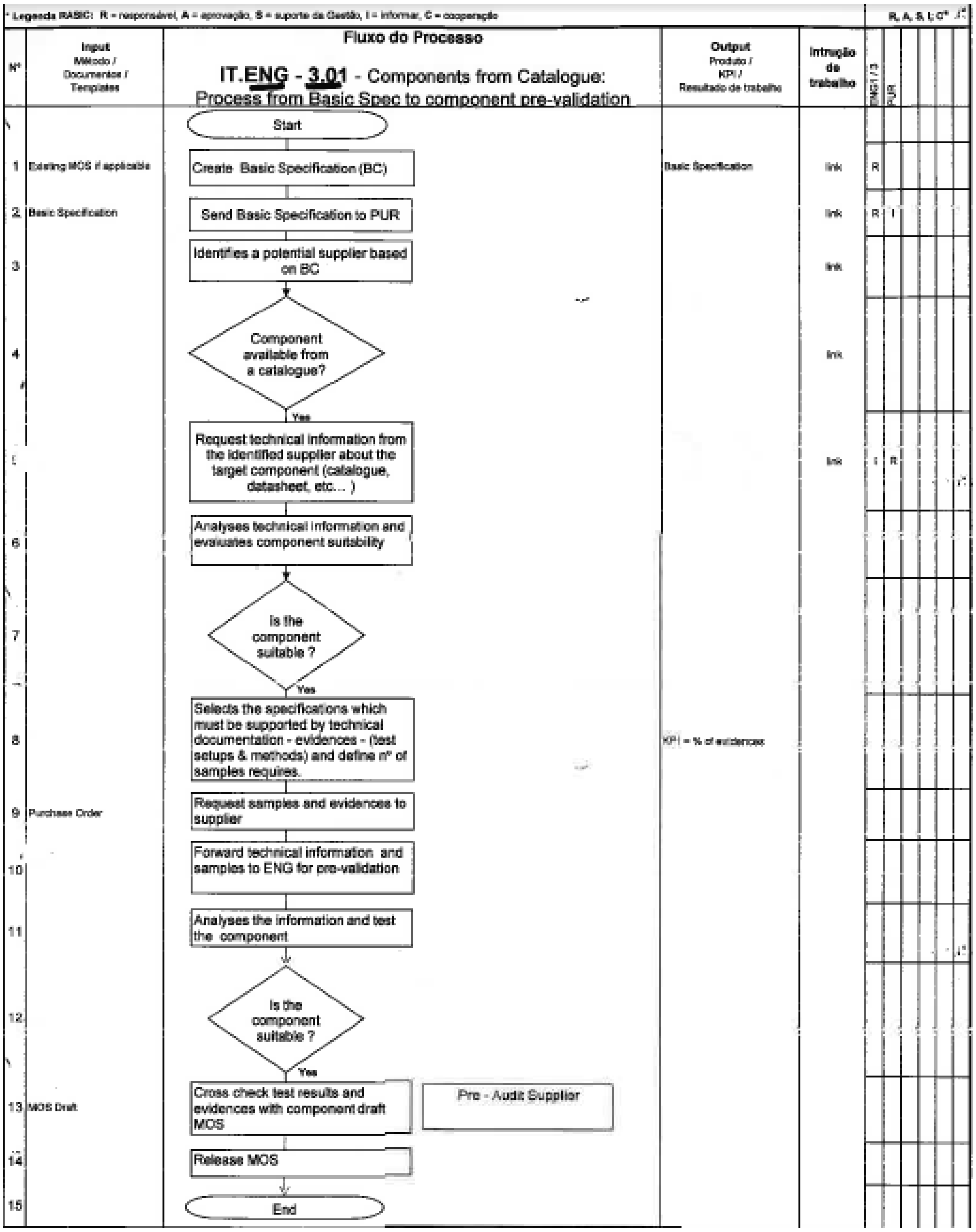


Figure 27 – RASIC: ENG example

RASIC represents an important tool to deploy a process, defining roles for each activity, from all levels (team level to top management level). For each activity the following roles are defined: Responsible (R), Approval (A), Support (S), Information (I) and Cooperation (C).

To better understand what were the results of lean implementation in the Engineering department and its impact on efficiency (see Fig. 28).

