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Master of Science in Management Engineering

Proposal of a Methodology for the Continuous Improvement of Product-Service Development Process

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Abstract

This thesis aims to widen a Methodology, based on the principles and techniques of Lean Thinking, which allows Companies to improve their Product Development processes into a methodology that also improves the service development process. It tries to give an answer to the Companies need to review and optimize their Product-Service development processes affected by constantly changing markets and increasingly complex customers.

The Methodology proposal is a result of the work of previous colleagues that was originated from the Lean Thinking techniques and their application in Product Development field. Afterwards, it has been adapted and tested by carrying on some "on the field" experiences with business subjects who have provided key knowledge to its refinement.

The Methodology seeks at continuous improvement of the Product-Service Development processes which are consonant with the context in which Companies operate. This means that when a corrective action is carried out it cannot be exclude from future analysis because maybe in those future analysis the change is a waste. This also fits with the Lean perspective that put the *constant research for perfection* as one of its pillar. For the same reason it is a recursive Methodology compound by five steps, that go from the systematic identification of waste in PSD process, to their removal, until the introduction of targeted corrective actions. Those steps are:

1. **Waste Identification & Evaluation**. The starting point to develop this phase is an existing list of waste likely to be found in NPSD processes and a Priority Index (PI) to evaluate them. This phase is the one widened so as to include and include the service into the product development analysis.

2. **Waste Prioritization**. On the basis of the PI, in this phase wastes are put in a priority order and the first to be removed are chosen. Beside this, in association to them also potential detection ways and corrective actions are defined.

3. **Sub process identification.** It consists in the determination of the sub process affected by the main wastes and so to be improved.

4. **Sub process analysis.** This phase deals with the sub process analysis to find the critical and eliminate them. Also in this phase several alternative methods have been proposed, with a deepening on Value Stream Analysis and Map.

5. **Corrective Actions.** In this phase, the correctives actions to be implemented are chosen according to the effort required and the effect that they produce, PICK matrix as a tool is suggested.

To test the previous steps listed and also to acquire some feedback about the rightness of the methodology, two cases were conducted. On the one hand, the 5 steps were applied in the car sharing company Car2go which is a very clear example of a product-service. On the other hand, the Politecnico di Milano involvement in Manutelligence consortium gave the opportunity to be in touch with Fundació CIM (based in Barcelona) which manages several Ateneus of Digital Fabrication. These ADFs are places where everyone can go with an idea and transform it into a prototype. Thanks to this collaboration, it was provided another case study with different level of servitization (compared to de Car2go one) on which to perform the first full application of the Methodology.
As a result, these activities have highlighted the forces of the Methodology that are its intuitiveness, short implementation time and easy to implement by people without experience, after a brief introduction to Lean Thinking and its techniques. At the same time, several limits have been found and accepted as starting points for future researches and insights.

The thesis is structured in the following Chapters:

- Chapter 1, ***Product-Service Systems***: This is the opening Chapter, it provides an overview of the context in which the work has been developed, focusing in particular on the current importance of Product-Service Systems. In addition, it explains the objectives and the structure of the thesis are stated.
- Chapter 2, ***Tools and Methodologies for LPSD process: State of the Art***: This Chapter is a deep analysis of literature on Lean, by exploring its principles and technique and it shows the state of the art as regards to their application in Product-Service Development context.
- Chapter 3, ***The proposed methodology***: In this Chapter is shown the initial methodology in which is based the new one and a guide to its implementation is provided. Then, the additions to it are explained and the process to get to them is detailed.
- Chapter 4, ***Business Case Application:*** It exposes the business cases of Car2go and ADF giving complete examples of Methodology implementation.
- Chapter 5, ***Conclusions:*** This is the final Chapter where a summary of the methodology analysis is given and suggests future researches and investigations.

Chapter 1

1. Product Service Systems

1.1. Introduction to PSS

In most developed countries, the service sector has a share of 70-80% of the entire gross domestic product [1]. The paradigm of developing solutions only in the form of physical products to be sold must be broken, because value is not necessarily provided through the sale of the product, but by means of the functionality or result it can generate. So even ordinary manufacturers experience an increasing need to understand and integrate services in the form of Product-Service Systems.

Product service system (PSS) is a new concept emerging in recent years due to the rise of competitive business environment, the call for sustainable development as well as the need of finding new ways for customer engagement (T. Tran & J.Y. Park [2]). Generally, PSS is the combination of product, service, delivery network and related stakeholders. In this new paradigm, a company provides its customers with an offering including tangible product and intangible service. This new concept of providing "offerings" is much different from the traditional selling of exclusively physical products which is a market in which is becoming more and more difficult to compete. Moreover, this difference is especially emphasized by today's scenario of economic crisis, growing environmental issues and diversified customer demands. What is more, the utilization of PSS in business can help companies to enhance competitiveness, achieve social, environmental, and economic goals, as well as attract and retain customers.

1.2. PSS definition

Goedkoop et al. [3] gave the first formal definition of a Product Service System (PSS), defining its three constitutional elements:

- Product: a tangible commodity manufactured to be sold, capable of fulfilling a user's need
- Service: an activity done for others with an economic value and often done on a commercial basis
- System: a collection of elements including their relations

Sassanelli et al. [4] explain some of the most relevant citations of what a PSS is, all of them, "adding some elements to the Goedkoop's definition, but keeping it as the core". The first

one, given by Goedkoop says that ‘a PSS is a system of products, services, networks of “players” and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models’.
In 2002 the Centre for Sustainable Design[5] defined a PSS as ‘A pre-designed system of products, supporting infrastructure and necessary networks that fulfil users’ needs on the market, have a smaller environmental impact than separate product and services with the same function fulfilment and are self-learning’.
Previously, in 2001, Mont [6] described it as ‘A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models’.
Later on, Manzini et al. [7] explained the concept as ‘an innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands’
At the same time, Brandstotter et al. [8] characterize a PSS saying that it consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs. Additionally PSS tries to reach the goals of sustainable development.
At last, Wong [9] characterized a Product Service-Systems (PSS) as a solution offered for sale that involves both a product and a service element, to deliver the required functionality.

1.3. Benefits, barriers and challenges for the adoption of PSS in the industry

For the customer, a PSS is seen to provide value through more customization and higher quality (e.g. improved machine availability for a machine tool within a specific factory context). The service component, being flexible, can also deliver new functionality better to suit customer needs and is often described as removing administrative or monitoring tasks away from the customer and back to the manufacturer. For most reported PSS cases, the customer receives value in a form that is close to current needs.
For traditional manufacturers, PSS is claimed to provide strategic market opportunities and an alternative to standardization and mass production. The fundamental business benefit of a PSS is an improvement in total value for the customer through increasing service elements. Competitive edge

is enhanced as, for example, a service element that is not easy to copy and facilitate, communicates information about the product-service package. The environment also benefits from PSS since a producer becomes more responsible for its products-services through take-back, recycling, and refurbishment – reducing waste through the product's life. For manufacturers, the potential to use their technical knowledge to find ways to deliver same or better value-in- use while using less energy or material is said to offer the potential to reduce cost (as well as environmental impact).

For a State and the global environment, adoption of PSS can lead to reduced resource use and reduced waste generated since fewer products are manufactured using fewer materials per use. Similarly, successful PSS applications can, through the increase in sales and service activities, offset the loss of jobs in traditional manufacturing and, as public pressure on environmental issues grows, the widespread promotion and adoption of PSS is favoured by government bodies. This is demonstrated by the interest shown in PSS by Sweden and the Netherlands who tend to lead in the adoption of environmentally sustainable business.

This exploration of the benefits leads to summarize that there are a wide range of benefits of a PSS. To the producer it means an offering of higher value that is more easily differentiated, to the customer it is a release from the responsibilities of asset ownership, and to society at large a more sustainable approach to business.

On the other hand, the adoption of a PSS strategy brings with it significant cultural and corporate challenges. As in [10] explain, the majority of authors see the main barrier to the adoption of a PSS as the cultural shift necessary, for a consumer to place value on having a need met as opposed to owning a product. Wong [9] argues that the success of a PSS solution in the consumer market is highly dependent on being sensitive to the culture in which it will operate. He notes that PSS solutions have been more readily accepted in the communal societies of Scandinavia, the Netherlands, and Switzerland. Within those organizations that might desire to design, make, and deliver a PSS, the significant change in the system of gaining profit could deter producers from employing the concept [3], firstly through limited experience in pricing such an offering, secondly through fear of absorbing risks that were previously assumed by customers, and thirdly through lack of experience in structuring an organization to be competent at designing, making, and delivering a PSS. Likewise, an effective PSS is likely to be more complex for a manufacturing organization than the existing way of delivering functionality through the provision of a product alone. This will require changes to be undertaken at the functional and systemic level.

1.4 Objective and Structure of the Research

On the sections above is explained the relevance of the Product Service Systems (PSS) in nowadays competitive environment. Due to this reason, this work is focused on this business model.

This section points out the objectives in this research and it explains how is structured and the goal of each part.

The aim of this study is to broaden the "*My waste methodology*" so as to detect not just the PD process wastes but to also achieve to recognize the ones produced when the service offer is added.

The proposed Methodology implements Lean principles and tools in five simple steps and support Companies when improving their PSS processes. This methodology is a schematic and well-organized tool that detects waste and removes it by introducing a series of corrective actions.

The final purpose of this tool is not to get to a definitive solution but to carry through regular and continuous improvements that are in concordance with the Lean viewpoint.

Thanks to the Politecnico involvement in the Manutelligence consortium it was possible to establish contact with the Fundació CIM that is also member of this consortium. Fundació CIM provided an important study case that was the Ateneu of Digital Fabrication (ADF). They were involved in the methodology implementation and they had the last word in the final decisions of the path to follow and the corrective actions that could be applied. The second case (Car2go) it was carried out from an external point of view because of the difficulty to make contact with the company to obtain data. All the results of these analyses are the main part of this thesis work and they are available in the next Chapters.

The thesis is structured in five Chapters. This one, the first, introduces the research context, objectives and structure. Chapter 2 contains a literature review on Lean New Product Development and the state of the art with Lean New Product-Service Development. Chapter 3 first describes the initial Methodology with its five steps and then it explains how it is improved. Chapter 4 deals with the full implementation of the Methodology in two study cases and its results. Chapter 5 which is the conclusive one summarizes the work and give leads to further researches.

Chapter 2

2. Tools and Methodologies for LPSD process: State of the Art

2.1. Introduction

In the long run, if a PSS was to be created there are two important changes in company processes that should be done: firstly, traditional product lifecycle has to be enhanced by including also service management; secondly, to realize a service-oriented ecosystem, the product-oriented company model must be extended. So as to do that, in this chapter it will be explained the Lean New Product Development theory and the techniques used to implement it. It also will be introduced an overview on what is it to apply lean techniques to the PSSs and how it is evolving in the recent years.

2.2. Lean New Product Development (LNPD)

2.2.1. Introduction to LNPD

In today's globally competitive environment speed is everything. Design teams need to be fast, flexible and highly effective. Markets are characterized by wide variety of products and product life cycles shorter and shorter, which means that Product Development activity is becoming increasingly important. To be feasible, new products must succeed both technically (customer approval) and financially (generate sufficient revenue to cover all costs). In this context, another important element is the ability for a company to develop new products faster than the competitors.

Lean concepts are applicable to a wide range of processes, people and organizations, from concept design to the factory floor, from the labourer to the upper management, from the customer to the developer. While at manufacturing level there have been many cases of lean principles and practices applications, which have been more or less successful, regarding product development, dissemination and application of these criterions and practices is still very low. In fact, most of companies still make use of traditional approach to Product Development. Anyway, these two approaches differ in the basic logic that characterizes them. The traditional launch strategy is forecast driven and is based on anticipatory logistics (push, figure 2.1).

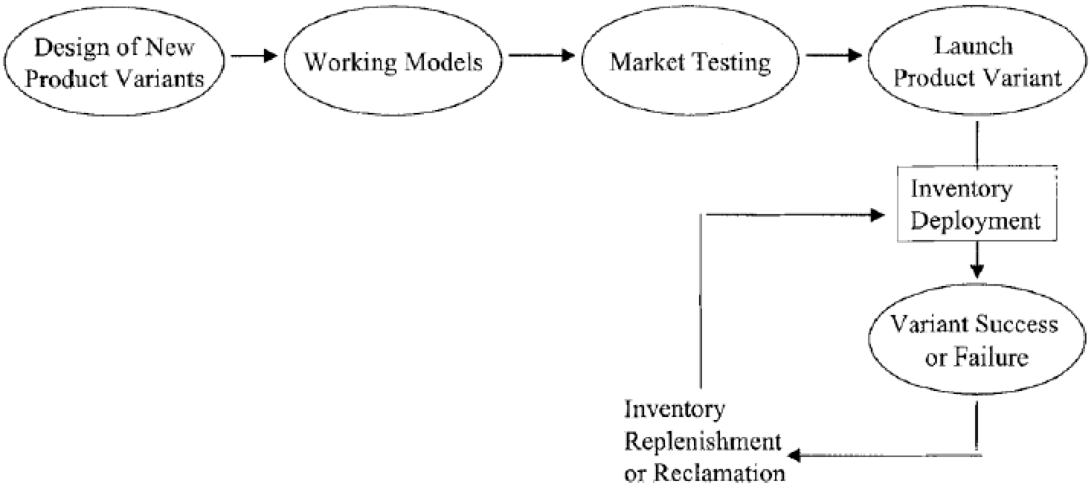


Fig.2.1: Traditional new product development process (Bowersox, Stank, Daugherty, 1999)

Otherwise, the lean launch strategy is formulated on principles of postponement and is based on response-based logistics (pull, figure 2.2) and supply management.

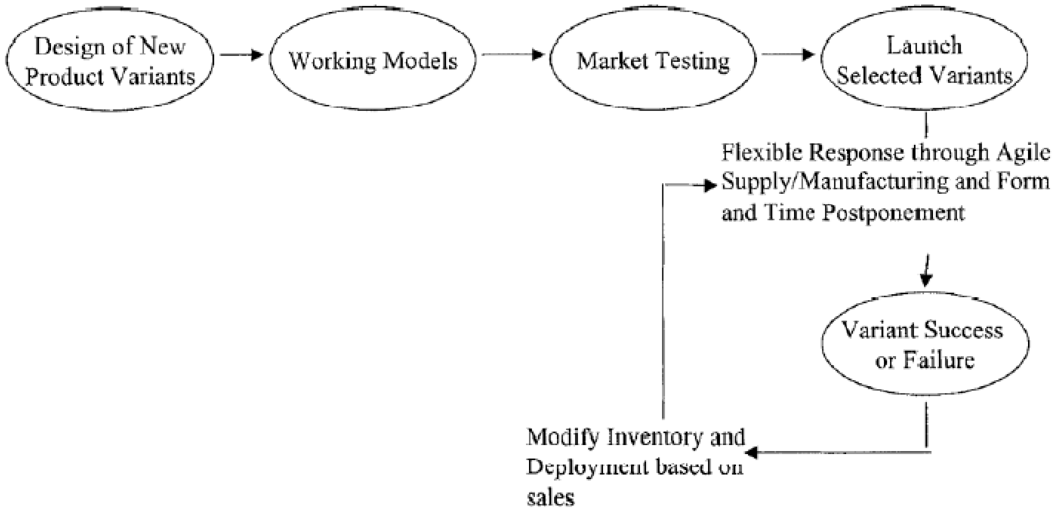


Fig.2.2: New product development process with Lean launch (Bowersox, Stank, Daugherty, 1999)

Applying lean philosophy in Product Development processes can lead to several advantages, some of them are given below:

- Enabling the company to develop products faster and with fewer engineering hours than the competitors.
- Manufacturability of products improvement, thanks to the emphasis on collaboration between different areas within the company.
- Production start up difficulties prevention, thanks to a conscious effort to use quality as a guiding principle through the whole development.

- Increase of technological sophistication of products and development process acceleration, due to the extensive use of suppliers as expert developers.

2.2.2. Lean 5 principles

The five-step thought process for guiding the implementation of lean techniques is easy to remember, but not always easy to achieve. Following these five principles of Lean ensure driving towards the overall organisational strategy by constant review of the processes to ensure that they are constantly and consistently delivering value to the customer. This allows the organisation to maintain its high level of service whilst being able to grow and flex with a changing environment.

These 5 steps are:

- ***VALUE***

Specify what the value is and what you're trying to do – an element that only can be described by the customer.

Establishing user value is far from as easy. It means understanding usefulness (user problem and the product is solving), usability (ease with which the user is able to benefit from the product), and desirability (emotional connection or social capital) and building these insights into a design from the first concepts. In order to achieve this understanding it should be secured early and regular feedback through spiral development and usability testing.

Companies can no longer afford to maintain a linear progression where all homework is done up front and then a full definition is fixed for the duration. Therefore, rather than the traditional "get it right first time" mindset, companies are discovering that it is actually faster and more accurate to do it wrong the first time. Get something (almost anything) out there, and customers can articulate what is failing to impress them (spiral development). This approach requires teams to think about product development and "failure" quite differently. With such an approach it is useful to think of product development as a series of decisions or forks in the road. Rapidly created and expendable prototypes can help teams to navigate these forks. The trick is to design the prototype that gives clear guidance at each fork – essentially being aimed at answering only one question – so that the team can get past it and move on to the next one, quickly and accurately.

- ***IDENTIFY THE VALUE STREAM***

The core set of actions required to produce a product – the individual steps you have to do to deliver the identified value.

The Toyota Way by Jeffrey Liker describes one method of developing and implementing value stream maps - through 'Kaisen' (continuous improvement) workshops. Toyota workshops are typically one-week events where participants analyze the current process, develop a lean vision for the process, and begin implementation. Participants in the event must include the manager responsible for the process being improved (process owner), who is the team leader of the event, along with the people who actually do the work within the process. It is also advisable to include customers and suppliers of the process in the event. However, wherever possible the workshop should also be limited to 15 people. There are three phases:

PREPARATION

a. *Clearly define the scope*: Determine the start point that begins the process and what the final deliverable is.
b. *Set aggressive goals and align goals with corporate objectives.*
c. *Create current-state map:* Have a side group of three or four participants walk through the current process and time how long it takes to perform the tasks and the wait times between processes.
d. *Collect documentation* (Samples of forms and documents used at each step).

THE WORKSHOP

a. *Identify the customer:* This step can be complex and there may be more than one
b. *Analyze the current state:* This is to identify what is value added (what is the actually transformation process that is core to the service the customer is paying for).
c. *Develop future-state map:* Challenge participants to create a future state map that eliminates waste, improves first-time quality and optimizes flow through the entire process and to lay out the new flow of tasks (brainstorming is useful here).
d. *Implementation:* Develop a project plan with what, when and who. Implementation activities might include workplace reorganization, creation of standard instructions, a redesign of forms and documents, problem-solving activities (to uncover quality problems), and training.
e. *Measure performance*: Track progress toward future state and ensure gains are sustained.

POST WORKSHOP

Follow plan-do-check-act cycle. The team should meet on a weekly basis to: Review status of open project plan action items, review process metrics, discuss additional opportunities for improvements, and continue to improve process.

- ***FLOW***

Managing flow is concerned with the movement of a product development programme through the sequential phases of development, engineering, design, validation, and launch. It's analogous to the movement of components and systems through the automobile assembly line. In product development it is not a physical product that flows along the "line," but all the business and technical programme information that is needed to create a winning product.

During product development, this information comes from many different sources and in different types of media - CAD files, blueprints, and presentations. With potentially hundreds of people working on a programme simultaneously, understanding the main line flow and supporting flows is critical for determining interdependencies and priorities. Understanding these flows also helps simplify the complex product development process so you can align the different phases of development and formulate clear target requirements. In addition, you can ensure that "main line stations" - the major steps within each development phase - are appropriately connected and sequenced. That way you can prevent wasteful rework cycles or worse, product characteristics and functions that don't meet your customers' needs.

The lean work cell is the basic unit of the product development factory. Unlike a traditional line up, where functions operate independently of one another, the work cell consists of representatives from each of the engineering and non-engineering functions needed to complete a particular product specification or development activity.

This setup helps both to reduce the time needed to complete the required activities and to identify potential problems early on in the process. It's instructive, in fact, to think of the entire product development process as a network of connected work cells.

Each product development work cell team completes its own set of deliverables, which it then hands off to the next work cell in the line to work on. When that work cell completes its set of deliverables, it hands it off to the next in line, and so on - a streamlined arrangement that reduces costs, improves quality, and increases productivity.

Fig.2.3: Work cell improvement flow [11]

- ***PULL***

Let the customer pull – the customer should begin to pull the product on an "as-needed basis" – don't simply turn the process on and begin to "pile up" product).