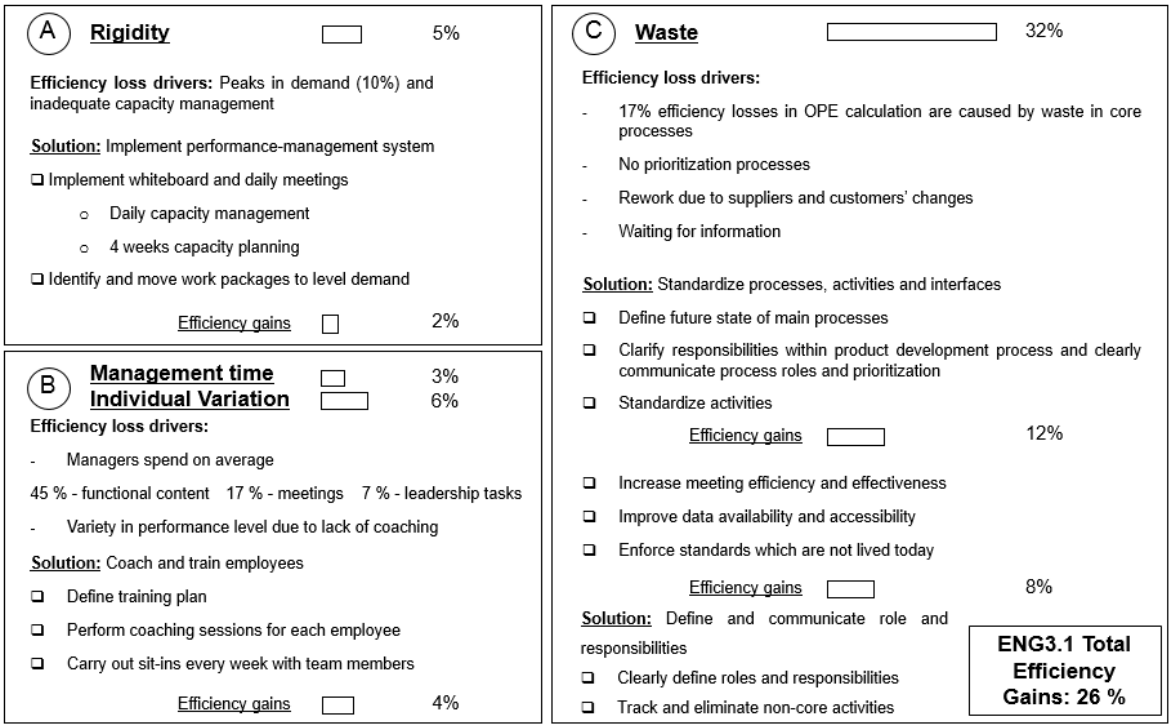


Figure 28 - PDDIS Framework: Efficiency Gains and Improvement actions

Top management normally focuses on numbers and efficiency gains, but one important factor should not be forgotten: employees' level of satisfaction. To assess employees' satisfaction, a survey was performed and the results compared with the survey done at the end of the diagnosis phase (presented in Fig. 29).

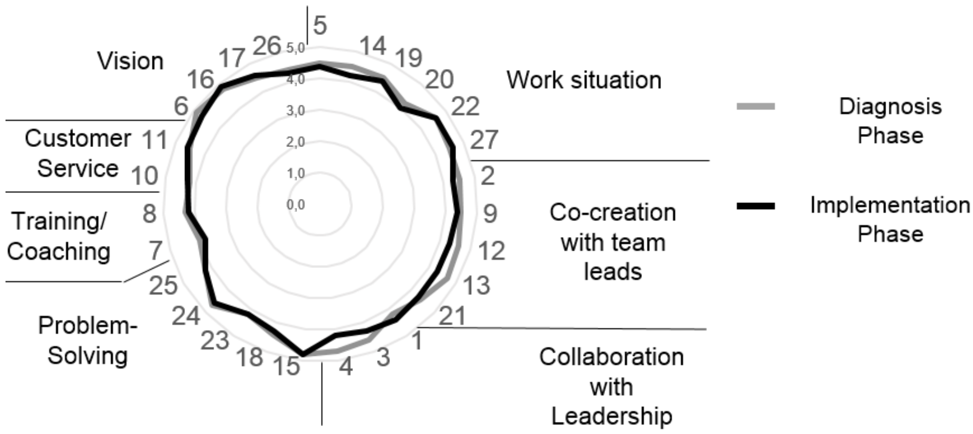


Figure 29 - Employee Survey

Increasing employee satisfaction contributes actively to achieving higher rates of performance and commitment towards lean transformation. Observing both survey results, employees show a high level in all categories (Vision, Customer Service, Training/Coaching, Problem Solving, Collaboration with Leadership, Co-creation with team leads and work situation), especially the last two. Due to some resistance to change and lack of time from managers, there was a drop in the work situation, relating to inconsistent implementation of guidelines and procedures in all areas and in training/coaching, without managers spending sufficient time on these elements. On the contrary, the survey showed an increase in high commitment to growth and the development of the site, vision for the future and customer service. These results made the difficulties faced during the Lean Management project clear, with much space for improvements.

Implementation ended the participation of researchers support and their active presence on site, giving managers the opportunity to act autonomously. To clearly state to all stakeholders the end of the researchers' action, a final meeting to present results to employees was organized, clarifying existing doubts and making a final balance of the project.

Phase 5: ***Sustainability.*** After completing the first cycle, the Engineering teams started a new one, generating new improvement ideas and using this methodology for all product development projects. These activities were often aimed at consolidating the results achieved in the first cycle or extending the solutions to a wider set of products. Thus, managers built a sustainable TIP containing open points from the implementation phase and new improvement ideas or existing problems, making a prioritization, taking into consideration benefits and effort. During sustainability, managers and engineers acted according to the new organizational culture, spreading the knowledge received during the previous phase and maturing the lean elements, to increase performance, effectiveness and the quality of products.

The Engineering teams have set an array of ideas and open points from implementation concerning email and meetings efficiency and effectiveness, shifting prioritization, and review of existing processes to search for improvement points, such as: Samples, Tests plan, templates and assessments and Front-desk evaluation and Creation of a steering committee.

When moving to sustainability, it was clear that the improvements achieved were not enough to change the level of performance of the Engineering teams, regarding lean philosophy and level of standardization. Thus, it was important to increase top management support and commit managers and head of department to lean transformation and the need to keep the pace.

Lean has a high impact on product development processes during sustainability, because it ensures a review of all methodologies and tools applied and forces managers and employees to improve continuously to react and adapt to meet customers' needs.

As this project and philosophy is a never-ending story, area managers and managers have a fundamental role in maintaining a kaizen culture active and act as role models, by focusing on each lean element, with a determined frequency, according to a sustainability checklist, as shown in table 16 and 17.

Lean element	Action	Frequency
One-on-one coaching	Direct report	Bi-weekly
Targets & Reports	Follow-up on status of lean management implementation	Bi-weekly
Performance dialogues	Direct reports and follow-up problem solving sessions as required	Weekly
Gemba	Attend one whiteboard meeting and provide coaching and feedback	Weekly
Problem Solving	Conduct structured problem solving meetings, where clear actions & next steps are defined and followed-up	Weekly
Communication	Communication about lean management into the organization	Monthly

Table 16 – Area Manager Sustainability checklist

Lean element	Action	Frequency
One-on-one coaching	Direct report	Weekly
Targets & Reports	Update status of KPIs and set realistic but ambitious targets	Weekly
Performance dialogues	Direct reports and follow-up problem solving sessions as required	Daily
Gemba	Conduct sit-ins with direct reports to confirm and improve best practice application	Daily
Problem Solving	Conduct structured problem solving meetings, where clear actions & next steps are defined and followed-up	Weekly
Communication	Communication of new success stories within the department	Weekly

Table 17 – Team leader/Head of department Sustainability checklist

Deductions

This thesis provides a guide for implementing Lean thinking in product development processes, within manufacturing companies, by suggesting an organization and a process, on the basis of the evidence from the implementation in a real case, through a practice based practice. This study is highly relevant for both research and practice, since on the one hand it provides elements to build a new framework on an under-investigated subject, i.e. Lean Product Development, while on the other hand it provides results, collected in a manufacturing company.

The suggested framework is derived from the literature, as a response to customers and market demands of value creation, incorporating sustainability and customisation. In taking into consideration Lean PD models proposed in literature, it is possible to identify significant differences: PDDIS framework represents a practice based program to enable companies to coordinate both lean and R&D day to day activities; it is constituted by five phases: Preparation, Diagnosis, Design, Implementation and Sustainability (iteration of the process), instead of four: Specification phase (first 12 months), Conceptual phase, Demonstration phase and Implementation phase. However, it is also possible to find some similarities, concerning literature framework principles: Kaizen, Standardization, Visualization, Flow and Pull, Zero-Defects, Employees and Leadership and Frontloading, reflected in the PDDIS framework dimensions: Customer, Efficiency and Effectiveness of Processes, Performance Management, Organization and Skills, and Behaviours and Mind-sets.

The voice of the customer is central to any Lean PD system, and it is fundamental to understand the motivating effects of a clear and common understanding of customer needs by the whole of the Development team.