The "pull" concept is especially important during the design phase because it ensures that all activities in the development program are in sync with end-customer requirements. "Pull" techniques help translate customer requirements accurately into product design, functional engineering, and process design. These techniques also ensure that critical requirements are transferred consistently between the different main-line stations. In addition to helping with design requirements, "pull" is useful for managing work cell flow. It helps streamline the flow of information and activity between individual work cells, and can even be applied to cells that start their work simultaneously. A "kanban," or "pull" signalling system ensures that specification documents are not delivered to the process customer until the "customer" - the cell that needs those documents to complete its work - sends a clear signal indicating it's ready to receive them. For example, a prototype build shop would publish open "Build Slots" as a signal for a program to submit final build specifications. There is a queue of work, which goes through a number of stages of development until it's done. When work is completed in a stage, it goes into a downstream queue for the next stage. When someone needs new work to do, they pull it from their upstream queue. However, there is one more important element which really defines a "pull" system, limits.

Queue limits

These are designed to avoid premature work (and is how just-in-time is achieved). The limit should be large enough to keep the team busy bust small enough to avoid premature prioritization (i.e. having things sitting in a queue before they are begun).

WIP (Work In Progress) limit

These are designed to reduce multi-tasking, maximize throughput and enhance teamwork.

- ***PURSUE PERFECTION***

Develop and amend the process continuously to pursue perfection – it's a changing world and you can always make things better

There are three major components to pursue 'perfection' in Lean Product Development:

- Having performance metrics in place
- Establishing team accountability for results
- Building in learning and improvement

2.2.3. Lean 8 wastes

Lean product development focuses on creating value, starting from the elimination of wastes. The eight wastes (7+1) elaborated by Locher (2008)[12], basing on Liker's classification (Morgan and Liker, 2006) are:

- ***Overproduction***: producing more or earlier than the next process needs. This is common when processes are not synchronized across functional organizations. Examples of this include any task that is completed before the next step is ready to process it, or on the contrary downstream operations working on upstream design prematurely in an effort to do concurrent engineering.
- ***Waiting:*** waiting for materials, information, or decisions. It happens when engineers seem to be in a state of perpetual motion, always rushing from meeting to meeting or absorbed in something on a computer screen. From the perspective of a work stream there is often some key activity that engineers should be working but cannot because they do not have what they need to proceed with the given task. Waiting is one of the most relevant wastes in NPD.
- ***Transportation or Conveyance:*** moving material or information from place to place. It means that information change hands, maybe by word, picture, data exchange. It is a commonly recognized dysfunction of NPD process.
- ***Processing:*** doing unnecessary processing on a task or an unnecessary task. This waste includes engineers' errors or system flaws. The first one can be reduced thanks to people training. It can also consist in re-design components instead of using carry-over or creating new manufacturing process for each program instead of working to a standard manufacturing process.

- ***Inventory:*** a build up for material or information that is not being used. As in manufacturing, it is the direct result of overproduction. It means excess of information, such as designs that wait for the next available resource. Information waiting in queue to be processed is the most dangerous waste. Often this leads to a late project. Usually these problems stay hidden and, by the time someone discover them, they have already resulted in extensive rework and long lead times.
- ***Defects and Corrections:*** inspection to catch quality problems or fixing an error already made. In product development means to made program audits, reviews, testing new components instead of reusing proven ones, late engineering changes and all for rework. This is also a common waste, often one third of resources are employed on this.
- ***Motion***: excess motion or activity during task execution. This happens when people attend unnecessary meetings, create redundant status reports or prepare and participate to unnecessary projects reviews (Morgan and Liker, 2006).
- ***Underutilized people's abilities:*** This waste concerned the bad management of people's capabilities. It happens when there is not sufficient sharing of knowledge between employees or when are given no responsibility to people that feel unmotivated. It is also a waste to bad communicate with suppliers. This eighth waste is shared by several firms that recognizing that front line workers are the most knowledgeable resource for improvement.

Since the object of the NPD process flow is information, an essential part of the whole Lean NPD process is surely the Knowledge Management.

2.2.4. Lean enablers for LNPD

Lean enablers allow the full and correct implementation of lean thinking because it is not enough identify waste and create value, simply by implementing the lean five principles. In other words, in order to obtain a lean product development process it is necessary to adopt several practices, supported by appropriate tools, which can be real instruments, methodologies or techniques (Lean Enablers, table 2.1). There are three enablers' types:

- **Knowledge** management and sharing. This class includes tools that allow capturing, store, and sharing and disseminating knowledge. They can be methodologies, such as the LAMDA-Process or tangible resources like A3-sheets.
- **Design** processes. This category comprises tools that support design activities, making them more efficient such as CAD or CAM technologies or more effective as QFD methodology.

- **Management** activities. This refers to a set of tools that facilitate the introduction of lean principles by acting on the organization, people and management techniques.

KNOWLEDGE	DESIGN	MANAGEMENT
LAMDA-Process	QFD	Cross-functional teams
A3-report	Design for X	Team integration
Trade-off curves	CAD/CAM Technologies	Chief engineer
Check-sheets	Modularity	Mentoring
Visual planning	Six Sigma	Introduction program
Obeya		Supplier involvement

Table 2.1: classification of the most relevant enablers

- **Knowledge:**

LAMDA-process. Represent the Toyota learning cycle that occurs inside the PDCA (Plan, Do, Check, Act) cycle. LAMDA-process includes five phases, which are:

Look → Go see for yourself.

Ask → Get to the root cause of the problem.

Model → Use some kind of analysis simulation or prototypes.

Discuss → Communicate with mentors, developers of interfacing subsystems etc.

Act → Test your understanding experimentally.

The main ideas of this process are enclosed in the first two phases: look and ask.

A3-report. It can be conceived as an instrument for documenting knowledge, during the learning process; LAMDA-process itself. This report aims to provide a summary of the problem through a brief visual presentation, which allows communicating and transferring information, instead of using long report in which the key points are covered by the large amount of information. The A3 report is so named because it is written on an A3 sized paper.

Trade-off curves. It is a simple, yet powerful tool, largely used by Toyota in their product development process and it is generally represented on sheets of A3 size. This size allows to see the whole picture without having attempted to remember something seen before and forces to bring in over the information in simple visual forms. The chart shows the limits of what can be done with a particular technology. It also represents data in a visual form, by transforming them in useful knowledge. Even if the curve is derived from an equation or a simulation, developers can instantly understand and apply.

Check-sheets. It is an essential tool, used by Toyota for collecting knowledge.

These can be seen as a map of the existing and owned knowledge in a particular sector. Liker associates them to checklists or reminders of items that cannot be overlooked in designing something.

Liker also states that ideally, engineering checklists are an accumulated knowledge base reflecting what a company has learned over time about good and bad design practices, performance requirements, critical design interfaces, critical to quality characteristics, manufacturing requirements as well as standards that communize design.

Visual planning. It is a tool to represent projects, problems and any other issue. It provides a physical representation of the problem, usually by a large billboard and several post-it attached to it. The goal is to have the whole problem exposed in a unique place with a logical illustration of the actions to be carried out, the people involved and the time line. It provides a global and immediate vision of the project status and evolution.

Obeya. It is a room where cross functional teams visualize knowledge through A3-reports or other visual presentation posted over the wall analyze progress and get an overall view of the status of the project.

- **Design**

- **QFD.** The basic design tool of management approach also known as Quality Function Deployment (QFD). It is a set of planning and communication routines, that focuses and coordinates skills within an organization, first to design, than to manufacture and market, goods that costumers want to purchase and will continue to acquire. The foundation of QFD is the belief that products should be designed to reflect customers' desires and tastes; for this purpose, marketing people, design engineers and manufacturing staff must work closely together from the product conception.

In particular, QFD identifies the general requirements a new product must satisfy, in order to ensure customer preference. The core of QFD is to translate customer requirements into relevant product design characteristics and thus develop a high quality product. In the "House of Quality'' the customer requirements serve as a basic foundation of the process. These requirements are qualitatively related to the engineering domain in the form of a matrix and they identify the relationship between the customer requirements and what engineering must be performed to deliver them.

The QFD method follows the steps shown in the "House of Quality", which is illustrated in Figure 2.4.

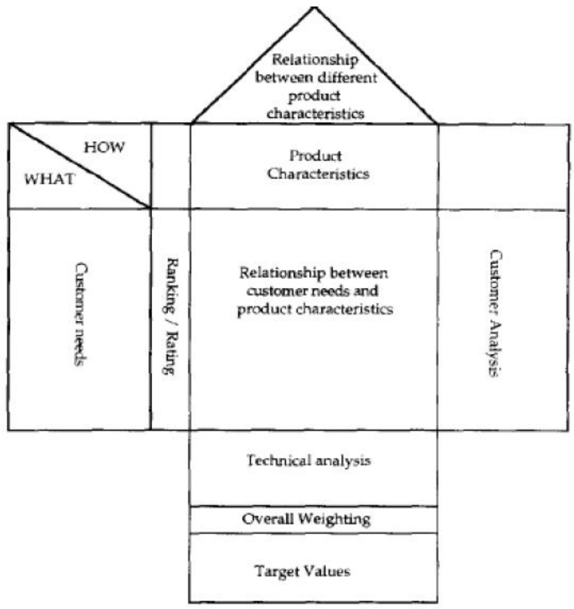


Figure 2.4: The house of quality (Bergquist and Abeysekera, 1996)

The first place to start is to identify costumers or users needs; this is probably the most important step. To gain information about costumer needs and its priorities several marketing methods, such as questionnaires, interviews, brainstorming etc, can be used. The next step consists in assessing the relative importance of each costumer need through ranking or rating activities. Then the technical specifications that meet customer requirements are listed. This kind of information can be obtained from the manufacturers of the products or from production engineers or experts in the respective products. After that the relationships, positive and negative, between the products characteristics have to be determinate. Next, the relationships between product characteristics and user needs have to be established in order to identify important product properties. Every user need is compared to every product characteristic. When determining what product characteristics are influencing the customer satisfaction an overall weighting is calculated. By multiplying the customer weighting and numerical weighting of the relationship, and summing these together, each product characteristic is given an overall weighting. The purpose of calculating the overall weighting is to identify those characteristics that are influencing the customer satisfaction to the greatest extent. Since the intention of the QFD analysis is to fulfil the customers' needs, each product characteristic is given a target value or a standard value. These values are taken from the relevant Standards or opinions of experts. Finally, a technical and a customer analysis are carried out in order to avoid design changes in the later phase of the planning and production process. Different products may be tested with regard to their ability to meet the technical as well as user demands. This is a method to find a competitive solution where the new product should meet the demands to a higher extent compared to the products of competitors [13] out the customer needs and their priorities

Below (Figure 2.5) is an example of the application of QFD method, carried out by Bergquist and Abeysekera (1996) on the use of safety shoes in a cold climate in a project entitled 'Ergonomic aspects of personal protective devices used in a cold climate', reported in their paper —Quality Function Deployment(QFD) - A means for developing usable products .

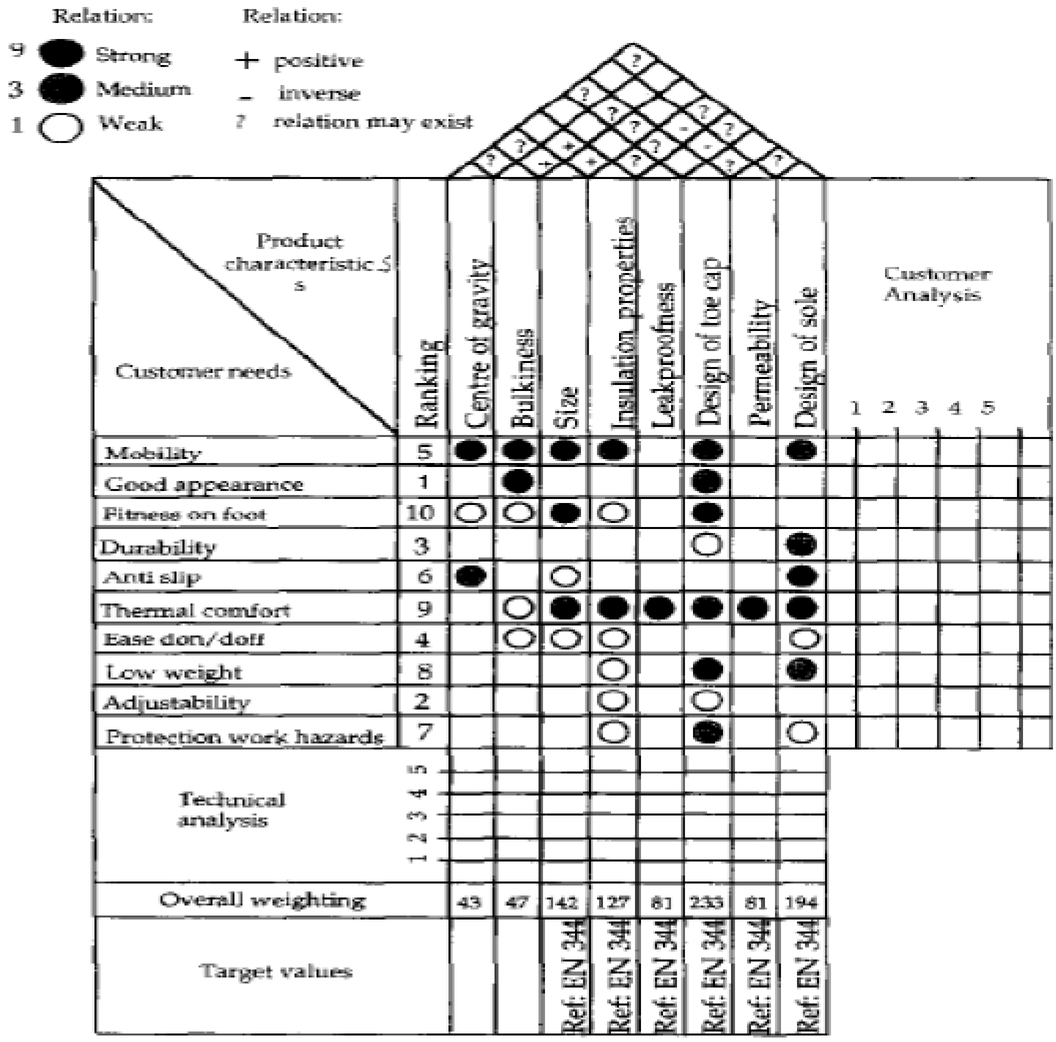


Figure 2.5: QFD analysis of safety shoes (Bergquist and Abeysekera, 1996)

- **Design for X.** Engineering design is a process that aims to develop a system, a component or a process, that meet specific needs (for 'X'). Traditionally it has always been based on the consideration of product functionality. The design was then passed from design department to the process-planning department and after that to the manufacturing department. All these activities were completed in a sequential way, without giving feedback to the designer. It is not infrequent for designed products to find difficulties in their manufacturing or that their production results in unreasonably high costs. To solve these problems, Design For Manufacturing (DFM) approach can be used. This approach integrates manufacturing considerations into the design process. This practice was inspired by the successful Design For Assembly (DFA). As time went by, more and more researches recognized that not only assembly and manufacturing constraints, but also other life-cycle issues such as disassembly, recyclability, etc. concerns need to be considered during the design process. Therefore, there are many applications of these approach, all grouped under the general name of Design For-X.

- *Design for Assembly* (DFA). This technique has the purpose to achieve the lowest assembly cost by designing a product in such a way that it can be economically assembled by the most appropriate assembly system. Therefore, during the design stage must be considered the two main elements that affect assembly costs: total number of parts to assemble and the ease of handling, insertion and fastening of the parts.
- *Design for manufacturing* (DFM). It refers to the selection of appropriate processes for the manufacture of a particular part based upon the matching of the required attributes of the parte and various process capabilities. It concerns raw material and process selection, modular design, standard component usage, multi-use part development and others. These applications can be efficiently carried out through CAD/CAM systems that are equipped with an integrated cost estimation function.
- *Design for disassembly and design for recyclability.* Nowadays recycling is a very important topic. Thus, disassembly of used products is critical in an economic way to recycle. For this reason, in design phase this problem must be taken into account. Approaches to design for disassembly can be freeing the part of all attachments, finding the succeeding part in the assembly sequence and disassembly it in sequence. Another aspect to be considered is that, in designing should aim to maximize recyclable components and minimize those which must be disposed as waste.
- *Design for environment.* It can be defined as the systematic consideration, during the design phase, of design issues associated with environmental safety and health over the full product life-cycle.
- *Design for life-cycle.* It is based on the analysis of life-cycle costs of a product, already in the designing stage. In carrying out this analysis is useful to decompose the entire life-cycle of the product in six stages: need recognition, design development, production, distribution, use and disposal; and for each phase make an estimate as exact as possible of the costs to be incurred (Table 2.2). Of course the objective is making the product design while minimizing these costs.

Life-cycle phase	Company costs	User costs	Society costs
Need	Market recognition		
Design	Development		
Production	Materials, energy, facilities, wages and salaries		Waste, pollution and health damage
Distribution	Transportation, storage, waste	Transportation, storage	Waste, pollution, packings and health damages
Use	Warranty service	Energy, materials, maintenance	Waste, pollution and health damages
Disposal		Disposal dues	Waste handling, disposal, health damages, pollution
Recycling		Recycling dues	Waste, pollution and health damages

Table 2.2 – Product Lifecycle costs (Jovane et Al., 1993)

- *Design for quality.* Since neither inspection nor statistical quality control can offset poor design, it's better already in product design phase to take account of the quality aspect. This can be done designing a product to meet customer requirements, designing a robust product that can counter or minimize the effects of potential variation in manufacture of the product and the product's environment and continuously improving product reliability, performance and technology to exceed costumer expectation and offer supervisor value.
- *Design for maintainability*. Its main objective is to assure that the product can be maintained through its useful life-cycle at reasonable expense without any difficulty. So there are guidelines referred to accessibility, ability to detect and isolate failure, weight limitations of replaceable units, dimensional limits and so on.
- *Design for reliability*. It consists in designing a product providing a certain level of reliability. That is ensuring that the product will work regularly for a certain timeframe, with a definite probability.

- **CAD/CAM Technologies.** They are not specific tools of lean product development, but there are two kinds of technology that because their features support collaborative product development and allow lean principles and practices implementation. CAD, computer aided design, computerize data bases and facilitate the standardization of parts. In this way it helps to minimize the variety of fittings, thereby reducing design time and manufacturing complexity. CAM, computer aided manufacturing, enhances accuracy, reliability, and efficiency, and allows the automation of ancillary tasks such as materials handling and tube cutting and debarring. Their integration offers extraordinary possibilities for simplifying the elaborate administrative and control system for cost estimation, lot release, shop orders, materials, and performance tracking.

- **Supplier Involvement. S**upplier participation in the initial product design process increases the competitive advantages derived from integrated product design. In fact purchased inputs have the potential to influence directly and substantively not only the cost and quality but also the development time of new products. Indeed, supplier involvement promotes better resource utilization, the development and sharing of technological expertise, and network effectiveness.

- **Modularity.** It consists in developing families of products based on certain product platforms and in postponing as late as possible product differentiation in product development process. Design process should allow feature modifications or evolution of the product, the re-use of certain elements such as previous designs, information about customer needs and the technology required for a certain product. In this way the product development process is simplified and the value flows.
- **Six Sigma.** It is a systematic methodology to home in on the key factors that drive performance of a process, set them at the best levels, and hold them there for all time. This technique arose in Motorola, is characterized by rigorous measurement and control and is focused on systematic reduction of process variability from all sources of variation: machines, methods, materials, measurements, people, and the environment. Six sigma aims to attain predictable, repeatable and proficient processes and defect free production, through a rigorous data collection, use of statistical analysis and depth management.

- **Management**

- **Cross-functional teams.** A cross-functional team is a group of people who apply different skills, with a high degree of interdependence, to ensure the effective delivery of a common organizational objective. This definition applies to team working within a functional, matrix or project-based organization. The key elements arising from it are variety of skills, interdependence of work and delivery of a common objective.

Cross-functional teams facilitate continuous transmittal of information concerning the evolving product and manufacturing process, improve the outcome of a design process and create a product that satisfies customer and market requirements.

- **Team integration.** This concept is complementary to the cross-functional team issue. To well-implement team integration there are some essential elements: accessibility of team members, team sharing of communication, overlapping of authority and duties, compatibility of databases and functional group loyalty.

- **Chief engineer.** An ideal project manager requires a special mix of skills [14]. He is multilingual and has multidisciplinary approach; he is more than a neutral arbitrator or passive conflict manager but willing to initiate conflict in order to prevent product designs from deviating from the original product concept; he possesses market imagination, or the ability to forecast future customer expectations based on ambiguous and equivocal clues in the present market; he walks around and advocates the product concept, rather than doing paperwork and conducting formal meetings; and he is principally an engineer by training with broad, if not deep, knowledge of total vehicle engineering and process engineering.