The Action Research process adopted has been very directive and structured, to allow the initiating of the PDDIS framework in a context that was new to the approach and also, in part, to the focal company. The good results achieved during the Lean Management project support the initial targets that were set, however, this does not exclude other ways to implement Lean Product Development, as seen in literature (Lean PD models and Toyota Product Development System). Another important result is the relevance of organizational issues, in particular the people involved. The selection of a collaborative and committed learning network seems to be critical for the successful implementation of Lean PD systems, but after the process is started it could be extended to other company departments.

Another relevant topic is the importance of having some maturity in lean culture. Although, lean has been applied for many years in manufacturing activities in the focal company, engineers were very reluctant and didn’t believe in the project and its impact on R&D activities, which created some initial barriers.

The truth is that not all companies succeed in implementing lean, because they have a wrong approach, considering indirect areas as being similar to manufacturing processes, highly repetitive and easily standardized. One of the concerns companies must have about applying the “lean” methodology is the impact on engineers. Engineers are not like workers on the shop floor. They are educated, well paid, and expect to have autonomy and be creative in their work. A common image of a lean shop floor can be quite negative. Imagine engineers in their natural work environment being pressured to follow standard procedures for everything they do and constantly pull minutes of non-value added activity out of the process leading to more intense and tightly controlled work for all hours of the day and night. It is no wonder we often see resistance from R&D professionals when the concept of lean is discussed.

The challenge of this thesis was exactly to show how Lean can surpass these barriers and demonstrate its success and impact on product development processes. To make this happen, people represent a critical asset to boost continuous improvement.

Once a Lean Management project starts and teams are selected, the adoption of lean requires the identification of open-minded employees, the right people to undertake the improvement activities. These persons are the key of lean transformation success, as normally there is a high share of employees who do not want to go into a continuous improvement transformation, due to different reasons: i) some employees have been working in the company doing the same thing for many years and they are sceptical of the success of new practices (mind-set); ii) fear of losing their job; iii) complaints about lack of time; iv) fear of failing; v) difficulty in identifying improvement actions; vi) lack of power to implement new actions (top management lack of support); vii) how lean fits with innovation and creativity and finally viii) difficulties to commit with targets and efficiency gains. AR showed that these were the main initial reasons for the reluctance of employees to adopt the lean attitude in product development process, within the Engineering department. Therefore, there is a need for managers to act as role models and identify possible lean catalysers, able to identify priorities and problems, people with technical knowledge, committed with a culture that is favourable to change and able to influence others.

During the project, the motivation goes up and down, but one thing must never change, the commitment and the will to change for the better. All entities must believe that this change will be beneficial for the company's success. To preserve and enhance communication between managers and top management, regular meetings were organized at the end of each phase, in order to update top managers about project results, efficiency gains, commitment with improvement actions and share success stories.

In the ENG3.1 team, it was not easy to create a kaizen culture, because there was a barrier concerning lean practices and whether they were able to really impact the core business of the company, taking in consideration the need to be creative. Thus, many were the doubts about the success of lean adoption, but at the end of the project it was possible to see the real impact of lean in the time process, management commitment and support to employees and communication within the department (between teams), among the departments and with the top management (see table 18).

Participant	Comment
Engineer	In whiteboard meetings and problem solving sessions, we can structure our own topics and take the picture with us back home.
ENG3.1 line manager	In indirect areas we were not used to do sit-ins. Some lean tools are new for us, helping to do more with less.
ENG3.1 line manager	I didn't believe, but I tried. After doing 2 rounds of coaching with my team members, I am converted.
ENG3.1 line manager	Basically, we are acting in cooperation with other departments.

Table 18 - PDDIS framework impact: participants' feedback

The reason behind Lean Product Development application failure stands the managers and employees' inability to continue performing according to lean methodologies, according to a kaizen culture, involving everyone in a common-sense, low-cost approach applied in the product development process, in order to standardize processes, skills and design methods, the lack of support and commitment from top managers, and the non- immediate impact on the efficiency of the product development processes. As ENG3.1 line manager stated, "One of the biggest challenges is to continue living all these initiatives as a pull system, but also pushed them across the whole organization".

So, the PDDIS framework was important, because it focuses on a practice based approach, instead of focusing on improving the process, which means, it helped to standardize general processes in the Engineering department, have a better activities calendar and plan, and a quicker follow-up of implemented actions. Right from the diagnosis phase, it was clear that an increase of transparency would be the basis for efficiency gains. Daily routines and problems causing inefficiencies were not discussed in a systematic way and best practices were not shared as standards. With the integration of whiteboard meetings, every day, for 15 minutes, ENG3.1 engineers have a clear perspective of daily deliverables. During these meetings, the previous day is revised and problems with impact on efficiency are identified, and these are the background for future improvements. If they are not immediately solved, they need to be discussed in detail, through problem solving sessions. The scope of the problem is large: from the way we formulate our tasks clearly, in order to avoid different interpretations and rework, how to reduce time spent discussing FMEA's (Failure Mode and Effects Analysis) to discussions regarding error elimination. Another example concerns regular sit-ins, which means, daily process observation of an engineer by a colleague or line manager. With this tool, best practices can be defined, as well as the identification of improvement points in each process.