The chief engineer at Toyota is first and foremost a technical expert who has a large input in the car's architecture. Although he is responsible for the project from concept to market, he has is mostly recognized by his experience, his technical and communication skills. He has a very small dedicated team of experienced product engineers as well as manufacturing engineers – but all his other resources are in the functional organization. He summarizes his vision for the car in a concept paper which leads into the system design phase.

- **Mentoring.** In Toyota managers are not seen as bosses, but rather as mentors and they are usually the ones to possess more knowledge within the group. This kind of manager generally, has a leadership style of asking questions rather than telling people the right answers.

Those receiving mentoring, can explore strengths and weaknesses of particular situations in a confidential atmosphere. In fact, the mentor provides a sounding board, challenging assumptions and encouraging wider thinking. On the other side, mentors gain from the relationship, too, widening their network of contacts and gaining insights into the issues faced by their staff and colleagues. A major reported benefit is often the increased sense of job satisfaction that the mentor gains. Mentoring is a way of unlocking talent in the organization and ensuring that specific groups are given additional support.

- **Introduction program.** At Toyota, recruitment of new employees is of paramount importance, they are not only chosen, through strict procedures, on the basis of their grades but also taking into account other characteristics such as love for cars and problem solving abilities.

Once hired, new employees, follow a well-structured introduction program, which involves a series of steps. First of all, the newly hired is subjected to a training period on general issues such as quality, the Toyota history and traditions. Then it spends a few months to work at a plant, someone to be closer to the machine and the customer, spend also few time at the dealership. After this introduction period, the engineer is assigned the freshman project for four to nine months, which is a technically challenging project that forces the engineer to seek out the people that are knowledgeable within several areas of knowledge and that practice the use of basic engineering tools. Finally the last step of the induction program is a two-tier period of approximately eight years after which management will begin to consider her or him an independent working engineer [15].

2.2.5. Liker's 13 principles

According to Liker (2006), despite value, waste and its identification are at the heart of Lean Product Development system, there are several interdependent components that work together to create the entire system, which cannot be understood only through the single component. In fact, what makes Lean Product Development really effective is the joint cooperation of tools, processes and people that give rise to the system as a whole. Only by examining people and tools work together is possible to obtain an overview of the system, also from a dynamic point of view, which is very important because outside world conditions change over time and with them, the system too.

To Liker Lean Product Development System is composed of three primary subsystems:

- Process
- People
- Tools and Technology

These three subsystems should be interconnected and interdependent and should influence the ability of a company to reach its internal target.

The first subsystem, Processes, includes all the tasks and sequences of activities necessary to bring a product from its conception to its launch production. It is a value stream map from raw materials (customer need, past product characteristics, competitive product data, engineering principles) to finished goods. Great attention should be given to daily operations through which information flows, design develops, tests are accomplished, prototypes built and a finished product emerges. This class contains the following principles:

1 *Establish customer defined Value to separate Value Activity from Waste*

Costumer is always the point of departure in a lean system, so to identify waste is first necessary to define what value is for the costumer. All the activities involving the use of money and time, but do not add value for the customer must be considered waste.

Liker (2006), states that in product development can be found two kind of waste:

- Waste generated by poor engineering whose effects are low levels of product or process performance. The best way to avoid this type of waste is a deep and concrete knowledge of how to create customer-defined value at each level of the organization.
- Waste in the product development itself. In this case it is helpful to use VSM to remove it.

2 ***Front load the Product Development process to explore thoroughly alternative solutions while there is maximum design space***

The opportunity to explore a wide range of design alternatives is the basis of lean product development process. The purpose is to maintain the —design space opened as long as possible, before facing uncertainty by taking critical decisions.

3 ***Create a levelled product development process flow***

After defining value, lean product development, requires a process without any waste to minimize the product time-to-market. It should minimize reworks and synchronize activities between the different functions.

4 ***Utilize rigorous standardization to reduce variation and create flexibility and predictable outcomes***

This principle aims to reduce variation in products, while still maintaining designers' creativity.

The second subsystem analyzed by Liker (2006), is the People Subsystem. It includes recruiting, selecting and training engineers, organizational structure and learning patterns. If one takes into account the degree to which an organization shares these elements with its membership and partners, this subsystem could be considered as a measure of the strength of the culture of lean thinking. The principles enclosed in this subsystem are listed and described below:

5 ***Develop a chief engineer system to integrate development from start to finish***

In many companies there are many functional departments, each responsible for a different piece of product development process and nobody responsible for all. In a system like this, manage to establish the state of the project and when the decisions are made could be hard. In Liker's opinion the solution to this problem is the chief engineer who is not just a project manager that manages people and time, but also a leader and a technical reference point.

6 ***Organize to balance functional expertise and cross functional integration***

To develop a product development system with excellent performance, one of the most difficult tasks is to balance the functional excellence within the various disciplines while achieving integration between the experts of the several functional departments.

7 ***Develop towering technical competence in all engineers***

This principle points out the importance of technical excellence in engineering and design resources in lean product development system.

8 ***Fully integrate suppliers into the product development system***

Company should handle and grow suppliers as if they were internal resources. They should be assessed both on their technical expertise and their parts-making capabilities. They also, should be involved from the first phases of product development process.

9 *Build in learning and continuous improvement*

The ability to learn and improve could be one of the most sustainable competitive advantages for a company. Toyota is leader in getting-together, spreading and applying information for the performance improvement.

10 *Build a culture to support excellence and relentless improvement*

Toyota culture supports excellence with expressly defined values and consistency to these ideals by leaders and team members. All the other principles are implemented because Toyota culture makes them to be part of how things are done.

The third and last subsystem deals with Tools and Technology necessary to bring a product into being. It includes CAD systems, machine technology and digital manufacturing; moreover, it also contains soft tools that support people involved in the development project, such as tools for problem solving, learning or standardizing best practices. The related principles are:

11 *Adapt technology to fit people and process*

Many companies seek to obtain performance improvements by simply applying a new technology; actually, the correct approach requires that before adopting a new technology, its impact on current processes and on people, is assessed. According to Toyota, a new technology is not always a competitive advantage for the company, as it can be easily replicated. It rather emphasizes the importance of spend time to understand where a technology is suitable for the existing set of processes and people.

12 *Align organization through simple visual communication*

Toyota uses a visual method of communication, very simple; it is often limited to the use of one side of a sheet paper. This communication tool can be used for different purposed: proposals, problem solving, status up dates and competitive analysis.

13 *Use powerful tools for standardization and organizational learning*

The basic idea of kaizen, is that without standardization is not possible to obtain continuous improvement. Toyota provides a series of tools in order to standardize learning, both at macro level and at detailed technical component level.

2.3. Lean New Product-Service Development

2.3.1. Introduction

PSS design and development is a process that requires a huge effort, also in terms of technical specialization, business organization, data and knowledge management. This is due by the intrinsic complexity of such PSSs and to the different needs and expectations they are supposed to satisfy in a fast and adaptive way. For this reason it is easy to understand why the majority of the methodologies proposed in literature for PSS design and development, as Sassanelli et al. highlight, "have a clear heritage in Concurrent Engineering and Lean Product Development methodologies: identification of customer value, early involvement of the customer in the system design, effective communication, information sharing, and continuous improvement".

2.3.2. State of the art

- ***Great breakthrough in technology: Internet of Things (IoT)***

First of all, it is necessary to explain IoT in order to understand the essential role that plays in the PSS design & development and how it is evolving.

The term Internet of Things describes a path (already started) in development technology according to which, through the Internet, every object of our daily life acquires its own identity in the digital world. Furthermore, it is a network of physical objects or "things" embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data [16]. This means that IT is becoming an integral part of the product itself and evolving them into smart objects.

Smart, connected products have three core elements: physical components, "smart" components, and connectivity components [17].

Physical components comprise the product's mechanical and electrical parts. In a car, for example, these include the engine block, tires, and batteries.

Smart components comprise the sensors, microprocessors, data storage, controls, software, and, typically, an embedded operating system and enhanced user interface. In a car, for example, smart components include the engine control unit, antilock braking system, rain-sensing windshields with automated wipers, and touch screen displays. In many products, software replaces some hardware components or enables a single physical device to perform at a variety of levels.

Connectivity components comprise the ports, antennae, and protocols enabling wired or wireless connections with the product. Connectivity takes three forms, which can be present together:

- **One-to-one**: An individual product connects to the user, the manufacturer, or another product through a port or other interface—for example, when a car is hooked up to a diagnostic machine.
- **One-to-many:** A central system is continuously or intermittently connected to many products simultaneously. For example, many Tesla automobiles are connected to a single

manufacturer system that monitors performance and accomplishes remote service and upgrades.

- **Many-to-many:** Multiple products connecting many other types of products and often also to external data sources. An array of types of farm equipment is connected to one another, and to geolocation data, to coordinate and optimize the farm system. For example, automated tillers inject nitrogen fertilizer at precise depths and intervals, and seeders follow, placing corn seeds directly in the fertilized soil.

Smart, connected products require that companies build an entirely new technology infrastructure (figure 2.6), consisting of a series of layers known as a “technology stack”. This includes modified hardware, software applications, and an operating system embedded in the product itself; network communications to support connectivity; and a product cloud (software running on the manufacturer’s or a third-party server) containing the product-data database, a platform for building software applications, a rules engine and analytics platform, and smart product applications that are not embedded in the product. Cutting across all the layers is an identity and security structure, a gateway for accessing external data, and tools that connect the data from smart, connected products to other business systems (for example, ERP and CRM systems).

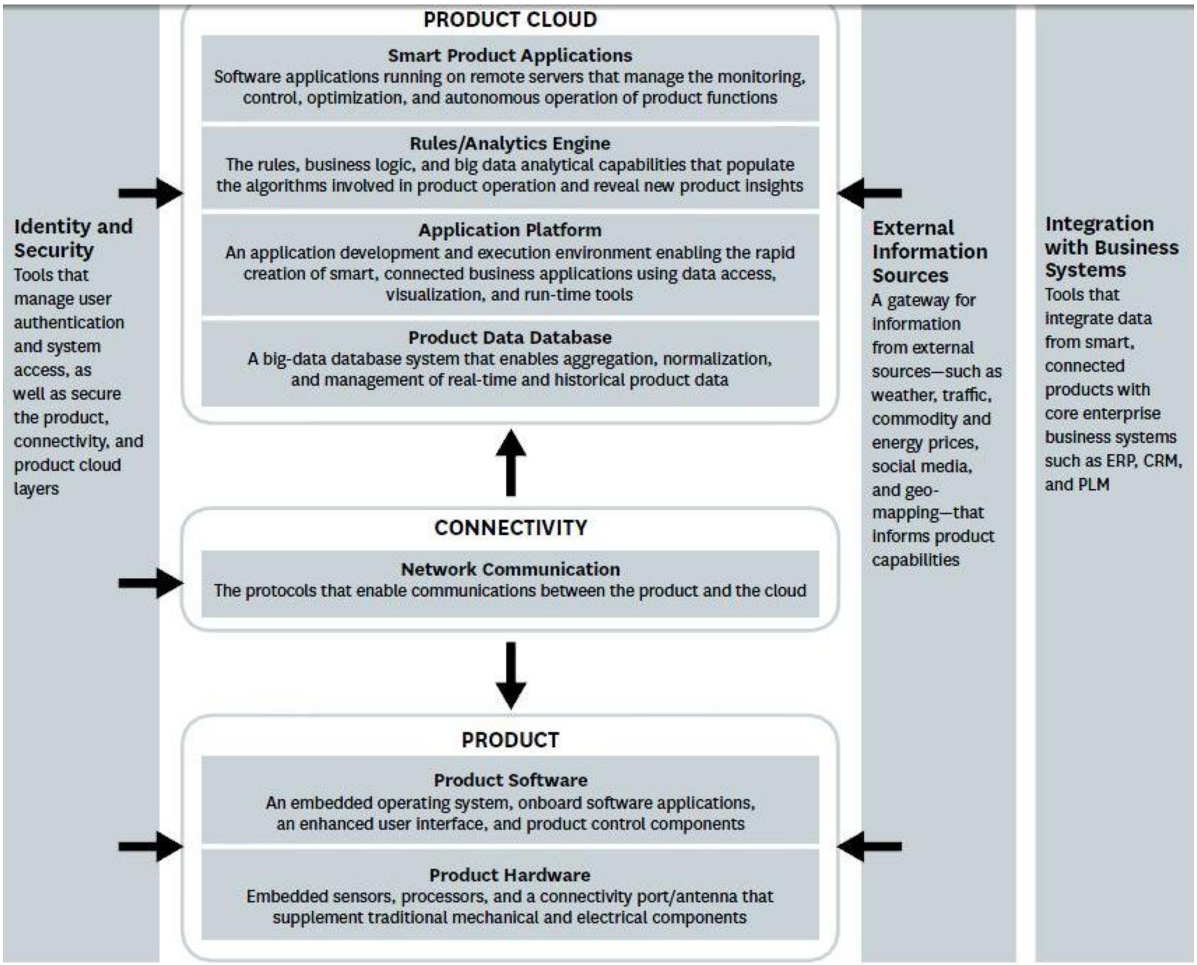


Fig. 2.6: General IoT schematic view [17]

This technology enables not only rapid product application development and operation but the collection, analysis, and sharing of the potentially huge amounts of longitudinal data generated inside and outside the products that has never been available before.

The increasing capabilities of smart, connected products not only reshape competition within industries but expand industry boundaries. This occurs as the basis of competition shifts from discrete products, to product systems consisting of closely related products, to systems of systems that link an array of product systems together (figure 2.7). A tractor company, for example, may find itself competing in a broader farm automation industry.

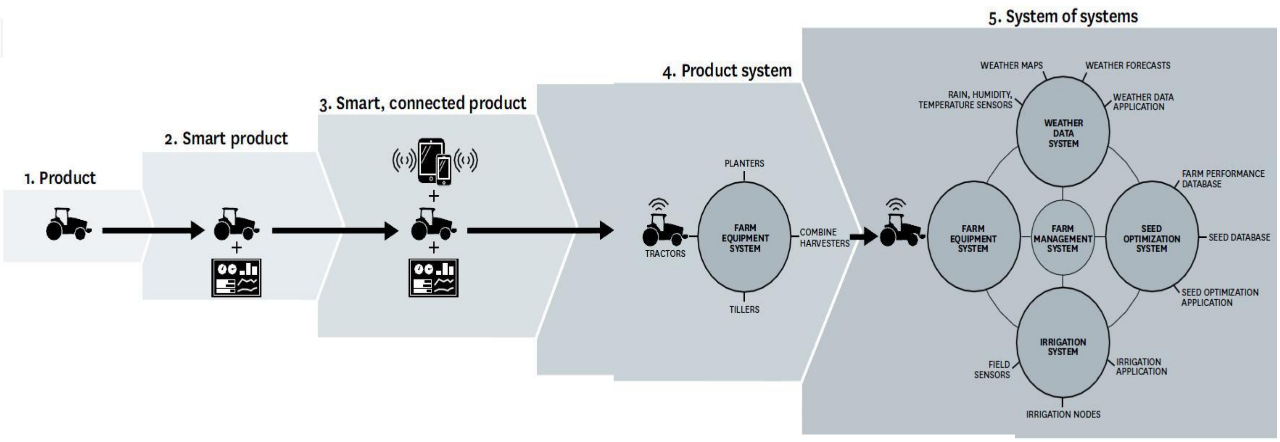


Fig. 2.7: Example of the IoT structure of a tractor company [17]

The powerful capabilities of smart, connected products not only reshape competition within an industry, but they can expand the very definition of the industry itself. The competitive boundaries of an industry widen to encompass a set of related products that together meet a broader underlying need. The function of one product is optimized with other related products. The basis of competition thus shifts from the functionality of a discrete product to the performance of the broader product system, in which the firm is just one actor. The manufacturer can now offer a package of connected equipment and related services that optimize overall results.

Increasingly, however, industry boundaries are expanding even beyond product systems to systems of systems, that is, a set of disparate product systems as well as related external information that can be coordinated and optimized, such as a smart building, a smart home, or a smart city. Smart homes, which involve numerous product systems including lighting, HVAC, entertainment, and security, are an example. Companies whose products and designs have the greatest impact on total system performance will be in the best position to drive this process and capture disproportionate value.

Some companies are intentionally seeking to broaden and redefine their industries. Others may find themselves threatened by this development, which creates new competitors, new bases for competition, and the need for entirely new and broader capabilities. Companies that fail to adapt may find their traditional products becoming commoditized or may themselves be relegated to the role of OEM supplier, with system integrators in control.

The net effect of smart, connected products on industry structure will vary across industries, but some tendencies seem clear. First, rising barriers to entry, coupled with first-mover advantages stemming from the early accumulation and analysis of product usage data, suggests that many industries may undergo consolidation.

Second, consolidation pressures will be amplified in industries whose boundaries are expanding. In such cases, single product manufacturers will have difficulty competing with multiproduct companies that can optimize product performance across broader systems. Third, important new entrants are likely to emerge, as companies unencumbered by legacy product definitions and entrenched ways of competing, and with no historical profit pools to protect, seize opportunities to leverage the full potential of smart, connected products to create value. Some of these strategies will be "productless" because the system that connects products will be the core advantage, not the products themselves.

- ***Towards Lean PSS Design***

Sassanelli et al.[4] explain that Lean Product Development elements are mentioned and used by the most of the PSS design methods and say that "*the most upsetting result is that all the methods involve Lean Thinking approaches even if they don't refer to them directly*". They also specify that Set-Based Concurrent Engineering (SBCE) appears to be the most appropriate approach to manage the PSS design process, even if almost none of the papers quote SBCE directly. In its essence, SBCE process should support the identification and the definition of the most appropriate integration of components and services, aiming at the resolution of the possible design trade-off along the whole development process, stage-by-stage.

Sassanelli et al. also highlight the fact that PSS design methods are focused to the waste elimination and value identification. All papers which were analysed by them propose the application of methods and tools for eliminating muda, like the 5C approach (Clear out, Configure, Clean and Check, Conformity, Custom and Practice) or similar. At the same time, most of those works suggest and support standardization practices in the PSS design process. Generally, they propose to adopt common process (e.g. BPMN , UML 2.0, SADT, etc.) as well as standard models (e.g. QFD) and templates (e.g. View model). These standardization practices are normally considered as the basis for promoting continuous improvement consciousness.

It is interesting to notice also what is missing in the analyzed contributions, in a Lean Product Development perspective. At first, none of the contributions has clearly and systematically identified which are the typical muda to be considered in a PSS design process, while also the definition of what is a value-added activity is often vague. Second, none of the contributions is quoting SBCE, even if all of them are proposing/suggesting a design process structured according to the SBCE archetype [4]. Third, practically no contribution is investigating/mentioning the role which could be played by computer-aided design and engineering tools already existing in the normal engineering practice. Fourth, the application of the proposed PSS design methodologies is most of the time at a prototype/piloting stage and no detailed guidelines on how lean-inspired mechanisms should be implemented are given.

- ***PSS lifecycle***

PSSs introduce a new business concept and therefore a new way of seeing its lifecycle is needed. Therefore, because it is a mix between a product and a service, a first approach should be a high level integration of the Product Lifecycle (figure 2.8) Management and the Service Lifecycle Management (Figure 2.9) as *Wiesner et al*. [18] propose in figure 2.10.

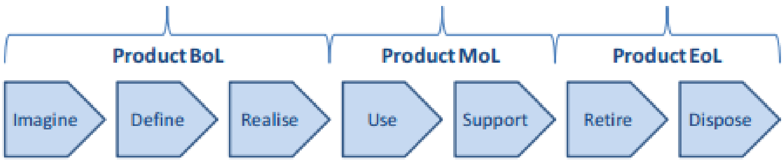


Fig.2.8: Product lifecycle [23]

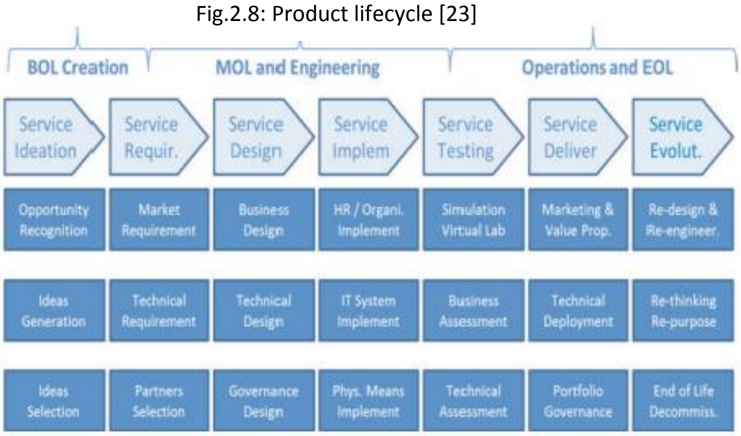


Fig.2.9: Service lifecycle [23]

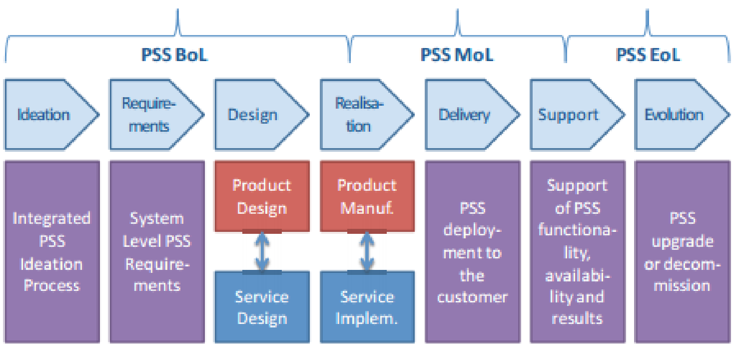


Fig.2.10: Product-Service lifecycle [23]

In order to introduce the service part into the product one or vice versa there are two types of relation: SLM aligned with PLM and SLM integrated with PLM. The first one is the right choice if adjustments take place on both sides. In other words, the product and the according service lifecycle are the same length but the interactions take part only if they are necessary. The second one would be a thorough integration of PLM and SLM, where both life cycles are managed in a highly integrative way, so that the separating managerial boundaries between PLM and SLM “disappear”. This kind of interaction pattern is a prerequisite to effectively realize PSS, where the product and service components blur into a holistic solution for a specific purpose.

a. PSS Beginning of Life

The PSS lifecycle begins with an ideation stage, similar to the PLM and the SLM alone. However, the process is not focused on the product or the service, but targets the PSS as a holistic solution. Therefore, product as well as service staff will participate in ideation. The same is true for the requirements stage. Starting from the PSS level, requirements for the solution will be defined, irrespective if they will be realized by product or service components. Only subsequently they will be broken down as input for the design stage. Here, an organizational separation between product and service design is still present, based on the different development streams. However iterative feedback loops ensure design compatibility.

b. PSS Middle of Life

The PSS MoL begins with its realization, which comprises the manufacturing of the product as well as the implementation of the service. Similar to the design stage, product and service realization is separated, but iterative testing of the results ensures that they can be combined into the PSS. As soon as this is verified, the PSS can be delivered to the customer as a package and the distinction between product and service disappears.

During its operation, the PSS has to be supported to retain its functionality, availability and results. This can be done through services, such as maintenance, as well as through product components, such as spare parts.

c. PSS End of Life

Should the PSS not be able to fulfil its intended application anymore, it enters the evolution stage. Here it will be decided, if the PSS can be upgraded through adapting the product or service, or if it has to be decommissioned.

▪ *Life Cycle Simulation for the design of Product-Service Systems*

Nowadays, CAD 3D systems provide excellent visualization functionalities, giving designers the possibility to simulate their ideas in advanced environments, in terms of appearances and dimensions, as well as component interfacing. Furthermore, CAE (Computer Aided Engineering) tools have extensively adopted simulation approaches, supporting engineers in their virtual tests on digitally modelled products. On the manufacturing engineering side, CAM/PP (Computer Aided Manufacturing, Process Planning) tools have been created to support production engineers in the definition and simulation of manufacturing processes. KBE (Knowledge Based Engineering) environments have been set up to support the automation of design rules, reducing redundant tasks in daily design work. All of these efforts have been characterized by their high degree of specialization to a specific issue, considering a particular phase of the system life cycle and attempting to reach a good solution for a particular problem in a limited context.

Given this background, a further step must be taken by enabling new simulation tools for virtually emulating the product behaviour during its expected operating life cycle. This implies a new era in the virtual prototyping evolutionary chain, which can be called the ‘‘Digital Life Cycle’’ wave. This wave could offer engineers of the next decade access to new simulation solutions, which may consider, in parallel, product and service models through time-dependent architectures, toward taking better lifecycle related decisions.

Product life cycle management and analysis is a well-known concept in the relevant literature. Methods for measuring and assessing the life cycle dimension of a product were created years ago. These methodologies are the basis of the life cycle design approach; they are used for conducting deep analysis of the different stages of the product life cycle, accumulating knowledge and defining different life cycle scenarios. Simulation has acquired an important role along the life cycle design phase because it provides tools for evaluating the performances of a system in virtual environments. Garetti et al. [19] explain that “*a reference framework, as well as a reference simulation tool/language for LCS, does not yet exist*”. That means that there is room for research efforts toward the definition of a reference architecture for LCS. Taking this into account, they also expose that what could be interesting and useful for the future industrial applications of LCS is a classification of the main ‘‘characteristics’’ to be considered in the development of a reference LCS platform. These characteristics could be used as preliminary requirements to be fulfilled in the deployment of a comprehensive LCS tool. They also add that “*from previous analysis, it is possible to identify four main characteristics*” which a LCS tool should have:

(i) ***Modularity***: Many authors have suggested and implemented LCS composed of reusable modules. Modularity is a key requirement to be considered in the definition of a reference LCS architecture. Modularity enables modelling flexibility, supporting various scenarios and applications. Moreover, modularity can save time in the modelling task, activating knowledge sharing and reusing. Modularity is a must for LCS.

(ii) ***Stochastic Behaviour of Modules***: In life, determinism does not exist: lack of resources, faulty events, and unconstrained activities occur in random ways. For this reason, in an LCS, resources, activities, and events might be modelled in stochastic way in order to provide a useful emulation of reality. Stochastic knowledge might be used for reproducing the behaviour of product attributes, as well of processes, activities, resources and users. Therefore, the Stochastic Behaviour of Modules is another key requirement to be considered in the development of a reference LCS architecture.

(iii) ***Life Cycle Cost Perspective***: LCC evaluation is the primary application of LCS. LCC is important not only from an economical point of view, but also in its wider implications. LCS is primarily a matter of LCC calculation. Costs are the key decision factors, and while engineers may be heavily supported in the cost calculation, it is not their primary job. The analysis of life cycle costs (costs coming from service/maintenance activities) is mandatory for enabling PSS success. Therefore, LCC perspective is a key requirement that future reference LCS architecture must clearly fulfil. Life cycle costs must be reliably measured and clearly displayed to the designers, thus providing valuable support in their decision-making

(iv) ***Social and Environmental Impacts***: Our world needs multidimensional sustainable development, in which economics, society, and environment must be considered at the same level and time. Therefore, it is evident that a reference architecture for a future LCS cannot avoid defining as a key requirement the analysis of the social and environmental impacts coming from a design decision of a PSS. As stated above for LCC, these social and environmental impacts must be reliably measured and clearly displayed to the designers, in order to provide valuable support in their decision-making.

- ***Expanding Value Driven Design to meet Lean Product Service Development***

LPSD and VDD literature highlight opinions which are opposed yet the authors believe are complementary rather than mutually excluding.

LPSD focuses on delivering the highest value to the customer by increasing efficiency and reducing waste, with a strong focus the managerial aspects of the product and service development process.

VDD adopts a more engineering-oriented perspective, looking at the hardware attributes (mainly technical performances) as enablers for service provision. Hence, it proposes methods and tools that use value as metrics to select, as early as possible in the design process, the optimal configuration for a system and its sub-systems.

These perspectives should not be seen as contrasting, instead they represent an opportunity for exchanging ideas between the managerial and the engineering design fields for mutual enrichment.
VDD research can mainly teach LPSD practitioners about the use of a model-based thinking when looking at value and impacts of design alternatives. VDD strongly focuses on the creation and use of models that are able to quantify what the system will be capable to deliver given a specific design configuration. This capability of developing and applying models to benchmark solution directions is something lean research may benefit from. Value models can be beneficial in their way to work as 'coordinative artifacts' serving as basis for conversation and knowledge sharing within the cross-functional design team. For several disciplines, such as cost and material analysis, a range of models is already established, as well as roles in the engineering design teams.
On the other hand, when looking at value assessment in the context of LPSD models promoting the understanding of value and the determination of efficient mechanism for information flow have not reached the same level of maturity as in other domains. Based on such reflection, Bertoni et al. [F] believe that the ability to apply a model-based approach in LPSD is critical for successful cross-boundary discussions. Therefore, the possibility for LPSD processes to use value models as "boundary objects" to facilitate cross-functional communication and to enable that the best (or at least the "most aware") decision is made, is regarded as a potential improvement. In particular the opportunity to use such objects to better understand and reconcile conflicts in stakeholder needs be regarded as a relevant improvement.
VDD existing case studies are deeply engineering focused. The value of a "system" is calculated on the basis of the technical performances of the hardware, while service aspects and managerial implications are poorly, or not at all, considered in the value models. This is not surprising: VDD was introduced with the objective to select the best set of technical capabilities to accomplish a mission, or a project, given some cost constraints.
However, some authors argue that some recent methods developed under the VDD "umbrella" term shall not be considered as limited to the VDD domain. They should rather be as plastic approaches to promote value driven innovation in the preliminary design stage of a Products-Service System, and they should belong to a complementary context overlapping both with VDD and LPSD. This context is defined as "Value Innovation" [20], mainly as a bookmark on which to anchor the discussion about future research directions in the common VDD/LPSD domain (Figure 2.11).

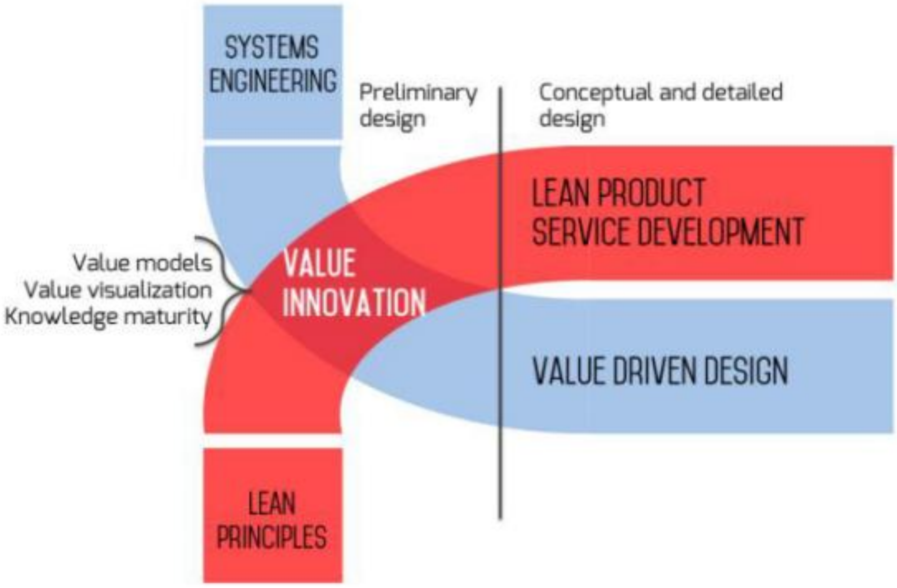


Figure 2.11: Value Innovation: overlapping research areas between VDD and LPSD [20].

Value Innovation (VI) expands and differs from VDD by acknowledging that, when assumptions and forecasts prevail, the use of a subjective definition of value is more appropriate. VI emphasizes the role of the “value model” as that of a boundary-object, which is of an artifact able to raise awareness on what eventually value means for customer and stakeholders. The underlying assumption is that this awareness can be raised only if ambiguities and uncertainties can be clarified already during preliminary design. To do so, it is necessary to establish a dialogue among all actors in the cross-functional team, under the assumption that only if experiences and knowledge about what “is valued” are shared, it is possible to take more confident (and rational) design decisions.

Decision-making matrixes, such as QFD (Quality Function Deployment), emerge as strong candidate approaches to perform a qualitative mapping between customer value perception and requirements for PSS. Still, the relationship between customer value and PSS is likely to be more complex than the pure product or service counterpart. The latter has already shown that dependencies can be highly non-linear: this phenomenon is likely exacerbated looking at product-service combinations.

VDD models have shown to be dependent from the availability of historical data, which are typically missing when performing a preliminary screening of new hardware service combinations. Using models in preliminary design implies the presence of not well-defined data suffering from a level of uncertainty in the evaluation. Claiming to evaluate the system value of a concept implies therefore to be able to address such uncertainty perhaps not by directly focusing on reducing it, but rather by assisting the decision makers to achieve a better understanding of what those uncertainties, ambiguities and assumptions actually involve. Research in the dynamics of decision-making in product development has lead to the definition of the concept of Knowledge Maturity as a way to model such uncertainties, ambiguities and assumptions used in early stage decision making. Such concept has been later adopted as an add-in for value models used in VDD.

Within a cross-functional team, the use of value as metrics for benchmarking design concepts is mainly a matter of conveying value-related information in a way that is clear, transparent and that stimulate associative processing and knowledge generation. The development of value visualization enablers is therefore another major topic in VI research. Recent contributions have proposed, for instance, the use of color-coded schemes in computer aided design environment to visualize the value contribution of PSS offers.

Chapter 3

3. The proposed methodology

This section introduces and describes the methodology proposed to have continuous improvement. In the first part of the chapter a general view on the methodology and its goals is given, while the other part presents an exhaustive description of the steps to implement it.

3.1. Introduction to the methodology

The methodology used allows employing lean principles and tools in a systematic and complete way. The selected procedure consists of five steps all based on the principles of lean thinking and all of them employ lean tools and enablers. These five steps are:

I. **Waste Identification & Evaluation.** Identify waste in product development process and evaluate them with a corresponding priority index.
II. **Waste Prioritization.** Give an order of priority to waste and for the main ones: define detection way and corrective actions.
III. **Sub process Identification.** Recognize the sub process that contains the main wastes, identified in the previous step.
IV. **Sub process Analysis**. Analyze the sub process using lean techniques.
V. **Corrective Actions**. Definition of appropriate corrective action on the basis of the analysis made before.

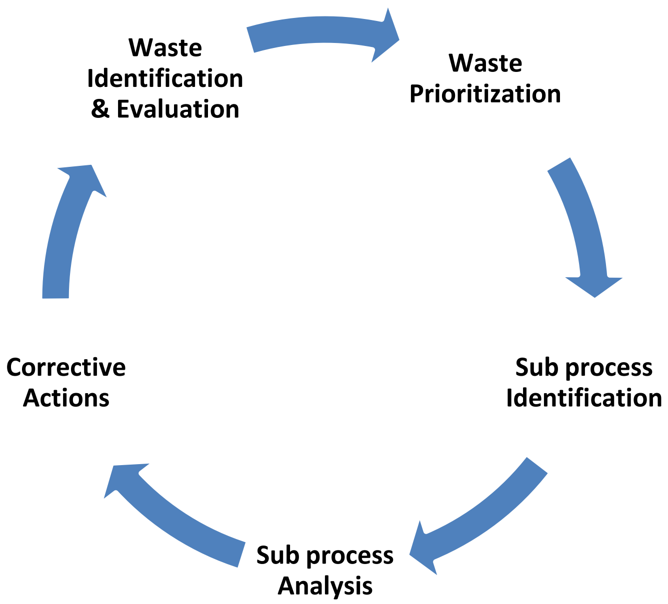


Figure 3.1: Overview of the five steps in which the methodology is based

The purpose is to apply them recursively (Figure 3.1), facing an issue at once, to obtain a continuous improvement of the entire process. Even in this the methodology reflects the lean principle of pursue perfection through progressive improvement activities. Applying this methodology means making the product development process *"lean"*, resulting in better performance in terms of effectiveness and efficiency.

3.1.1. Waste Identification & Evaluation

The first aim of these activities is to identify all the existing waste in the process, to do this a list of potential waste is provided. The waste check-list includes thirty-three types of waste, in turn divided into eight classes, which have been conceived drowning inspiration by the lean waste categories in PD defined by Morgan and Liker (2006). The check-list with a brief description of each waste is presented in the Table 3.1 (Rossi, 2010).

Waste Macro-class	Waste Class	Description
Over Producing / Engineering	Over specification	Specifications not needed and/or not implemented are formulated
	Over specification	Specifications are formulated with too much details and/or too much earlier (for the specific NPD phase)
	Over designed	Product functionalities not asked / needed are implemented
	Over designed	Projects not needed and/or not convenient are studied
	Over information	Design data and info are formulated with too much details and/or too much earlier (for the specific NPD phase)
	Over components	Components / materials not needed are used in the product
Waiting	Waiting to process information	Time spent (without adding value) waiting to process information
	Waiting for information	Waiting for decisions, persons, resources, data, information, documents
Conveyance / Transportation	Information systems	Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate
	Manual transcodification	Information might be manually retyped from one process / system to another
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unneeded and not useful activities are performed along the development phase
	Unnecessary / Excessive activities	Unnecessary and not useful tests are performed
	Unnecessary / Excessive activities	Unnecessary and not needed tolerances are included
	Unnecessary / Excessive activities	Development of parts / components / products already designed and existing, without re-using previous works and projects
	Unnecessary /	Too many authorizations / controls are needed to perform an activity

	Excessive activities	
	Inappropriate process	Unnecessary, not useful, not appropriate, immature, not error-free technologies are used
	Inappropriate process	Development of changes not asked or not needed
	Inappropriate process	Time spent for bad definition of priorities
	Inappropriate process	Time is spent for reworks and revisions due to changing priorities, information, data, requirements
	Inappropriate process	Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed
	Inappropriate process	The development process is performed in different ways, depending by customers / suppliers / others
Inventory	Bad accumulation	Designs wait for the next available resources
	Bad accumulation	Batches of projects remains untouched
Motion	Travel	Unneeded travels might be done for visit customers
	Travel	Unneeded travels might be done for managing projects and teams
	Meeting	Unneeded and useless meetings are continuously organized with customers
	Meeting	Unneeded and useless meetings are continuously organized inside the company
Correction (Reworks / Defective)	Poor design	Reworks and revisions derived from poor-quality products
	Poor design	Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements
	Poor product	Reworks and revisions derived from not successful products
Unused Employee Creativity	Bad knowledge managed	Communications failure and non-conformance
	Bad knowledge managed	Inability to reuse previous knowledge
	Bad knowledge managed	New employees cannot retrieve company knowledge easily

Table 3.1: First list of wastes with its definition macro and normal class

Both for the causes and for the effects recognized was first carried out a general list, in which both were classified according to two different criteria. Regarding the causes, they have been classified recovering the Liker's three categories of Process, Skilled People and Tools and technology, and their meaning (table 3.2).

WASTE POTENTIAL CAUSES CLASSIFICATION		
PROCESS	**SKILLED PEOPLE**	**TOOLS & TECHNOLOGY**
No initial Project Review	No culture of sharing	Obsolete rules
Work is not structured in a systematic way	No culture of reuse	Rules are too general
Focus on local optimization of costs	Training and motivating staff's problems	Inappropriate business practices
High variability of product range	Ineffective social mechanisms	Inappropriate archives
Copy of existing products	Lack of communication	No common database
No common definition of priorities	Knowledge confined to the single individual or team	Unstructured information system

Imitation rather than innovation	No inter functional teams	Too many interfaces required for the activity of product realization, low integration, long times
Sequential activities	PM doesn't evaluate feedback	Outdated information
Limited knowledge of the market	PM is not a reference and integration figure also from a technical point of view	Lack of tools to support productivity and design, that allow a fast implementation of standard activities
The costumer doesn't specify the initial requirements	Inappropriate communication	Incompatibility format of the information
Requirements change ongoing	Decision making is not concentrated at the beginning	No knowledge sharing system
Priorities change ongoing	Ineffective role of the PM	Lack of a communication and sharing remote system
Failure to understand customer needs	Wrong communication	
Inability/impossibility to translate requirements into technical specifications	The team's components are situated in different areas	
Scarce resources		
Inefficient management and allocation of resources		
No scheduling of competing facilities		
Data flow not clearly defined		
No common definition of the objectives		
No analysis of customer's needs		

Table 3.2: List of wastes' causes classified by process, skilled people and tools and technology

On the other hand, the effects found were categorized on the basis of the three main aspects (table 3.3) that affect the success of a product development process and on which every effect found can be traced. They are: time, cost and performance.

WASTE POTENTIAL EFFECTS CLASSIFICATION		
TIME	**COST**	**PERFORMANCE**
Rise of development times	Rise of development costs	Productivity reduction
Delays generation	Rise of product costs	Increase of the critical of project
	Waste of resources	Reduced reliability
		Mistakes repetition
		Low products' standardization
		Inefficiencies generation
		People move away from core activities
		Unnecessary test and checks are performed
		Reduction in customer satisfaction
		Reduction of perceived quality

		Products with reduced innovative content
		Risk of team frustration
		Imitation rather than innovation

Table 3.3: List of wastes' potential effects classified by time, cost and performance

After that, an association between the eight waste categories and the potential causes and effects have been made, in order to create a check list to support the subject during the application of the methodology (table 3.4).