During the project, two main topics were addressed: E-mail and Meetings. In both cases, a great efficiency gains potential was identified, through organization adherence to restricted rules, regarding meetings' schedule and moderation, and redaction of e-mails.

To end this chapter, it is important to highlight the importance of Top Management support during a Lean Product Development framework application. Top managers have a fundamental role in maintaining this culture alive, by participating actively in whiteboard meetings, aligning with managers frequently to assess maturity of lean elements, as well as having a clear overview about the current state, success stories, existing problems and improvements in the product development process, motivating managers to perform better, which means developing new products with higher quality, lower costs, highly innovative and available on the market before competitors, increasing the company's market share and success.

As this whole process is a never-ending story, top managers must constantly push managers and team members to improve themselves, suggesting new ideas and improvement actions, which will enable companies' growth.

5. Conclusions

The following chapter starts by answering the research question raised at the end of the literature review. Subsequently, practical managerial implications will be addressed, as well as future research proposals.

"How can companies implement successfully a Lean Product Development framework, able to impact R&D processes' efficiency?"

The increased international competition in the current open global market is putting pressure on companies to improve the performance of their Product Development systems. As seen in the literature, Lean Product Development is an emerging topic and has been introduced as a concept which is able to improve the product development process, by applying lean thinking to the early stages of the product life cycle, from initial concept through to the start of full production or delivery to the client.

The Product Development process is very complex. The complexity of the process is constantly increasing as customers are ever more demanding, unstable and highly influenced by new trends, such as: customized products, innovative products with high quality and low-cost, which forces companies to adapt and react very quickly, in order to achieve a competitive advantage towards competitors.

Currently, most organizations deeply depend upon the introduction of new products to survive and conquer new markets. Thus, companies need to undergo a lean transformation, which will have a clear impact on the quality, cost and delivery of products.

The reason behind most companies' failure to try to implement lean is simple: Companies see lean as an opportunity to achieve competitive advantage but disregard the fact that the Lean philosophy is a never-ending story, set in a sustainable organizational culture of the pursuit of excellence. First of all, companies need to focus on building a strong kaizen culture, supported by a knowledge-based environment, a Chief engineer (entrepreneurial) technical leadership, a Value-focused planning and development, and finally a focus on creating a flexible, adaptable and highly responsive product development process. If companies do not have an organizational culture, based on strong continuous improvement values, implementing changes will be impossible. People are the core asset of an organization and are fundamental in the success of lean transformation.

The focus of this thesis is to understand how companies can implement a lean product development framework successfully, one that is able to impact the efficiency of product development processes. Taking into consideration the AR process and consequent application of PDDIS framework in the Engineering department, it is possible to conclude that Lean Product Development is fundamental to boost performance and growth, through a continuous improvement culture and high focus on value creation, based on daily capacity management, transparency and visualization.

To understand the real impact on the Engineering department, it is important to establish the initial state. Initially R&D teams didn't have a fluid flow of information and were not collaborative, and also had a low level of standardized processes. Thus, they felt the need for guidelines to help improve the resolution of problems and avoid wastes, such as: time waiting for information, high share of time spent at meetings and producing too many reports. Apart from this, the Engineering teams were not able to meet customers' needs and requirements, and were not measuring projects and the product development process. Additionally, engineers didn't believe in the Lean Management project, concerning product development, thus creating several barriers.
PDDIS framework implementation enabled R&D teams to build an organizational culture of continuous improvement, to identify improvement points and solve problems in a sustainable way, to level daily capacities between employees, to optimize processes, eliminating non-value tasks, and finally, to share knowledge and best practices within the department. As PDDIS framework is a continuous improvement cycle, managers must assess the department's current state, by answering to the following questions:

1. Are the changes leading to new standardized processes that are the basis for further waste reduction?
2. Are people throughout the organization engaged in continuous improvement and aligned around a common set of objectives?
3. Are all the soft tools and harder technologies being used to support people improving the delivery of products and services to customers?