EFFECTS	8 WASTES	CAUSES
□ Rise of development times	**1. Over Producing/ Engineering**	□ Limited knowledge of the market
□ Delays generation		□ Inability/impossibility to translate requirements into technical specifications
□ Rise of development costs		□ No analysis of customer's needs
□ Rise of product costs		□ Copy of existing products
□ Productivity reduction		□ Imitation rather than innovation
□ Reduced reliability		□ Obsolete rules
□ Increase of the critical of project		□ Rules are too general
□ Rise of development times	**2. Waiting**	□ Scarce resources
□ Delays generation		□ Inefficient management and allocation of resources
□ Rise of development costs		□ No scheduling of competing facilities
□ Rise of product costs		□ Sequential activities
□ Productivity reduction		□ No knowledge sharing system
		□ Inappropriate communication
		□ Incompatibility format of the information
		□Lack of tools to support productivity and design, that allow a fast implementation of standard activities
		□Outdated information
□ Rise of development times	**3. Conveyance/ Transportation**	□ Unstructured information system
□ Delays generation		□ No common database
□ Rise of development costs		□ Too many interfaces required for the activity of product realization, low integration, long times
□ Rise of product costs		□ No culture of sharing
□ Productivity reduction		□ Data flow not clearly defined
□ Rise of development times	**4. Processing over/ inappropriate**	□No analysis of costumer's needs
□ Delays generation		□The costumer doesn't specify the initial requirements
□ Rise of development costs		□ Requirements change ongoing
□ Rise of product costs		□ Decision making is not concentrated at the beginning
□ Productivity reduction		□ No common definition of priorities
□ Waste of resources		□ No clear definition of the objectives
		□ Ineffective role of the PM
		□ PM is not a reference and integration figure also from a technical point of view
		□ Lack of communication
		□Wrong communication

		□ No inter functional teams
		□ Training and motivating staff's problems
		□ Ineffective social mechanisms
		□ Inappropriate archives
		□ Inappropriate business practices
□ Delays generation	**5. Inventory**	□ Scarce resources
□ Inefficiencies generation		□ Inefficient management and allocation of resources
		□ No scheduling of competing facilities
□ Rise of development times	**6. Motion**	□ No initial Project Review
□ Delays generation		□ Work is not structured in a systematic way
□ Rise of development costs		□ Decision making is not concentrated at the beginning
□ Productivity reduction		□ Priorities change ongoing
		□ Requirements change ongoing
		□ Inappropriate communication
		□ The team's components are situated in different areas
		□ Lack of a communication and sharing remote system
□ Delays generation	**7. Correction**	□ Failure to understand customer needs
□ Inefficiencies generation		□ Copy of existing products
□ Rise of development costs		□ No project review
□ People move away from core activities		□ Wrong communication
		□ No culture of sharing
		□ Lack of staff training
		□ PM doesn't evaluate feedback
		□ PM is not a reference and integration figure also from a technical point of view
		□Unstructured information system
□ Delays generation	**8. Unused employee creativity**	□ Focus on local optimization of costs
□ Inefficiencies generation		□ High variability of the product range
□ Unnecessary test and checks are performed		□ Lack of communication
□ Mistakes repetition		□ No culture of sharing
□Imitation rather than innovation		□ Knowledge confined to the single individual or team
□Risk of team frustration		□No inter functional teams
□Low products' standardization		□ No culture of reuse
□Reduction of perceived quality		□Unstructured information system
□Products with reduced innovative content		□No common database

Table 3.4: Waste macro-classes with its correspondent possible causes and effects

Without this, the ultimate goal of this phase is to evaluate any waste by associating each one a priority index (PI). The value of this index is calculated on the basis of three characteristics of the waste in question, which are: probability of occurrence (P), severity of the side effects (S), detection (D) and avoidability (A). Each of these parameters is calculated on the basis of a scale of values that goes from 1 to 4, with specific meaning for each of them. The priority index is obtained as the product of them:

PI = P x S x D x A

The Figure 3.2 below shows the scales of value used in the methodology proposed.

Probability	Severity	Detection	Avoidable
How many times the waste occurs in NPD? How is the probability it occurs?	How much the waste represents a problem for the company? How much serious is this waste?	How easy is it to detect the waste in NPD?	Is it possible (or not) to avoid this waste? How much avoidable is it? Indicate the level.
□Never/rarely_1	□Unimportant_1	□Very easy_1	□Avoidable waste_4
□Sometimes_2	□A little_2	Easy enough_2	□Not so avoidable waste_3
□Enough_3	□Enough_3	□Hard enough_3	□Difficult to avoid waste_2
□Very much_4	□Very much_4	□Impossible_4	□Not avoidable waste_1

Figure 3.2: Part of the questionnaire related to the Priority Index

3.1.2. Waste Prioritization

This phase of the methodology consists of ordering the waste found according to the priority index, in order to identify the main ones, that are the first on which must intervene.
As regard to the methods of detection, the methodology it provides some, which are represented in the Table 3.5 below and then described.

WASTE DETECTION METHODS
Post project review or Lessons Learned
BPR (Business Process Reengineering)
Work Sampling
Set of indicators

Table 3.5: Waste detection methods

- ***Post-project review or "lessons learned"***

According to the last standard definition given by the DOE's Society for Effective Lessons Learned Sharing (SELLS) organization, a "*lessons learned*" is the knowledge acquired from an innovation or an adverse experience that causes a worker or an organization to improve a process or activity to work safer, more efficiently, or with higher quality.
Based on this definition, LL can have different purposes including learning by mistakes and avoid wasting resources.

There are different forms of lessons learned and they can be divided in two categories: process-based and documentation-based. The first describes the steps and sequence in a project (for instance post-project appraisal, project audit, post control and after-action review), whilst the latter is a description of the experiences from the project (as micro articles and recall/Wiki). Process-based methods to learn from experiences:

- Project review/ Project audit: It is generally done after project completion or in the course of the project during individual project phases. It's carried out by moderators or people external to the project; project team and third parties that are involved into the project participate.
- After action review: It is generally done during the work process, it's carried out by a facilitator and the project team participate.
- Post-control: It is done exclusively at project end by the project manager.
- Post-project appraisal: It is done approximately two years after project completion, it's carried out by an external unit and project team and third parties that are involved into the project participate.

- ***BPR, Business Process Reengineering***

In literature several definitions of BPR can be found. For example Davenport and Short (1990) have described BPR as the analysis and design of work flows and processes within and between organizations. Hammer and Champy (1993) define it as the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed. Other authors such as Talwar (1993) have focused on the rethinking, restructuring and streamlining of the business structure, processes, methods of working, management systems and external relationships through which value is created and delivered. In other words BPR is about significant change and a rethinking of why things are done in a certain way and not about tinkering with or speeding up what is already in place.

Many are the instruments and methodologies that can be used for BPR, they include:

- Flow Diagram Charts
- Structured Systems, for example IDEF0
- Architectural Systems
- Modelling and simulation software
- Value stream analysis and mapping

- ***Work sampling***

It's a statistical technique that allows evaluating the time spent by the workers in doing specific activities.

Applications:

- Get the immediate comprehension of a process
- Get more information about particular issues
- Fix standard

- ***Set of indicators***

In a NPD process, in order to detect waste, it can be useful to define a set of indicators to be kept under control during the whole process and even to be analyzed at the end of it.

At the end of the process:

- Development time
- Development cost
- Product cost

Also with regard to the potential corrective actions, the methodology proposes several solutions. It comes to a good part of the lean tools and enablers exposed in the previous chapter as well as a number of actions of common sense drawn from the field. They are summarized in the following table (Table 3.6).

Corrective actions	
A-3 Reports	Multi functional teams
Balance of the work load	Obeya
CAD/CAM Technologies	LAMDA process
Centralized and structured database	QFD_ Quality function deployment
Check sheet	Six Sigma
Chief engineer	Staff training
Concurrent engineering	Standard information's format
Design for X	Supplier involvement

Table 3.6: Possible corrective actions

To support the subject during the implementation of the methodology has been created an additional check list that associates each waste category to the most suitable potential corrective action taken from the general list. It is presented below in Table 3.7.

Waste Macro-category	Potential Corrective Actions
Over Producing / Engineering	LAMDA process
	QFD_ Quality function deployment 1. Over
	Design for X Producing/
	Check sheet Engineering
	Value analysis
	Six Sigma

	Chief engineer
Waiting	LAMDA process
	Concurrent engineering
	Supplier involvement
	Initial schedule of available resources 2. Waiting
	Knowledge sharing system
	Standard information's format
	Visual planning
	CAD/CAM Technologies
	Balance of the work load
Conveyance/ Transportation	LAMDA process 3. Conveyance/
	Centralized and structured database Transportation
	Knowledge sharing system
	Standard information's format
Processing (Over / Inappropriate)	LAMDA process
	Multi functional teams
	Chief engineer 4. Processing over/
	Use modularity
	Mentoring
	Centralized and structured database
	Knowledge sharing system
	Visual planning
Inventory	LAMDA process 5. Inventory
	Zero buffer/ inventory
	Initial scheduling of available resources
	A-3 Reports
Motion	LAMDA process 6. Motion
	Effective management of meetings
	Team integration
Correction (Reworks / Defective)	LAMDA process
	Check sheets
	Staff training 7. Correction
	Chief engineer
	Use modularity
	Obeya
	Centralized and structured database
	Knowledge sharing system
Unused Employee Creativity	LAMDA process 8. Unused
	Multifunctional teams employee creativity
	Introduction program
	Centralized and structured database
	Knowledge sharing system

Table 3.7: Potential corrective actions according to each waste macro class

Thus, at the end of this step should be obtained a set of the most significant waste, each one accompanied by some detection methods and potential corrective actions. They are the waste to be removed first.

3.1.3. Sub process Identification

The third step consists in tracing the whole product development process in order to detect one or more sub processes containing as many as of the waste identified in the previous step. These sub processes are the first on which is necessary to act to eliminate waste and give rise to the continuous improvement procedure of the entire product development process. Once identified, switching to the next stage of the methodology, an analysis of them is made.

3.1.4. Sub process Analysis

The purpose of this phase is to analyze the selected sub process in order to locate the waste and then eliminate them. In carrying out this operation one of the detection methods identified in the second step of the methodology has to be used:

- Post Project Review or Lessons Learned
- BPR, Business Process Reengineering
- Work Sampling
- Set of indicators

The choice of the detection method should be made taking into account not only the type of waste that has to be detected, but also the kind of sub process that is being analyzed. For example Work Sampling method, which is a statistical technique with long time application, is better for short sub processes, featured by short and detailed actions; on the other hand BPR, in particular the VSM is good for long and complex sub processes, because it can be implemented outside the field and in a relative short time.

3.1.5. Corrective Actions

This is the last step of the methodology; at this point the aim is to choose among the potential corrective actions identified in the previous steps of the methodology and during the VSM application, which one actually implement.

To make the choice easier, the methodology suggests making use of the PICK chart. This is a Six Sigma tool, developed by Lockheed Martin, for organizing process improvement ideas and categorizing them. It is also a powerful and simple decision support tool. It helps to quickly decide what is the most beneficial option in terms of highest pay-off and the least effort.

When faced with multiple improvement ideas or options it may be used to determine the most useful.

There are four categories on a 2x2 matrix: horizontal is a scale of payoff or benefits; vertical represents the ease of implementation. By deciding where a decision option or as in this case, a corrective action, falls on the chart, four proposed project actions or decisions are provided:

- Possible: low payoff, easy to do.
- Implement: high payoff, easy to do.
- Challenge: high payoff, hard to do. So challenge it to see if there is an easier way like, for example, break down the solution into smaller components.
- Kill: low payoff, hard to do.

The vertical axis, representing ease of implementation would typically include some assessment of cost to implement as well. In the Figure 3.3, below, a simple PICK chart is presented.

	HIGH PAYOFF	LOW PAY-OFF
HARD TO DO	Possible	Kill
EASY TO DO	Implement	Challenge

Figure 3.3: PICK matrix

As already mentioned before, these five steps have to be implemented in a systematic and recursive way, by choosing few wastes to be eliminated at time and pursue the continuous improvement of the process.

3.2. My waste method for PSS design

PSS add different opportunities but also comes with new wastes that should be found. Hence, the described methodology should be modified in order to embrace all the possible problems that a Product-Service System could face. To do so some proceedings have been followed:

- **Brainstorming & ideas evaluation**

First of all, some research needs to be done so as to find possible new wastes and in which way they could affect the process. In order to do that, a first brainstorming was made. The first list of wastes is shown below:

- Action range not suitable
- Scarce integration between product and service
- Inappropriate communication platform
- Uneasy communication between user and business

- Incorrect Hub location
- Low adaptation to consumer needs
- Low response system
- Long times to access the service

This enumeration had the purpose of clearing ideas. For instance, to realize what a service waste could be and, the most important thing, that was trying not to mix them up with the causes and effects. Hence, these initial ideas were analyzed in depth.

The first one, "***action range not suitable***" was discarded because it was a cause and not a waste. This was easy to understand when the question "*how do I remove this waste?"* was asked. For example, it would be a waste if it was called "*wrong definition of the service action range*". However, this it is already included in the waste *"Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements"*.

The second one, it has to be rewrite to "***Reworks and revisions derived from scarce integration between Product and Service***"*,* in order to become understood as a waste. This one in particular is one of the most important in the PSS environment because if the integration of product and service is not well managed the company would have difficulties to go on. Therefore, designers must pay attention to this waste because not considering it would be fatal.

Inappropriate communication platform, as it is, is referred to not only having the required grade of technological progress in this area but to achieve an optimized and effective interaction between all the stakeholders of the process.

Uneasy communication between user and business is related to the fact that sometimes the user wants to ask for technical advice or for some information but it seems impossible for him/her to get it. That could be since the company does not allocate enough resources to establish fruitful relations with the clients, because the ways offered to do so are old-fashioned or due to the trouble it implies finding the information about the customer service.

The next two ideas were finally effects originated by wastes such as, for instance, *"Specifications not needed and/or not implemented are formulated", "Development of changes not asked or not needed"* or *"Unnecessary, not useful, not appropriate, immature, not error-free technologies are used"*.

To conclude this initial revision it has been thought about how the last one works inside the methodology. Written as such, it is just an effect and it is also very general. At that point, thinking some time about this, it was decide to try to change the viewpoint so as to see the waste behind this effect. At last, a more correct waste definition came up. This was focused on the fact that there are some services that require too many things, which sometimes are demanding, in order to give the service and spends a lot of time in the attempt. For instance, when going to the state offices they require lots of documents to obtain renewal or be given scholarships, etc. These documents sometimes can be found on the same site or maybe not so the user must look for them by himself/herself. Therefore, the waste was named "***Long times to get access to the service because steps to get to it are too difficult/burdensome***". Thanks to this last search, another waste appeared. This is also related the fact that not always a customer needs which service offer he/she really wants o maybe knows it still cannot find a clear way to obtain it. The waste is ***"Unnecessary movements to get to the service"***

- **Fit the selected ideas into the model**

Once having the final waste list, these must be included in the already existing methodology. The path to follow is to incorporate them into the 8 waste macro-class and then find the waste class for each one.

Reworks and revisions derived from scarce integration between Product and Service was easy to classify since it is correcting something that is going wrong. Hence the macro-category is "***Correction"*** and the waste class is "***poor design"*** due to this kind of waste arise because there is no communication between product and service designers in the design and development phase.

Inappropriate communication platform is related to the way of transmitting information with the stakeholders so the macro-class is "***Conveyance/Transportation***" and the waste category is "***Inappropriate tech choice***".

Uneasy communication between user and service it also because there are not enough resources to exchange information with the consumer. For that reason, the macro-class is "***Conveyance/Transportation***" and "***Bad resource allocation***" the waste class.

Long times to get access to the service because steps to get to it are too difficult/burdensome is clearly included in the "***Waiting***" macro-category and class is "***Too many steps***".

Finally, ***unnecessary movements to get to the service*** is contained in the "***Motion***" macro-class and because it is referred to the lack of traceable route to obtain the service the waste class is "***Undefined path***".

To sum up, the whole list containing the wastes (the new ones are in bold) and their description is presented in the table 3.8 below:

Waste Macro-class (8 Wastes)	# Waste	Waste Class	Description
Over Producing / Engineering	1	Over specification	Specifications not needed and/or not implemented are formulated
	2	Over specification	Specifications are formulated with too much details and/or too much earlier (for the specific NPD phase)
	3	Over designed	Product functionalities not asked / needed are implemented
	4	Over designed	Projects not needed and/or not convenient are studied
	5	Over information	Design data and info are formulated with too much details and/or too much earlier (for the specific NPD phase)
	6	Over components	Components / materials not needed are used in the product
Waiting	7	Waiting to process information	Time spent (without adding value) waiting to process information
	8	Waiting for information	Waiting for decisions, people, resources, data, information, documents
	9	**Too many steps**	**Long times to get access to the service because steps to get to it are too difficult/burdensome**
Conveyance / Transportation	10	Information systems	Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate
	11	Manual transcodification	Information might be manually retyped from one process / system to another
	12	**Inappropriate tech choice**	**Inappropriate communication platform**
	13	**Bad resource allocation**	**Uneasy communication between user and business**
Processing (Over / Inappropriate)	14	Unnecessary / Excessive activities	Unneeded and not useful activities are performed along the development phase
	15	Unnecessary / Excessive activities	Unnecessary and not useful tests are performed
	16	Unnecessary / Excessive activities	Unnecessary and not needed tolerances are included
	17	Unnecessary / Excessive activities	Development of parts / components / products already designed and existing, without re-using previous works and projects
	18	Unnecessary / Excessive activities	Too many authorizations / controls are needed to perform an activity
	19	Inappropriate process	Unnecessary, not useful, not appropriate, immature, not error-free technologies are used
	20	Inappropriate process	Development of changes not asked or not needed
	21	Inappropriate process	Time spent for bad definition of priorities
	22	Inappropriate process	Time is spent for reworks and revisions due to changing priorities, information, data, requirements
	23	Inappropriate process	Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed
	24	Inappropriate process	The development process is performed in different ways, depending by customers / suppliers / others
Inventory	25	Bad accumulation	Designs wait for the next available resources
	26	Bad accumulation	Batches of projects remain untouched
Motion	27	Travel	Unneeded travels might be done for visit customers
	28	Travel	Unneeded travels might be done for managing projects and teams
	29	Meeting	Unneeded and useless meetings are continuously organized with customers
	30	Meeting	Unneeded and useless meetings are continuously organized inside the company

	31	**Undefined path**	**Unnecessary movements to get to the service**
Correction (Reworks / Defective)	32	Poor design	Reworks and revisions derived from poor-quality products
	33	Poor design	Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements
	34	Poor product	Reworks and revisions derived from not successful products
	35	**Poor design**	**Reworks and revisions derived from Scarce integration between Product and Service**
Unused Employee Creativity	36	Bad knowledge managed	Communications failure and non-conformance
	37	Bad knowledge managed	Inability to reuse previous knowledge
	38	Bad knowledge managed	New employees cannot retrieve company knowledge easily

Table 3.8: Final wastes' list that will be used in the next study cases

Chapter 4

4. Business Case Application

4.1. Car2go

4.1.1. Introduction to the company

Daimler Financial Services history began following initial steps in the leasing and financing business until the company became a global services group in the 1990s. The merger of Daimler and Chrysler accelerated the company's internationalization, and automotive financial services became the company's core business as a result. Since the start of the new decade, the company has expanded its business model to include intelligent mobility services [21]. Car2go is a joint project of Daimler AG and Europcar. The car2go GmbH based in Ulm is owned by Daimler AG. The car2go Europe GmbH is headquartered in Stuttgart and is a joint venture between car2go GmbH (75%) and Europcar (25%). Under this society the individual subsidiaries are bundled in Europe. In Germany there are in addition to the *car2go GmbH Germany* the *car2go GmbH* in Ulm. On 20 November 2012, the car2go Germany GmbH took over the business operations for the car2go GmbH in Ulm. Other regional companies are the *car2go Austria GmbH* in Austria, *car2go NA LLC* in the USA and *car2go Canada Ltd.* in Canada.

The company offers exclusively Smart Fortwo vehicles and features one-way point-to-point rentals. As of May 2015, car2go is the largest carsharing company in the world with over 1,000,000 members and it is present in 32 different countries worldwide, 16 of them in Europe. The list of the actual, previous and future Car2go emplacements (table 4.1) is shown below.