The problem is lean must be applied by everyone, every day, everywhere, and without a set deadline. The essence of lean application lies exactly in the continuous challenge of being better and working towards perfection and customer satisfaction.
Lean Product Development is highly beneficial to produce faster, high quality and low-cost products, as it provides a significant contribution to fixing cost reduction and implements a new standard for sustainable continuous improvement in indirect areas, by means of:

1. A truly holistic approach with focus on customer value and management of capacities and capabilities;
2. Daily whiteboard meetings with deep associate involvement and transparent performance management based on KPI;
3. A systematic way to solve problems and improve work;
4. Top to bottom connected organization (executives on the shop floor support teams with role-modelling and coaching;
5. Daily living culture of solving problems, giving feedback and achieving targets.

To conclude, Lean management at the focal company had some problems regarding standardization of processes, as the R&D department was characterised by non-repetitive processes. The reason behind this fact has to do with the conflict between standardization and creativity/innovation, as companies, to achieve competitive advantage, must deliver products, meeting customers' demands in terms of innovation, customization, quality and sustainability at a competitive price. Despite this, the PDDIS framework was able to achieve a high share of efficiency gains, in total 26 %, representing the impact of lean product development framework regarding R&D processes efficiency towards cost, quality and delivery.

5.1 Managerial Implications

The PDDIS framework provides a new concept that goes beyond the typical Lean Manufacturing paradigm of waste elimination to an environment that supports creativity and value creation. Its implementation requires a high commitment and a continuous focus on changing for better, in order to achieve excellence. From all stakeholders involved, managers play a key role, as they must act as role models, raising engineers' attention about the need for change and being adaptable to volatile demand from customers.

In order to achieve a successful implementation of the PDDIS framework, managers must focus on the following topics:

Organizational culture: In order to improve understanding and raise awareness in the organization, regarding the PDDIS framework, managers must organize regular meetings with employees frequently, to present results and share success stories, to show lean impact regarding product performance, quality, cost and efficiency gains, increasing the commitment of people to change, since they feel they play an important role in the company's growth and success.

Setting goals: Any process improvement requires pre-defined goals and targets. Managers must commit and involve employees in the process, establishing real but ambitious Specific, Measurable, Action-oriented, Relevant and Time-Bounded (SMART) targets.

Role-modelling: Managers are examples to employees. Accordingly to Liker and Morgan (2006), a successful Chief Engineer is sometimes referred to as a 'heavyweight project manager', who has proven engineering excellence, leadership skills to control the programme, and acts as the critical link between engineering and customer satisfaction.

PDDIS framework: The Engineering department must use this framework in all product development processes, ensuring a standard procedure regarding products. Managers must share this knowledge among employees and implement mature lean standard elements, such as: Whiteboards, Tactical Implementation Plan (TIP), Coaching, Trainings, Sit-ins, Problem Solving Sessions, Feedback, Best Practices and Skills Matrix, enabling employees' development.

Design of product development process roadmap: In order to find improvement points, regarding the product development process, managers must schedule frequent meetings with employees with the aim of creating a roadmap of activities, addressing problems, finding solutions and defining responsibles. This must be an action that is not dependent upon problem identification by employees, rather a fixed time slot dedicated to generating process improvements and new ideas, to boost performance. With this roadmap, Engineering teams must define what must be considered as value-addition in the R&D processes.

5.2 Limitations and future research

With regard to the limitations of this thesis, some issues must be pointed out, which influence the quality of the output. Firstly, only preparation, diagnosis, design and implementation phases have been completed during the internship, the tools of which need to be re-tested and matured during the sustainability phase, as differences are expected in the organizational settings, in the way activities are carried out and in the maturity of lean elements. Another important limitation regards confidentiality of focal company information and the Lean Management project, which focused on creating a continuous improvement culture, based on a knowledge based environment, with a chief engineering entrepreneurial leadership, instead of focusing on process improvement.

This thesis' findings have helped identify some challenges that will have to be addressed in future research. This research has had an explorative nature since research done in Lean Product development still lacks physical evidence of Lean impact, concerning the product development process. Thus, a new Lean Product Development framework was tested in a manufacturing company, with the purpose of gathering results regarding lean impact in R&D processes. This impact was achieved by the creation of a daily living culture of solving problems, feedback and the definition of Specific, Measurable, Action-Oriented, Relevant and Time-Bounded (SMART) targets, with a focus on customer value and management of capacities and capabilities.

Finally, PDDIS framework is a standard model, which can be applied to all indirect areas. Therefore, in future, an AR process could be applied to other areas, such as: Logistics, Product Management, Process Development, Marketing, Quality, Purchasing, among others.

6. References

Al-shaab, A. & Sobek II, D. K. (2013). Lean Product and process development: a value creation paradigm that beyond lean manufacturing. International Journal of Computer Integrated Manufacturing, 26:12, 1103-1104.