City	Country	Creation
Ulm	Germany	March 2009 (closed in December2014)
Austin	United States	May 2010
Hamburg	Italy	Apr. 2011
Vancouver	Canada	June 2011
San Diego	United States	Nov. 2011
Amsterdam	Netherlands	Nov. 2011
Vienna	Austria	December 2011
Dusseldorf	Germany	Jan. 2012
Washington DC	United States	March 2012
Denver	United States	June 2013
Munich	Germany	June 2013
Milan	Italy	Aug. 2013
Twin Cities (Minneapolis, St.	United States	September 2013
Columbus	United States	October 2013
Montreal	Canada	Nov. 2013
Rome	Italy	March 2014
Florence	Italy	June 2014
Los Angeles (South Bay)	United States	June 2014 (closed in June 2015)

Portland	United States	March 2012
Berlin	Germany	Apr. 2012
Toronto	Canada	June 2012
Miami	United States	July 2012
Calgary	Canada	July 2012
Cologne	Germany	September 2012
Stuttgart	Germany	Nov. 2012
London	United Kingdom	December 2012 (closed in May 2014)
Seattle	United States	December 2012
Birmingham	United Kingdom	May 2013 (closed in May 2014)
Frankfurt	Germany	September 2014
Copenhagen	Denmark	September 2014
New York (Brooklyn)	United States	October 2014
Eugene / Springfield	United States	October 2014
Stockholm	Sweden	December 2014
Turin	Italy	Apr. 2015
Madrid	Spain	Nov. 2015
Bologna	Italy	2015 (planned)
Chongqing	China	2015 (planned)
Honolulu	United States	2015 (planned)

Table 4.1: Cities in which Car2go has been or is planning to be [22]

The Car2go service up-to-date and with no strings attached functioning makes it attractive for people who lives in big cities where owning a car is a headache. For example, a city like Milano in which during rush hours there is “chaos” in the streets, where the best way of going from one place to another is by bike, motorbike or public transport having a car it is just a problem. Where do I park it? How long will it take to do so? How much will it cost? There is also another extremely important reason: there are many people that live in Milano but they are not from there. They have come to work, to study, etc. So Car2go solve their problem of no having a car when, at some point, they need it just for a few minutes.

The Car2Go business model is similar in all markets, although rates vary by location. The company charges per minute rate, with discounted fixed rates for hourly and daily usage also available and applied automatically. The rates are all-inclusive and cover rental, gas, insurance, parking (in authorized areas) and maintenance. A low fixed annual fee is sometimes also charged. In most markets, car2go vehicles can park in either specially designated parking spots, or in standard parking areas, with a special permit from the local municipality.

The way it works is divided in 4 steps:

Figure 4.1: Illustration of a typical Car2go parade advertisement

- Registration & validation

First of all, anyone who wants to use this service has to register via website or in a Car2go parade (figure 4.1). After that, the client goes to a validation point to confirm the licence information given in the registration.

- Car rental

The first trip must be started with the member card (figure 4.2), and the next one can be both begun with the member card or the mobile app (figure 4.3).

Figure 4.2: Member card and NFC sensor that opens the car

Figure 4.3: User booking a car and opening it with the app

So once booked the car, the personal pin code must be inserted in the touchscreen, some questions about the car internal and external status must be answered so as to detect any flaw (figure 4.4).

Figure 4.4: General steps to start the rental

- Car driving

Now the key is unlocked and can be taken to start driving. There is a GPS system which helps the driver and there is also the radio option. The user can make stops during the trip, the only this he/she has to do is to take the car keys with him/her.

- End trip

Finally, the user turns of the car and chooses the end trip option. The car asks if there are now damages (figure 4.5) and finally the user leaves the keys where he/she has taken them from, exits the car and closes it with the member card.

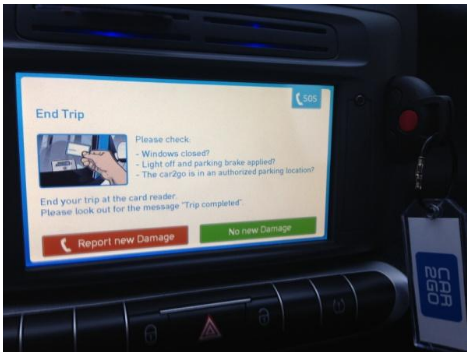


Figure 4.5: Damage report at the end of the trip

Figure 4.6: Car2go's smart parked in a permitted spot marked with blue lines

4.1.2. Business case

This new version of the "my waste methodology" has been implemented in this carsharing service, more exactly, the booking and rental of the car. The driving and the end of the trip processes have not been analysed all together with the other two because the process would become too wide for an exhaustive analysis.

The method it has been implemented taking into account the customer point of view. That being said, the steps followed are the ones previously explained in chapter 3 which are developed below.

The first step was to understand how the service works and then how the costumer sees it. To do so, it was necessary to have access to the service and to become a regular costumer. This helped to fill out the initial survey (figure 4.7) where the wastes are identified and hazard estimation (Priority Index) is made along with the recognition of their probable causes and effects. The people involved in this initial phase were aware of the methodology pace and understood the whole survey so as to not misunderstand some of the wastes.

Waste	Waste potential effect	Waste potential cause	Probability	Severity	Detection	Avoidable	Detection way	Corrective action
	□ Rise of development times	□ Limited knowledge of the market	□Never/rarely_1	□Unimportant_1	□Very easy_1	□Avoidable waste_4	□Post project review or —Lessons Learned	□ LAMDA process
1. Over specification Specifications not needed and/or not implemented are formulated	□Delays generation	□ Inability/impossibility to translate	□Sometimes_2	□A little_2	□Easy enough_2	□Not so avoidable waste_3	□BPR _ Business Process Reengineering	□ QFD_ Quality function deployment
	□ Rise of development costs	requirements into technical specifications	□Enough_3	□Enough_3	□Hard enough_3	□Difficult to avoid waste_2	□Work Sampling	□ Design for X
	□ Rise of product costs	□ No analysis of customer's needs	□Very much_4	□Very much_4	□Impossible_4	□Not avoidable waste_1	□Set of indicators	□ Check sheet
	□ Productivity reduction	□Copy of existing products					□More collaboration among departments	□ Value analysis

	□ Reduced reliability □ Increase of the critical of project □ Wrong estimates of costs/sales □Waste of design □Staff discontent □Stressful work conditions □_____________	□Imitation rather than innovation □ Obsolete rules □ Rules are too general □ Lack of control by top management □Try to innovate □Lack of coordination/planning □________________					□___________	□ Six Sigma □ Chief engineer □Product architecture formalization □________

Figure 4.7: Part of the questionnaire used in the methodology

The results of the survey are shown below (table 4.2).

Waste Macro-class (8 Wastes)	Waste Class	Description	(P)	(S)	(D)	(A)	PI
Over Producing / Engineering	Over specification	Specifications not needed and/or not implemented are formulated	1	2	2	2	8
	Over specification	Specifications are formulated with too much details and/or too much earlier (for the specific NPD phase)	2	1	2	2	8
	Over designed	Product functionalities not asked / needed are implemented	1	1	3	3	9
	Over designed	Projects not needed and/or not convenient are studied	1	2	2	3	12
	Over information	Design data and info are formulated with too much details and/or too much earlier (for the specific NPD phase)	1	3	2	4	24
	Over components	Components / materials not needed are used in the product	1	1	3	4	12
Waiting	Waiting to process information	Time spent (without adding value) waiting to process information	4	3	2	2	48
	Waiting for information	**Waiting for decisions, people, resources, data, information, documents**	**4**	**4**	**2**	**3**	**96**
	Too many steps	Long times to get access to the service because steps to get to it are too difficult/burdensome	3	4	2	1	24
Conveyance/ Transportation	Information systems	Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate	2	4	1	4	32
	Manual transcodification	Information might be manually retyped from one process / system to another	1	3	1	3	9
	Inappropriate tech choice	Inappropriate communication platform	2	3	3	3	54
	Bad resource allocation	**Uneasy communication between user and business**	**3**	**3**	**3**	**3**	**81**
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unneeded and not useful activities are performed along the development phase	2	2	3	3	36
	Unnecessary / Excessive activities	Unnecessary and not useful tests are performed	1	2	3	4	24
	Unnecessary / Excessive activities	Unnecessary and not needed tolerances are included	1	3	2	3	18
	Unnecessary / Excessive activities	Development of parts / components / products already designed and existing, without re-using previous works and projects	1	2	2	4	16
	Unnecessary / Excessive activities	**Too many authorizations / controls are needed to perform an activity**	**3**	**4**	**3**	**3**	**108**
	Inappropriate process	**Unnecessary, not useful, not appropriate, immature, not error-free technologies are used**	**3**	**4**	**3**	**2**	**72**
	Inappropriate process	Development of changes not asked or not needed	2	3	2	3	36
	Inappropriate process	Time spent for bad definition of priorities	2	2	3	3	36
	Inappropriate process	Time is spent for reworks and revisions due to changing priorities, information, data, requirements	3	3	2	1	18
	Inappropriate process	**Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed**	**2**	**4**	**3**	**3**	**72**
	Inappropriate process	The development process is performed in different ways, depending by customers / suppliers / others	2	3	1	3	18

Inventory	Bad accumulation	Designs wait for the next available resources	2	2	1	2	8
	Bad accumulation	Batches of projects remain untouched	2	3	2	3	36
Motion	Travel	Unneeded travels might be done for visit customers	1	2	2	2	8
	Travel	Unneeded travels might be done for managing projects and teams	1	2	3	2	12
	Meeting	Unneeded and useless meetings are continuously organized with customers	1	2	3	3	18
	Meeting	Unneeded and useless meetings are continuously organized inside the company	1	2	2	3	12
	Undefined path	Unnecessary movements to get to the service	2	4	3	2	48
Correction (Reworks / Defective)	Poor design	Reworks and revisions derived from poor-quality products	2	4	2	3	48
	Poor design	**Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements**	**3**	**4**	**2**	**3**	**72**
	Poor product	Reworks and revisions derived from not successful products	2	4	2	2	32
	Poor design	Reworks and revisions derived from Scarce integration between Product and Service	1	4	2	4	32
Unused Employee Creativity	Bad knowledge managed	Communications failure and non-conformance	2	4	3	2	48
	Bad knowledge managed	Inability to reuse previous knowledge	1	3	2	2	12
	Bad knowledge managed	New employees cannot retrieve company knowledge easily	1	3	2	3	18

Table 4.2: Results for Car2go of the questionnaire

The next step is to order them in a descending way basing it on the PI value. Consequently, the wastes prioritization is obtained and also the fulfilment of the second step of the methodology. The ordered list can be found in table 4.3 and the same information can be visualized in figure 4.8

The first waste of the list, are those from which is appropriate to begin the removal action, since for several reasons that may relate to severity of their effects, rather than their high occurrence or others, are the more severe.

Waste Macro-class (8 Wastes)	Waste Class	Description	#	Pos	PI
Processing (Over / Inappropriate)	**Unnecessary / Excessive activities**	**Too many authorizations / controls are needed to perform an activity**	**18**	**1**	**108**
Waiting	**Waiting for information**	**Waiting for decisions, people, resources, data, information, documents**	**8**	**2**	**96**
Conveyance/ Transportation	**Bad resource allocation**	**Uneasy communication between user and business**	**13**	**3**	**81**
Processing (Over / Inappropriate)	**Inappropriate process**	**Unnecessary, not useful, not appropriate, immature, not error-free technologies are used**	**19**	**4**	**72**
Processing (Over / Inappropriate)	**Inappropriate process**	**Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed**	**23**	**5**	**72**
Correction (Reworks / Defective)	**Poor design**	**Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements**	**33**	**6**	**72**
Conveyance/ Transportation	Inappropriate tech choice	Inappropriate communication platform	12	7	54
Waiting	Waiting to process information	Time spent (without adding value) waiting to process information	7	8	48
Motion	Undefined path	Unnecessary movements to get to the service	31	9	48
Correction (Reworks / Defective)	Poor design	Reworks and revisions derived from poor-quality products	32	10	48
Unused Employee Creativity	Bad knowledge managed	Communications failure and non-conformance	36	11	48

Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unneeded and not useful activities are performed along the development phase	14	12	36
Processing (Over / Inappropriate)	Inappropriate process	Development of changes not asked or not needed	20	13	36
Processing (Over / Inappropriate)	Inappropriate process	Time spent for bad definition of priorities	21	14	36
Motion	Bad accumulation	Batches of projects remain untouched	26	15	36
Conveyance/ Transportation	Information systems	Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate	10	16	32
Correction (Reworks / Defective)	Poor product	Reworks and revisions derived from not successful products	34	17	32
Correction (Reworks / Defective)	Poor design	Reworks and revisions derived from Scarce integration between Product and Service	35	18	32
Over Producing / Engineering	Over information	Design data and info are formulated with too much details and/or too much earlier (for the specific NPD phase)	5	19	24
Waiting	Too many steps	Long times to get access to the service because steps to get to it are too difficult/burdensome	9	20	24
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unnecessary and not useful tests are performed	15	21	24
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unnecessary and not needed tolerances are included	16	22	18
Processing (Over / Inappropriate)	Inappropriate process	Time is spent for reworks and revisions due to changing priorities, information, data, requirements	22	23	18
Processing (Over / Inappropriate)	Inappropriate process	The development process is performed in different ways, depending by customers / suppliers / others	24	24	18
Motion	Meeting	Unneeded and useless meetings are continuously organized with customers	29	25	18
Unused Employee Creativity	Bad knowledge managed	New employees cannot retrieve company knowledge easily	38	26	18
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Development of parts / components / products already designed and existing, without re-using previous works and projects	17	27	16
Over Producing / Engineering	Over designed	Projects not needed and/or not convenient are studied	4	28	12
Over Producing / Engineering	Over components	Components / materials not needed are used in the product	6	29	12
Motion	Travel	Unneeded travels might be done for managing projects and teams	28	30	12
Motion	Meeting	Unneeded and useless meetings are continuously organized inside the company	30	31	12
Unused Employee Creativity	Bad knowledge managed	Inability to reuse previous knowledge	37	32	12
Over Producing / Engineering	Over designed	Product functionalities not asked / needed are implemented	3	33	9
Conveyance/ Transportation	Manual transcodification	Information might be manually retyped from one process / system to another	11	34	9
Over Producing / Engineering	Over specification	Specifications not needed and/or not implemented are formulated	1	35	8
Over Producing / Engineering	Over specification	Specifications are formulated with too much details and/or too much earlier (for the specific NPD phase)	2	36	8
Inventory	Bad accumulation	Designs wait for the next available resources	25	37	8
Motion	Travel	Unneeded travels might be done for visit customers	27	38	8

Table 4.3: Waste list ordered by Priority Index number

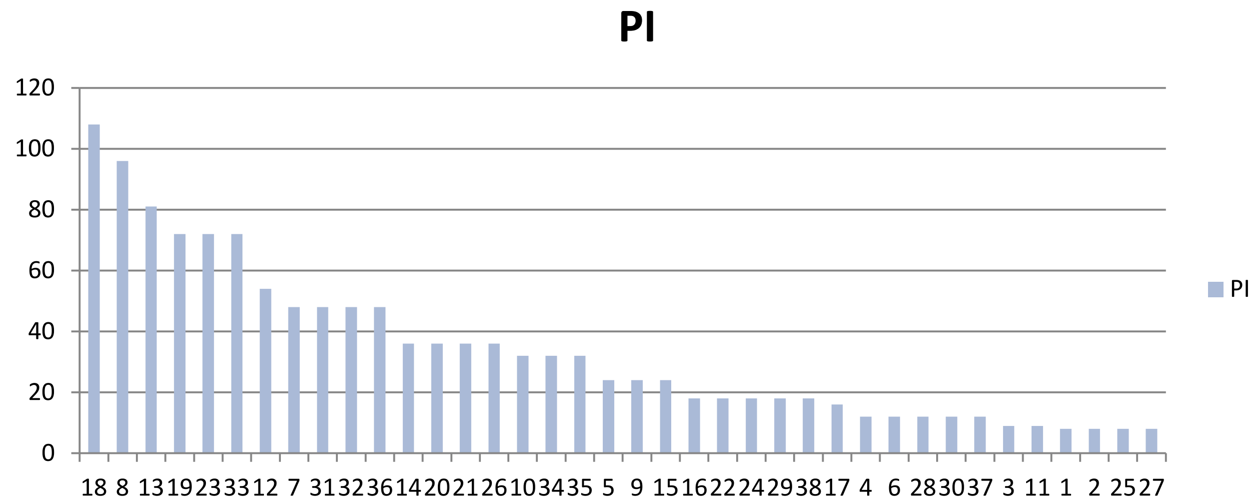


Figure 4.8: Bar chart of the Car2go prioritization

This results arise from the implementation of the first two phases of the “my waste” methodology. Taking into account the PI, it can be said that the first waste to inspect is #18 but then it is not easy to decide if also consider the next two or the next five since the priority index from the third then takes values that differ slightly. It can be arbitrarily decided to take the first three wastes or the first six ones; also Pareto analysis can be carried on or even consider that the maximum value that the PI can reach is 256 (assuming that all parameters P, S, D, A take on their worst value) and based on this determinate value ranges for PI to be considered on an alarm level. In this first application of the Methodology it has been simply decided to take the top six wastes, which are:

- # **18**_*Processing (Over / Inappropriate)*; *Unnecessary / Excessive activities*; Too many authorizations / controls are needed to perform an activity.
- # **8**_ *Waiting*; *Waiting for information;* Waiting for decisions, people, resources, data, information, documents.
- # **13**_ *Conveyance/ Transportation; Bad resource allocation;* Uneasy communication between user and business.
- # **19**_*Processing (Over / Inappropriate); Inappropriate process*; Unnecessary, not useful, not appropriate, immature, not error-free technologies are used.
- # **23**_*Processing (Over / Inappropriate); Inappropriate process*; Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed.
- # **33**_*Correction (Reworks / Defective); Poor design*; Reworks and revisions due to incomplete/ incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements.

If we focus on these highly dangerous wastes it can be seen that the top two are associated with being too many steps which prolong the process (#18) and with the tardiness between these steps (#8). The other four, are referred to wrong choices in tech, processes and information. Finally, to close the second phase it was asked to think about some potential detection way and corrective actions for these six main wastes. In order to ease their selection, they were given a check list with detection ways and corrective action which were gathered and validated in previous Politecnico di Milano's thesis. This check list is presented below in the Figure 4.9.

Waste macro-category	Detection way	Corrective actions
2. Waiting	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □High project control	□ LAMDA process □ Concurrent engineering □ Supplier involvement □ Initial schedule of available resources □ Knowledge sharing system □ Standard information's format □ Visual planning □ CAD/CAM Technologies □Implementation of ICT technologies □A more clear role definition □Correct level of delegation □ Balance of the work load
3. Conveyance/ Transportation	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □ Standard information's format
4. Processing over/ inappropriate	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □ Visual planning
7. Correction	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators	□ LAMDA process □ Check sheets □ Staff training □Chief engineer

	□Customer satisfaction control	□Use modularity □Obeya □Centralized and structured database □Quality control activities □All the activities in order to understand a product failure □Knowledge sharing system

Figure 4.9: Check list of the selected wastes and their detection way and corrective actions

The results of this task are reported in the Table 4.4 below.

# Waste	Detection way	Corrective actions
18	□BPR _ Business Process Reengineering □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □New technologies implementation □ Visual planning
8	□BPR _ Business Process Reengineering □Set of indicators	□ LAMDA process □ Concurrent engineering □ Supplier involvement □ Initial schedule of available resources □ Knowledge sharing system □ Standard information's format □Implementation of ICT technologies □ Balance of the work load
13	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □ Standard information's format
19	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Anonymous surveys or questionnaires	□ LAMDA process □ Chief engineer □ Centralized and structured database □ Knowledge sharing system

		□Redefinition of decisional processes and decision making activities □New technologies implementation
23	□BPR _ Business Process Reengineering □Set of indicators □Anonymous surveys or questionnaires	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □Redefinition of decisional processes and decision making activities
33	□BPR _ Business Process Reengineering □Work Sampling □Customer satisfaction control	□ LAMDA process □ Staff training □Chief engineer □Centralized and structured database □Quality control activities □Knowledge sharing system

Table 4.4: Possible detection ways and corrective actions selected for the Car2go analysis

Once the six wastes were identified, the participants were requested to put their thinking cap on to find a sub process were most of these wastes could be found. At the end, they came to the conclusion that the initial rental of the car is the most suitable sub process.

So as to begin the next phase the sub process was briefly analyzed analyze by doing two activities:

1. Delineate the boundaries of the sub process by specifying: the process owner, who is the responsible; the requirements to perform the sub process; knowledge and information needed; the constraints to be taken into account and finally the expected output.
2. Map the sub process using the VSM logic, symbols and language.

From the first activity turned out Figure 4.10. This was obtained simply through a discussion of the people involved.

The initial idea was to examine the whole renting process, from the search of the car to the end of the car rental including the driving phase. However, there were too many activities involved so it would have been hard to make a deep analysis of the activity flow. For this reason, a smaller process with most of the wastes detected as damaging was selected. This last option encompass from the moment the customer wants to rent a car to the moment where this costumer can start the trip.

Once the process which was to be examined was selected, the process boundaries definition was made, specifying requirements, information and knowledge, constraints and output of the process.

- Requirements:
  - IoT architecture,
  - User credentials, which include the user name and the password
  - Car fleet
  - Car location & user location
- Constraints:
  - Time to reach the rental car that is of 30 min
  - Previous registration via website and the first trip done
- Knowledge & Information:
  - Car tidiness
  - Car availability
  - Car & user location
- Output:
  - Car activation
  - Car location & status
  - User routes

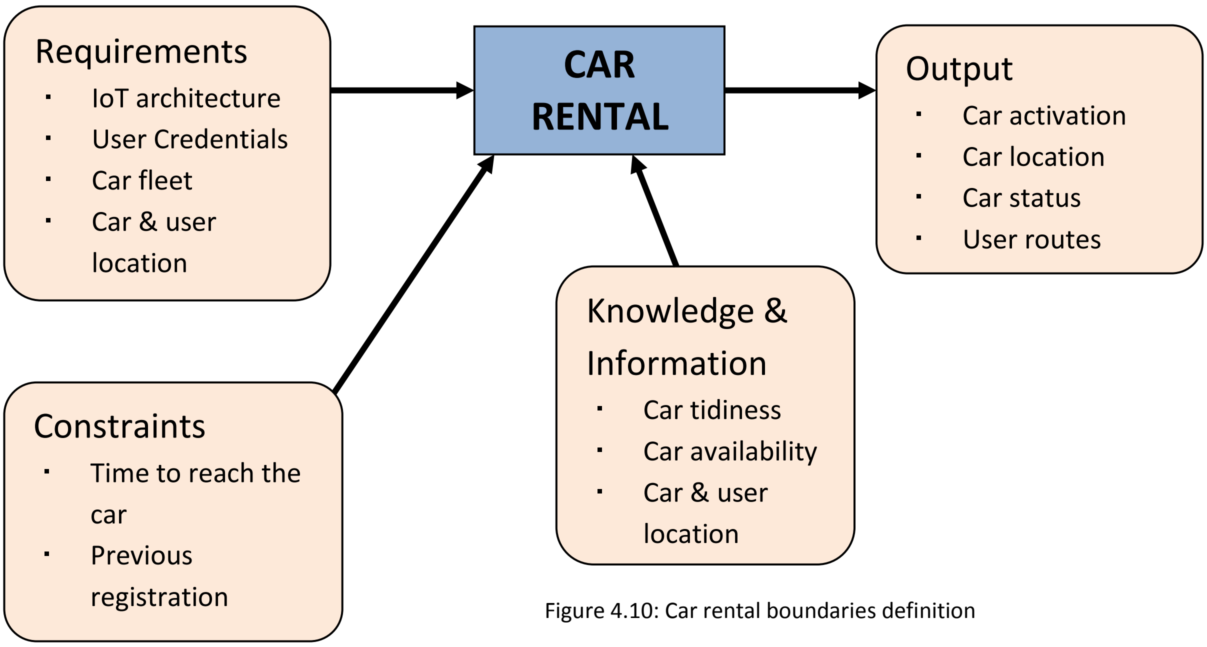


Figure 4.10: Car rental boundaries definition

After that the Value Stream Map was made. Within each activity the minimum and maximum processing time is specified, while between the activities the minimum and maximum waiting time is indicated, if any.

The whole process of renting a car starts when the Car2go user needs to go somewhere by car so it runs the mobile app. The first step is to find a car near the user location. The app will show the city map and the exact position of every car in the fleet. After that, the log in must be done book a car therefore the credential must be introduced. In case that they are wrongly taped they can be reintroduced. If the client does not remember them the app redirects him/her to the change log webpage where the recovery e-mail is introduced to obtain a new password. This action could be burdensome if there is no a good internet coverage. Once logged in, the car is booked and the user goes to take it. The main problem in this part is that sometimes it is really difficult to find the car because smarts are really small cars and sometimes cannot be seen or, what is worse, they are parked inside some building where the user does not have access. If it is just that the user fails to see it, he/she can reopen the app to see where the car is and retry to find it. On the other hand if it is in an inaccessible place the problem is that the user should restart the whole process which can drive anybody mad. This last problem will be further discussed on the corrective actions part. Following the flow, once reached the car, it can be opened with the application or with the member card. Subsequently, the user gets into the car and introduces a four digit pin code and if it is correct answer some questions about the car tidiness and if there is any external damage and finally, the trip can be started.

In this case study, due to the data unavailability, it was decided to take into account only two kinds of time:

- The processing time, which in the Current State Map is indicated with 'T' and 't' and stands for the value added time within each activity, so the effective time in which the designer has worked on the project;
- The waiting time between sequential activities, indicated with 'W' and 'w', in which the designer had to wait before starting to perform a new activity.

As the exact time values were not available, the best and the worst cases had been considered, in order to make an average. As said before, in the next page the Current State Map Visio version is available (Figure 4.11), it follows a label in order to read and understand it.

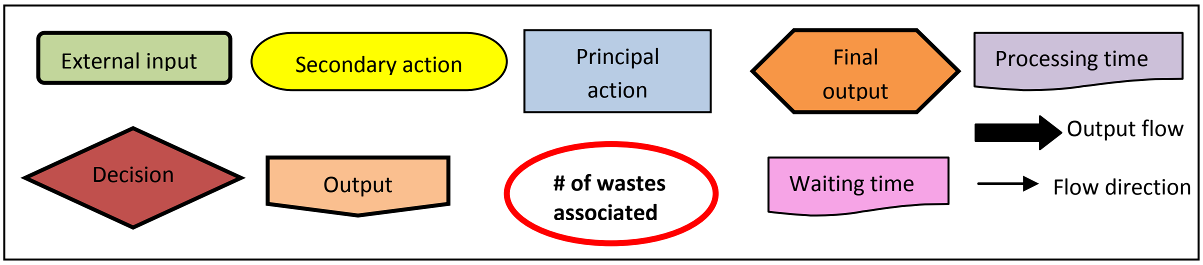


Figure 4.11: Vale Stream Map labels definition

Once the VSM was made it was also asked to locate the wastes in the activities where they could be found. According to the collaborators tips, a table has been made connecting the wastes with their possible location in the process (table 4.5):

# Waste	Possible location
18	□log in □Insert pin code □Car opens?
8	□Run app □Find a car near your location □Change password
13	□Run app □Car opens?
19	□Find a car near your location □Launch the app to see where the car is □Car opens? □Run the app
23	□Car found? □Right id? □ Right code? □Insert car status
33	□Car found? □Right id? □ Right code?

Table 4.5: Potential wastes and their possible location in the VSM

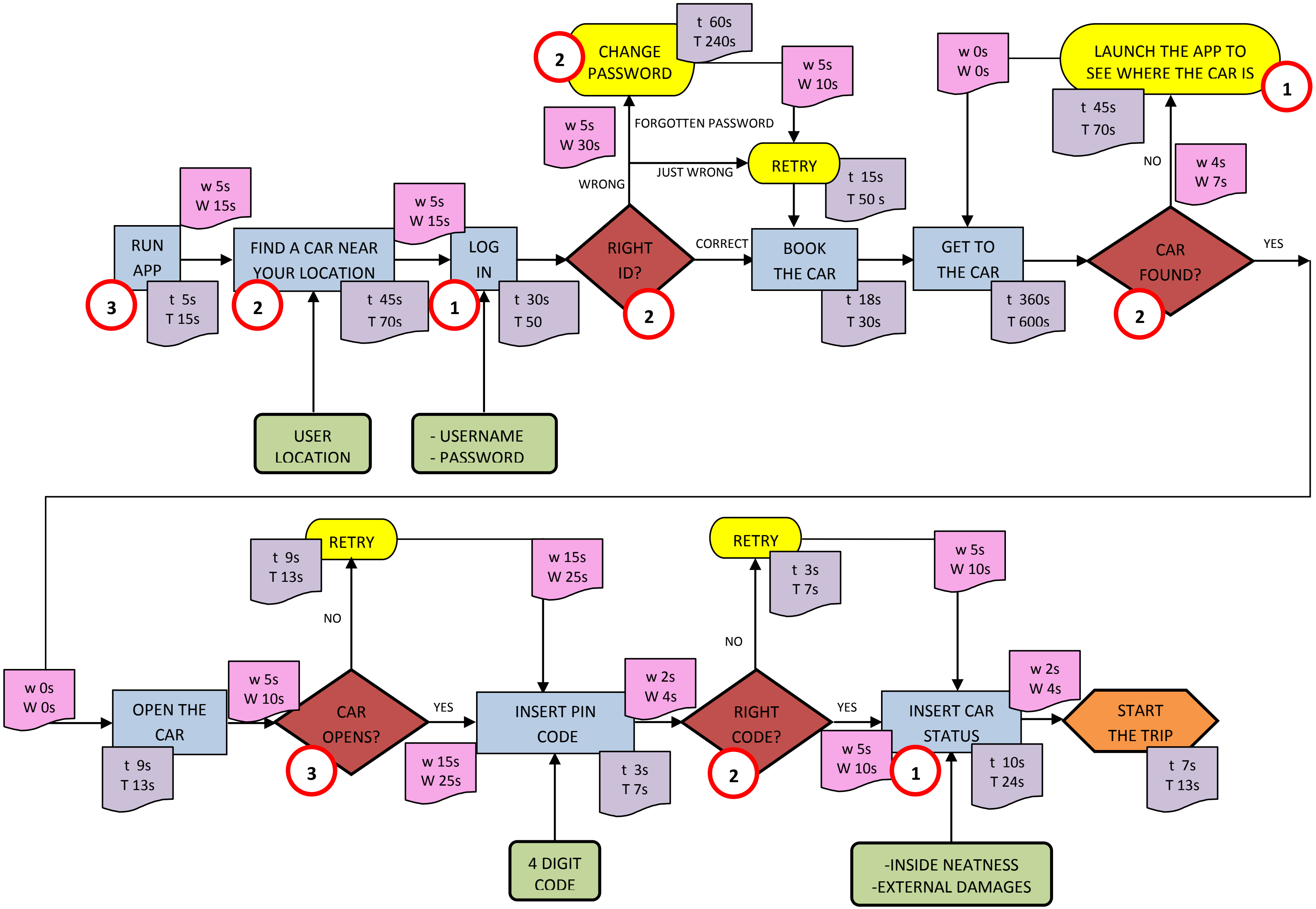


Figure 4.12: Rental process **Current State Map**

Figure 4.12 is the current state map of the car rental process. The following phases consist on locating the waste and, after that, implement the corrective actions to remove them and, therefore, improve the process.

Analyzing the CSM some considerations came up:

1. The longest waiting times and processing times are found when the user goes to find the car which is a physical process
2. The longest IT related process is when the user forgets the credentials.
3. The recirculations are due to errors in the communication with the servers, in the NFC (Near Field Communication) technology or Human mistakes like when some character is typed or the user does not see the car.
4. All the activities are sequential which means that it cannot begin one until the previous one is finished.

Moreover by the time calculation exposed in Appendix B it can be noticed that the difference between the worst and the best case scenario. The best case would be when the user remembers every password and finds the car without problems. In this scenario, the total time would be around 9min. On the other hand, the WCS would be forgetting all the credentials and having difficulties to find the car that would increase the lead time until roughly 30min. The overall time on the worst case is nearly 3 times the time in the best case. It is important to mention that if the user cannot access the car because is in an unreachable place the lead time will increase from 5 to 10 minutes.

Finally, from the observations exposed above and the time calculation results, some improving hypotheses have been made.

The waste with the highest priority index, waste 18(*Too many authorizations / controls are needed to perform an activity*), can bother some users because of the time invested and attempts made introducing credentials and pin codes (2,5 to 4 min). According to this, a different system could be implemented where the users do not need just need to log in the app and then do it everything with it. However, this could increase the attempts and the problems needed to start the rental because the actual redundancies help skip some problems like, for instance, if you run out of battery. Being this said, the option taken would be to *kill* the correction action.

The next waste, *"waiting for decisions, people, resources, data, information, documents"*, it would be a problem if the waiting times were comparable to the processing times. In this case, the waiting times are the 7% of the whole lead time. The ways of decreasing this percentage is to upgrade the communication technology, optimize the mobile application or the car system in order to achieve fastest response between devices. This measure would be costly and the reductions achieved would be nothing to shout about and for this reasons it would be a *kill* in the PICK analysis.

Waste 13 ("*Uneasy communication between user and business*") can be due to a problem with the communication platform and because of the technology used which is also connected with waste 19(*"Unnecessary, not useful, not appropriate, immature, not error-free technologies are used*"). However, the problem with their solution is that is the same that for the previous wastes which were *kill* actions and hence it is difficult to implement.

Finally, the biggest problems in the rental process are wastes 23 and 33 ("*Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed"* and "*Reworks and revisions due to incomplete/ incorrect / inappropriate / not reliable information, data, requirements" respectively*). These are the ones that disproportionally raise the overall time. The translation for both of them in this case study is the moment when the user physically searches for the car. This takes form 6 to 10 min if everything goes right and the user find it in the first attempt. If not, the client invests 3-5 min to find it and in some cases they never find it because it was parked in some private parking that force them to look for another car(6-10 min more if he/she is lucky). Taking into account these facts, the measures proposed are:

- Adding a "parked in a private parking" option that would allow the user to report if the car is in a prohibited spot. This if confirmed could mean a fine for the last driver.
  This possibility is hard to implement but it would have a great acceptance between the users. Hence the action would be classified as *Challenge*.
- Making special fares depending on the zone that the car is parked in order to avoid great concentrations in one zone and scarce in another. The measure is not so complicated but it is not clear if the people would embrace it because in some areas it would be cheaper but in others it would be more expensive. Therefore, it is a *Possible.*
- Allow to activate any light signal from the car for a limited time in order to spot it much faster. This last one it is easy to achieve and the clients would be much than grateful because sometimes it can be really hard to spot them. In consequence, this corrective action is to *Implement.*

4.2. Ateneus of Digital Fabrication (ADF)

4.2.1. Fundació CIM

Fundació CIM is a technologic centre affiliated to the UPC – "Universitat Politecnica de Catalunya" dedicated to R&D and knowledge transfer in relevant fields of manufacturing, automation and production management. FCIM is distinguished as a reference centre in Manufacturing technologies, technological projects, research, Innovation and training for industries.

Fundació CIM is very intensive in machinery and production applications, with highly innovative labs in Machining, Additive Manufacturing, Metrology and state-of-the-art processes for manufacturing. The Research and Development activities of the Fundació CIM are focused on production technologies, addressing the applicability and sustainability of the solutions materialized. The services offered are the result of more than 20 years of background in the field of production technologies and, as a result, FCIM counts on specialists in the areas of systems engineering, manufacturing, automation, robotics, mechanics and design, which can contribute to solve in a holistic manner the problems of existing systems of industrial production.

Fundació CIM is active in the development of new emerging processes. The four research lines undertaken by FCIM are (i) New manufacturing processes, (ii)Manufacturing and production systems, (iii) Product engineering and (iv) Application of ICT to production systems. At the same time, special attention is given to the emerging strategic alliances with institutions that develop scientific and auxiliary disciplines to FCIM developments. In this aspect, the Fundació CIM is member of EFFRA, Manufacture, AM Platform, and national platforms. Moreover, FCIM manages XaRTAP, a Research Network in Advanced Production Technologies that combines the strength of 400 researchers in 11 academic different groups.

FCIM participation in ADF

Being aware of the relevance that Barcelona City Council was putting into the development of FabLab/ADF network and the global dissemination of FabLabs networks, since 2012 FCIM is enrolled in the ramp-up phase and technical management of FabLabs/ADF facilities. FCIM poses itself as an excellent technological manager of FabLabs/ADF facilities taking advantages of the following:

- Being the reference centre in production technologies of the Universitat Politècnica de Catalunya (UPC), with close relation with Barcelona School of Industrial Engineering, where it was founded in 1990.
- Creating RepRapBCN project with the main objective of promoting 3D Printing open source across Spain and Europe developing and selling its own 3D Printers. RepRapBCN contributes

to the 3D Printing community organizing workshops in its own facilities and spreading the knowledge of this cutting edge technology with students of engineering of several fields (industrial, mechanical, materials and electronics).

- Developing "0 km" production machinery for digital fabrication such as: 3D Printers (BCN3D+, BCN3DR, BCN3D SIGMA), laser cutting/engraving machinery (BCN IGNIS), machinery based on direct light processing additive manufacturing technology (BCN3D LUX).

FCIM has created within its staff a team dedicated to the management and creation of new FabLab/ADF facilities, formed by experienced manufacturing engineers managers and skilled operators (Figure 5). The services provided by FCIM include:

- Selection and purchase of productive machinery (own products and not).
- Tuning phase of production machinery: unpack, turn on each machine and verify proper operation to give the approval.
- Operation of production machinery and training of FabLab/ADF staff: tutoring and offering a continuous service.
- Management and coordination of FabLab/ADF: Design and manufacturing of sample parts with the available technologies for neighbourhood groups, trophies organizations, educational games for schools, etc.
- Educational courses and workshops in digital fabrication for teachers, students and groups of each district.

4.2.2. Manutelligence

The Manutelligence project is supported from both industrial and research perspectives, by a very strong consortium, composed by 12 European partners among them *Politecnico di Milano* and *Fundació CIM.*

Manutelligence aims to integrate best in class methodology and tools from research and industry, resulting in a secure, cross disciplinary collaborative Product/Service Design and Manufacturing Engineering Platform. This platform will enable designers and engineers to access through natural 3D experiences to data from both the traditional enterprise IT systems (CAD, CAX, PLM, MES, etc.) and IoT enabled systems for physical products information and knowledge management. Such a platform, to have success on the market, needs to be inclusive, facilitating the cooperation and collaboration of enterprises.

Business based on Product-Services is increasing, both in the business to business and in the business to consumer sectors.

Manutelligence aims at supporting this emerging trend, allowing enterprises to develop innovative product-services, more sustainable, addressing customer needs. Some of these services can be provided only after punctual and accurate analysis of customers’ product usage in order to acquire useful information for new product improvements or services provision. Often the misalignment between the product and service development processes and incapability for concurrent engineering between both processes arise due to the lack of information exchange among the product and service life cycle phases. That generates longer time to market for the product and service, misalignment between the product and service life cycle phases, lack of sharing knowledge and product-services not adapted to the business environment/customers’ needs. Manutelligence aims to integrate best in class methodologies and tools from research and industry, resulting in a secure, cross-disciplinary collaborative Product/Service Design and Manufacturing Engineering Platform (figure 4.13). This platform will enable designers and engineers to access through natural 3D experiences to data from both the “traditional” enterprise IT systems (CAD, CAX, PLM, MES, etc.) and IoT enabled systems for physical products information and knowledge management during its whole life cycle phases. The activities carried out by Manutelligence will improve the product and service development by connecting them together through cross-disciplinary feedback loops by means of modular collaborative secure ICT manufacturing intelligence. It will be possible to design a product from the first life-cycle stage onward so it acts as an enabler for multiple services on top, to enable manufacturers to design and develop new innovative services based on their existing products, to develop new product and tailored services based on product usage information and customer’s wishes.