Baines, T., Lightfoot, H., Williams, G.M., and Greenough, R. (2006). State-of-the-art in lean design engineering: A literature review on white collar lean. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 220:1539.

Cagliano, R., Caniato, F., Corso, M. & Spina, G. (2005) Collaborative improvement in the extended manufacturing enterprise: lessons from an action research process, Production Planning & Control: The Management of Operations, 16:4, 345-355

Chiesa, V., Frattini, F. (2007). Exploring the differences in performance measurement between research and development: evidence from a multiple case study. R&D Management 37, 283-303

Cooper, R.G., & Edgett, S. J. (2008). Maximizing Productivity in Product Development. Industrial research Inc., 47-58

Dombrowski, U., Zahn, T. (2011). Design of a Lean Development Framework. Institute for Production Management and Enterprise Research

Driva, H., Pawar, K., & Menon, U. (2000). Measuring product development performance in manufacturing organizations. International Journal of Production Economics, 147-159.

Dutton, W. (2014). Lean New Product Development - learning in action. Manchester Business School

Fontes, N. (2013). Walking to the TOP – Como alcançar uma performance exceptional. Top Books

Geisler, E. (1994). Key Output Indicators in Performance Evaluation of Research and Development Organization. TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE 47, 189-203.

Geisler, E. (1995). An Integrated Cost-performance model of research and development evaluation. Omega International Journal of Management Science (23), 281-294.

Idhammar, C. (2010). Leading and lagging reliability and maintenance key performance indicators. Maintenance. Pulp & Paper International (PPI), 10.

Imai, M., (2012) Gemba Kaizen – A commonsense approach to a continuous improvement strategy. Second Edition. Mc Graw Hill

Kennedy, M. (2004). The Toyota product development system. Machine design, 154.

Khan, M. S., Al-Ashaab, A., Shehab, E., Haque, B., Ewers, P., Sorli, M. & Sopelana, A. (2013). Towards lean product and process development. International Journal of Computer Integrated Manufacturing, 26:12, 1105-1116.

Lander, E., & Liker, J. K. (2007). The Toyota Production System and art: making highly customized and creative products the Toyota way. International Journal of Production Research, Vol. 45, No. 16, 3681-3698.

Liker, J. K., & Morgan, J. M. (2006). The Toyota Way in Services: the Case of Lean Product Development. Academy of Management Perspectives, 5-20

Mohammadi, Ali (2010). Lean Product Development – Performance Measurement System. Master of Science in Innovation and Industrial Management, University of Gothenburg.

Parmenter D. and. Wiley, J. (2010). Key Performance Indicators. CMA MANAGEMENT,6.

Reinerten, D. & Shaeffer, L. (2005). Making R&D Lean. Industrial research Institute Inc., 51-57

Ringen, G. and Holtskog, H. (2011). How enablers for lean product development motivate engineers. International Journal of Computer Integrated Manufacturing, 26:12, 1117-1127.

Sorli, M., Sopelana, A., Taisch, M., Al-Shaab, A., Keast, J., Flores, M., Skotic, D. and **Martinez, L. (2010).** Applying Lean thinking concepts to New Product Development. International Conference Advances in Production Management Systems Book of Abstracts

Womack, J.P. and Jones, D.T. and Roos, D. (1990). The machine that changed the World. New York. Simon and Schuster.

Womack, J. P., Jones, D. T. (1996). Lean Thinking (Simon & Schuster, New York)

Womack, J., & Jones, D. (2003). Lean Thinking: Banish Waste and Create Wealth in Your Corporation. New York: Simon and Schuster.

Appendices

Appendix I – Maturity Assessment template

Observations	0 ⇨ Level 1 ⇨	Level 2 ⇨	Level 3 ⇨	Level 4 ⇨	Level 5 ⇨
A. Daily whiteboard meetings	☐Whiteboard with all mandatory content established ☐All elements covered in meeting ☐Timing is respected	☐Level 1 fulfilled ☐Connection between different whiteboard elements is understood ☐Purpose can be explained	☐Level 2 fulfilled ☐Balanced talking / listening ☐Associates are involved in bringing up problems on a regular basis	☐Level 3 fulfilled ☐Involve associates in systematically identifying issues whenever there are gaps on KPIs and sharing best practices	☐Level 4 fulfilled ☐Whiteboard meetings are leading to actions for coaching of associates ☐Regular review of whiteboard and benchmarking with others
B. Best practices	☐Associates are aware of purpose of best practices and routine of best practice sharing is defined ☐>3 best practices related to core tasks under development	☐Level 1 fulfilled ☐>3 best practices related to core tasks tested and approved by managers	☐Level 2 fulfilled ☐>3 best practices related to core tasks adequately documented and used systematically ☐Further (small) best practices shared	☐Level 3 fulfilled ☐Entire team involved, best practices continuously updated / adapted ☐Best practices for tasks covering 50% of the department's time	☐Level 4 fulfilled ☐Best practices for tasks covering 80% of the department's time ☐Best practices revised at least every 6 months (enforced)
C. Sit-ins	☐Objectives of Sit-ins are clear to managers and associates ☐First Sit-ins have been done with all associates	☐Level 1 fulfilled ☐Sit-ins are prepared upfront (e.g. what to observe) ☐Sit-ins are used to verify adherence to best practices	☐Level 2 fulfilled ☐Sit-ins are done in adequate frequency, planned ahead and not skipped / shortened on short notice	☐Level 3 fulfilled ☐Issues identified in Sit-ins are leading to problem solving ☐Best practices identified in Sit-ins documented and shared with team	☐Level 4 fulfilled ☐Training of new processes / new associates / technical support is clearly differentiated from Sit-ins
D. Coaching sessions	☐Manager is taking a deep dive on how associates are feeling and root causes	☐Level 1 fulfilled ☐Manager asks open questions ☐Coaching sessions are action oriented and manager is responsive	☐Level 2 fulfilled ☐Sessions scheduled in appropriate frequency with each associate ☐Manager balances talking / listening, involves staff, shows empathy	☐Level 3 fulfilled ☐Formalized personal development plan (e.g. coaching log) owned by associate ☐Coaching sessions build on trustful relationship, sharing of feelings	☐Level 4 fulfilled ☐PDPs in line / linked to future state skill matrix
E. Performance dialogs (structured performance review with next higher hierarchy level)	☐Covering all KPIs, productivity and non-productivity ☐Discussion of deviations	☐Level 1 fulfilled ☐Meeting prepared and meeting agenda clearly defined ☐Timing is respected	☐Level 2 fulfilled ☐Dialogs are structured and leading to adequate problem solving sessions and update of TIP	☐Level 3 fulfilled ☐Balanced talking / listening ☐Involving associates, escalations from teams and teams' solutions	☐Level 4 fulfilled ☐Timely sharing of information, clear split between short-, medium- and long-term issues
F. Problem Solving and weekly team meetings	☐Problem solving sessions are being scheduled as a routine ☐Team is coming up with clear problem statements	☐Level 1 fulfilled ☐Problems for specific problem solving session are selected properly	☐Level 2 fulfilled ☐Problems addressed continuously ☐Deep dive on problem root causes (e.g. issue tree used regularly) ☐Problem solving linked to other tools (e.g. TIP) to ensure follow-up	☐Level 3 fulfilled ☐Manager balances doing and delegating and involves associates ☐Team members are coached in problem solving	☐Level 4 fulfilled ☐Problems identified are rapidly solved and solutions implemented ☐Structured PS sessions used on appropriate topics
G. Tactical Implementation Plan (TIP)	☐Purpose of TIP understood	☐Level1 fulfilled ☐Weekly review / discussion of TIP ☐TIP updated on a regular basis by each team	☐Level 2 fulfilled ☐Management reviews TIP regularly ☐TIP used as single plan for all actions of the team	☐Level 3 fulfilled ☐Actions of TIP are being completed according to plan	☐Level 4 fulfilled ☐TIP includes actions to strengthen Continuous Improvement and the team
H. Skills matrix	☐First version of skills matrix established (list of skills with priorities and evaluation of each team member)	☐Level 1 fulfilled ☐Development target is defined for each skill and each team member	☐Level 2 fulfilled ☐Detailed action / training plan to reach development target	☐Level 3 fulfilled ☐Sit-ins are leading to a reflection on necessary updates of Skills Matrix ☐Skills matrix is used as an input for Capacity Mgmt decisions	☐Level 4 fulfilled ☐Skills matrix is used to drive capacity management between teams and also revised with respect to strategy of area
I. Capacity management	☐Daily capacity is visualized and reviewed during daily check-in ☐Team understands how to evaluate daily capacity	☐Level 1 fulfilled ☐Daily tasks are prioritized in check-in based on available capacity and re-allocated where possible	☐Level 2 fulfilled ☐Issues identified in daily capacity mgmt leading to problem solving ☐Mid-/long-term capacity mgmt tool is existing (can be simple tool)	☐Level 3 fulfilled ☐Mid-/long-term capacity reviewed regularly and mid-/long-term tasks planned accordingly ☐Capacity mgmt improved continuously	☐Level 4 fulfilled ☐Capacity mgmt linked with other elements (skill development, future organization, strategy of the area)