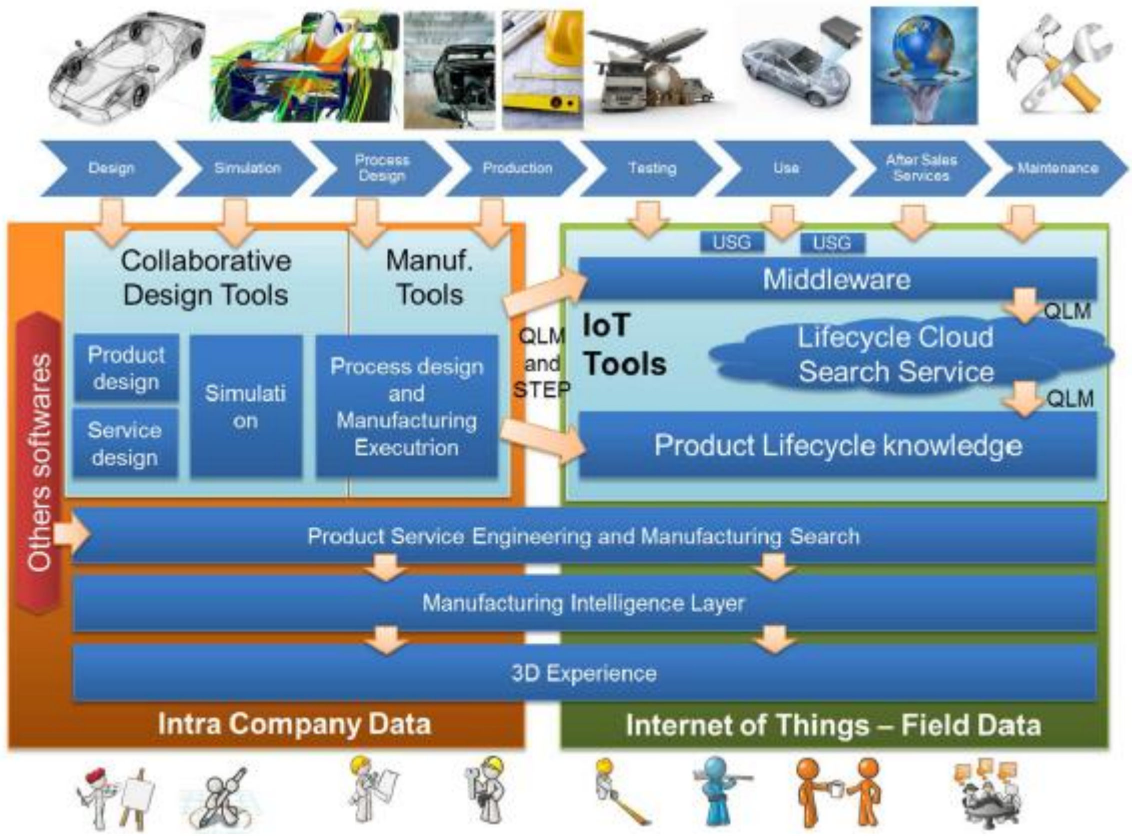


Figure 4.13: Manutelligence draft architecture concept

Fundació CIM in the Manutelligence project

The use case ADF in the Manutelligence Project intends at extending the Manutelligence concepts and tools to an emerging production paradigm for digital fabrication and rapid prototyping. The level of customization in a FABLab is usually very high, leading to a less structured design and production environment that has to meet the needs of customers with different level of expertise. The FABLab acting as a pilot for Manutelligence is the network of Fablab-like facilities existing in Barcelona city, represented by the *Ateneus of Digital Fabrication* (ADF) whose features are described in the next section.

The **ADFs** are today a minor relevance on the EU GDP but represent a growing and important trend of the future manufacturing. 3D printers and 3D printing services are now available for the public, even if still not wide-spread. The aim of this pilot is twofold; first of all to enable collaborative design for ADFs, allowing "makers" to cooperate using best in class design collaboration tools. Secondly to enable the manufacturing of "Internet of Things" enabled objects, though the possibility of adding single boards PCs with sensors (the Universal Sensor Gateway, described in the following) to a fully working IoT platform (the Holonix i-LiKe). The aim is to give to FabLabs users, often youngsters, to learn and start using the potential of 3D printing and the IoT. This will support the growth of the future generation of designers and engineers, used to think from the beginning to product-services and Internet enabled things.

4.2.3. Introduction to the Ateneus of Digital Fabrication

Ateneus of Digital Fabrication (ADF) is the response of Barcelona City Council to the massive usage around the world of digital production and Internet as a global knowledge network, accompanied by developments combined with the dynamics of co-creation, co-innovation, knowledge sharing generation, the culture of sharing and fast implementation of FabLabs facilities around the globe.

The city of Barcelona has created a FabLab facility with the MIT badge, promoted by the founder of the Institute of Advanced Architecture of Catalonia (IAAC). A Fabcity vision is being pushed through the gradual opening of public funded *Ateneus of Digital Fabrication* (ADF) for each Barcelona district, as can be seen in Figure 4.14. Besides there are other FabLab type facilities like the Barcelona Advanced Industry Park. The network of ADF is envisaged as becoming part of the public infrastructure of a sustainable city.

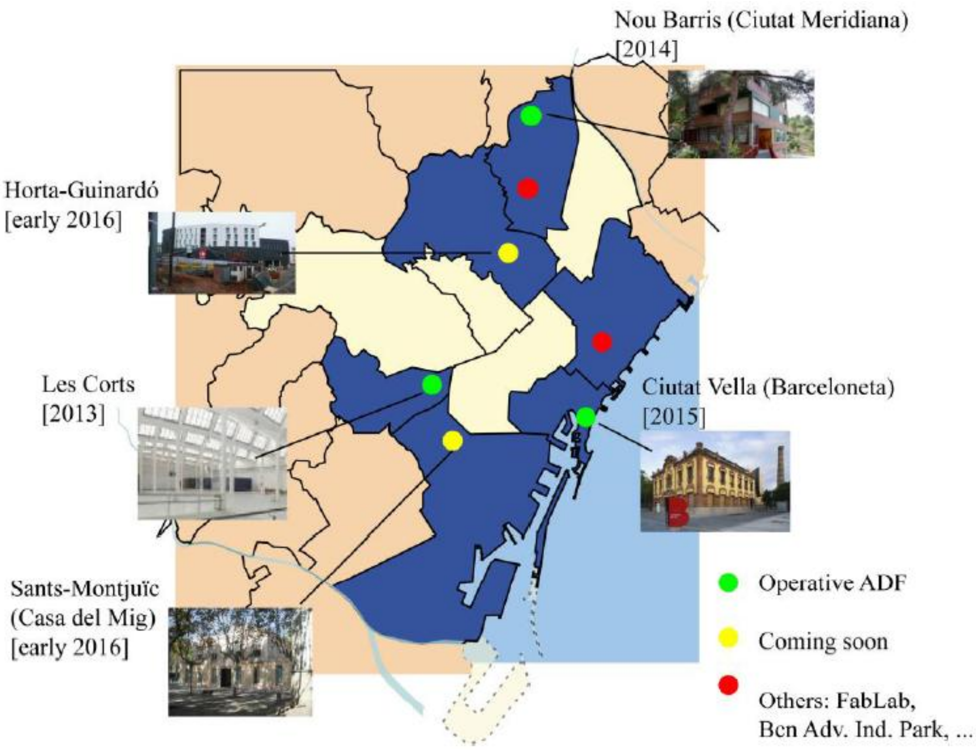


Figure 4.14: Current situation of ADF in Barcelona

The aim is to have a network of laboratories, one for each of the 10 districts of Barcelona.

The will of Barcelona city council is to implement 1 ADF per year.

According to the Barcelona City Council, ADF are spaces dedicated to creation and learning connected to social innovation and new technologies where citizens are the active users and protagonists. These are spaces for public-private collaboration, where citizens, but also local associations and groups, universities and businesses join together to develop activities for social innovation with the support of a laboratory dedicated to digital fabrication: a workshop equipped with machines to turn ideas into physical things that are useful to society. The social objectives assigned to ADF are:

- Introducing production and prototyping locally in the neighbourhood.
- Encouraging open learning of productive processes.
- Increasing opportunities for companies and act as a magnet for international talent.
- Becoming an urban laboratory where testing real solutions to achieve a more efficient and sustainable city.
- Attracting into FabLab/ADF a wider audience than well educated and technology interested people.

Every FabLab/ADF is dedicated to one topic, which has been considered of importance according to several district agents with major social relevance. In Figure 4.15, it is shown the topic of the three operative FabLab/ADFs plus the next ones planned to be opened during next year.

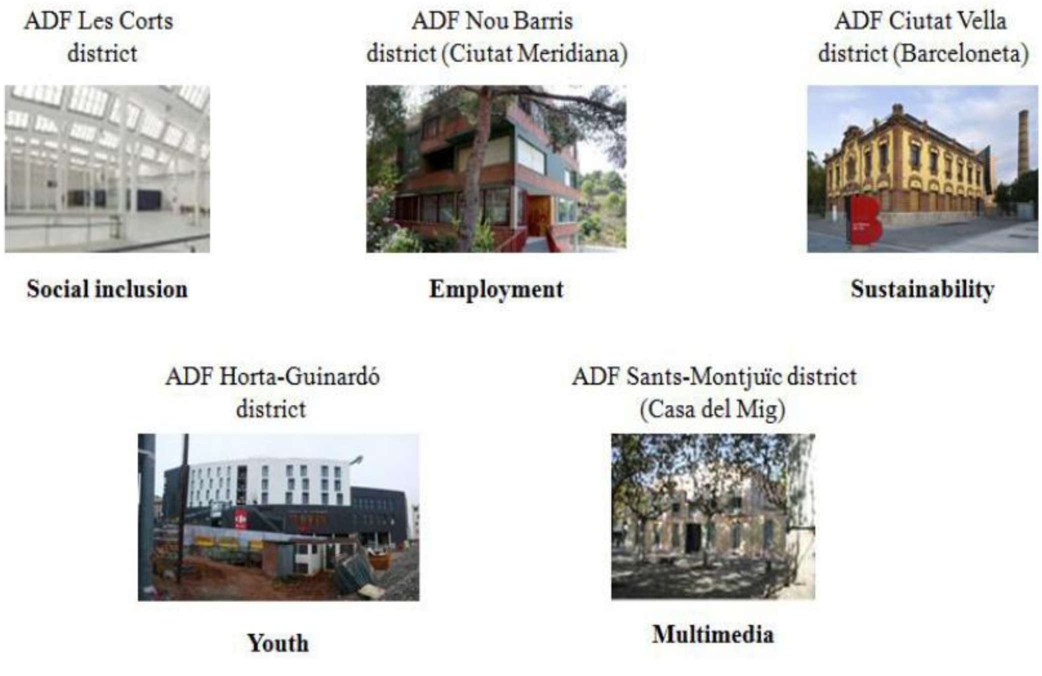


Figure 4.15: ADF social focus topic

ADF network was created by Barcelona City Council, with complete public funding to undertake the project. Nonetheless, ADF facilities must become financially sustainable in order to ensure their continuity, so their social mission could be empowered. For this reason ADF network could implement models to generate income in a same manner as private funding FabLab facilities. Some ideas could be:

- To collect membership fees. In return for the use of the facilities and its technology for individual projects, fulfilling the norms of FabLab Charter.

- To arrange and provide facilities as a resource, paying a previously agreed fee.

- To support private projects developed by companies in order to facilitate their viability, with remuneration offered by the company and determined by the local FabLab/ADF or FabLab/ADF network both sides if necessary.

- To provide professional services of design, architecture and other disciplines for the production of models, prototypes and project development.

Working lines

FabLab/ADF network shares the same framework of working lines for all the FabLab/ADF facilities, but increasing the focus to each specific topic (youth, employment social inclusion, sustainability). The working lines include three main working programs and other types of activities described below.

Educational program:

- Challenges:
  - Digital fabrication as a learning resource of high intensity.
  - Technology competency: from 2D to 3D (CAD training).
  - Teach and learn about design.
  - Know and understand social changes.
- Activities:
  - Presentations and visits to schools, teachers, school community, professional education.
  - Workshops of design and manufacturing for students and teachers.
  - Develop internal projects of educational centre.
  - Elaborate educational material.
- Example of activity: In ADF of *Ciutat Meridiana*, constructing of a mock-up of the neighbourhood developed for the *Escola Tècnica Superior d'Arquitectura de Barcelona* (ETSAB) in collaboration with the *Oficina d'Habitat Urbà*.

Family program:

- Challenges:
  - Creation of inter generational linkages, to break any barriers from older people to access to new digital technologies and manufacturing techniques, while facilitating

their own relationships and intergenerational communication through new forms of communication, such as social networks.

- To learn from an entertainment perspective the potential of design and digital fabrication.
- Know and understand social changes that involve a world within digital fabrication.

▪ Activities:

- Workshops of design and digital fabrication addressed to families.
- Specific outreach activities open to families (e.g. vailets hacklab ...).
- Summer camps.
- Out-of-school activities.

▪ Example of activity: Celebration of Scratch world day (tool to introduce kids to computer programming) in FabLab/ADF Les Corts, counting with the voluntary participation of 62 parents plus FabLab/ADF staff.

Social Innovation program

▪ Challenges:

- Define a model of civic participation based on open participation methodologies to address the social challenges faced by Barcelona through their neighbourhoods and districts, taking advantage of new technologies as tools for the transformation of people and the environment.

▪ Activities:

- Workshops of civic participation.
- Support areas for the development of specific projects aimed at a social return.

▪ Example of activity: In FabLab/ADF of Ciutat Meridiana, it was organized a monographic workshop on home automation and construction materials for insulation of buildings addressed to vocational training.

Granting of spaces:

Provide an income model to take advantage of the facilities of the network with different rates for different groups of users (Schools, entrepreneurs, foundations, etc).

▪ Example of activity: FabLab/ADF of Ciutat Meridiana counts with spaces to enhance the collaboration within a group of people like one classroom and one multipurpose room. The equipments available are PC’s, projectors, printers or video conference equipment as can be seen in Figure 4.

QUARK: Open Knowledge Management Ecosystem

In parallel to the programs that take place in the different FabLab/ADF facilities, a space for participation and dissemination will be developed to establish an open knowledge management ecosystem called Quark. Quark is a set of different technological platforms interconnected and located in the cloud, allowing joint management and open of all the knowledge generated in the FabLab/ADF network.

4.2.4. Business case

Once the Methodology is understood, it seemed suitable to have a case study to which apply it fully. The Manutelligence Project, in which the Politecnico di Milano is involved, has presented the opportunity to interact and work with the *Fundació CIM* and the ADF that they control. Therefore, a business case involving them has been done in order to apply the new additions of the methodology.

In this paragraph the case study description is provided and the relative results are reported.

The case study was conducted in the Fundació CIM centre in Barcelona. In particular, it has involved the whole process where the customer design, develop and build their prototype. For the implementation of the Methodology it became available a group of Project Managers heavily involved in the coordination and management of several Ateneus of Digital Fabrication. This has permitted to have a wider and deeper understanding of the process which was to be studied.

The implementation was carried out in stages occurring at different times but following the steps of the Methodology. In particular, three were the opportunities to meet and study with the Company, each of which has enabled the accomplishment of one or more steps of the methodology proposed.

First of all, it was needed to arrange some meetings in order to obtain the maximum information about Fundació CIM but most importantly about the Ateneus of Digital Fabrication. The first meeting was meant to understand how ADF's work in order to make a thorough analysis without misunderstandings. The second meeting has been given to the group of Project Managers who were involved with the ADFs a sort of questionnaire (Appendix A) that put together the first two phases of the Methodology in order to identify waste, evaluate and prioritize them in a short time and in an intuitive way.

After that, on the basis of the questionnaire results, another meeting was carried out, in which the sub process was identified and analyzed and subsequently the third and fourth phases were implemented. Finally, the last reunion concerned the corrective actions definition through the PICK Matrix.

- ***First meeting: Immersion into the Ateneus of Digital Fabrication functioning***

This first contact with Fundació CIM was during one of the Manutelligence Project's reunions which only take place once every few months. The situation helped to comprehend in a deep way the working line and the future goals of Fundació CIM within the ADF project.

- ***Second meeting: waste identification, evaluation and prioritization.***

During this meeting, the first activity carried on was a brief introduction on Lean and its application in Product Development field and a subsequent preliminary explanation on the methodology proposed and its purposes. This was made to ensure the use this instrument as adequately as possible.

After that a sort of questionnaire was given to them. It is a tool, already introduced in the previous chapters, in which are grouped:

- The waste check list, to identify them;
- The causes and effects lists;
- The scale of values of parameters needed to calculate the Priority Index.

At the end of this meeting, the information was input into the computer so as to calculate the Priority index and evaluate and prioritize the wastes. An example is shown below (Table 4.6).

Waste Macro-class (8 Wastes)	Waste Class	Description	(P)	(S)	(D)	(A)	(PI)
Over Producing / Engineering	Over specification	Specifications not needed and/or not implemented are formulated	3	2	2	4	48
	Over specification	Specifications are formulated with too much details and/or too much earlier (for the specific NPD phase)	1	1	1	4	4
	Over designed	Product functionalities not asked / needed are implemented	1	3	1	4	12
	Over designed	Projects not needed and/or not convenient are studied	3	3	1	4	36
	Over information	Design data and info are formulated with too much details and/or too much earlier (for the specific NPD phase)	2	2	2	4	32
	Over components	**Components / materials not needed are used in the product**	**3**	**3**	**3**	**4**	**108**
Waiting	Waiting to process information	Time spent (without adding value) waiting to process information	4	4	1	4	64
	Waiting for information	Waiting for decisions, people, resources, data, information, documents	4	4	1	4	64
	Too many steps	Long times to get access to the service because steps to get to it are too difficult/burdensome	1	2	1	4	8
Conveyance / Transportation	**Information systems**	**Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate**	**4**	**4**	**3**	**2**	**96**
	Manual transcodification	**Information might be manually retyped from one process / system to another**	**4**	**4**	**3**	**2**	**96**
	Inappropriate tech choice	**Inappropriate communication platform**	**4**	**4**	**3**	**2**	**96**
	Bad resource allocation	Uneasy communication between user and business	1	1	2	3	6
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unneeded and not useful activities are performed along the development phase	2	2	2	4	32
	Unnecessary / Excessive activities	Unnecessary and not useful tests are performed	2	2	2	3	24

	Unnecessary / Excessive activities	Unnecessary and not needed tolerances are included	1	1	1	4	4
	Unnecessary / Excessive activities	Development of parts / components / products already designed and existing, without re-using previous works and projects	3	3	2	1	18
	Unnecessary / Excessive activities	Too many authorizations / controls are needed to perform an activity	1	1	2	4	8
	Inappropriate process	Unnecessary, not useful, not appropriate, immature, not error-free technologies are used	3	4	3	1	36
	Inappropriate process	Development of changes not asked or not needed	2	2	2	3	24
	Inappropriate process	Time spent for bad definition of priorities	1	1	1	4	4
	Inappropriate process	Time is spent for reworks and revisions due to changing priorities, information, data, requirements	3	3	2	2	36
	Inappropriate process	Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed	3	4	2	3	72
	Inappropriate process	The development process is performed in different ways, depending by customers / suppliers / others	3	3	2	2	36
Inventory	**Bad accumulation**	**Designs wait for the next available resources**	**4**	**4**	**3**	**2**	**96**
	Bad accumulation	Batches of projects remain untouched	3	3	2	2	36
Motion	Travel	Unneeded travels might be done for visit customers	3	3	2	3	54
	Travel	Unneeded travels might be done for managing projects and teams	1	2	2	3	12
	Meeting	Unneeded and useless meetings are continuously organized with customers	1	1	1	4	4
	Meeting	Unneeded and useless meetings are continuously organized inside the company	1	1	1	4	4
	Undefined path	Unnecessary movements to get to the service	1	1	1	4	4
Correction (Reworks / Defective)	Poor design	Reworks and revisions derived from poor-quality products	4	3	3	2	72
	Poor design	Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements	4	3	3	2	72
	Poor product	**Reworks and revisions derived from not successful products**	**4**	**4**	**3**	**2**	**96**
	Poor design	Reworks and revisions derived from Scarce integration between Product and Service	2	4	2	4	64
Unused Employee Creativity	Bad knowledge managed	Communications failure and non-conformance	4	3	2	3	72
	Bad knowledge managed	Inability to reuse previous knowledge	4	3	2	3	72
	Bad knowledge managed	**New employees cannot retrieve company knowledge easily**	**4**	**4**	**3**	**3**	**144**

Table 4.6: Results of the ADF questionnaire

Finally, ordering in descending based on the PI value, the waste prioritization is obtained. And so, the second step of the Methodology is fulfilled. The ordered list can be found in Table 4.7 and the same information can be visualized in figure 4.16.

The first waste of the list, as it was previously explained, are those from which is appropriate to begin the removal action, since for several reasons that may relate to severity of their effects, rather than their high occurrence or others, are the ones more severe.

Waste Macro-class (8 Wastes)	Waste Class	Description	#	Pos	PI
Unused Employee Creativity	**Bad knowledge managed**	**New employees cannot retrieve company knowledge easily**	**38**	**1**	**144**
Over Producing / Engineering	**Over components**	**Components / materials not needed are used in the product**	**6**	**2**	**108**
Conveyance/ Transportation	**Information systems**	**Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate**	**10**	**3**	**96**

Conveyance/ Transportation	**Manual transcodification**	**Information might be manually retyped from one process / system to another**	**11**	**4**	**96**
Conveyance/ Transportation	**Inappropriate tech choice**	**Inappropriate communication platform**	**12**	**5**	**96**
Inventory	**Bad accumulation**	**Designs wait for the next available resources**	**25**	**6**	**96**
Correction (Reworks / Defective)	**Poor product**	**Reworks and revisions derived from not successful products**	**34**	**7**	**96**
Processing (Over / Inappropriate)	Inappropriate process	Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed	23	8	72
Correction (Reworks / Defective)	Poor design	Reworks and revisions derived from poor-quality products	32	9	72
Correction (Reworks / Defective)	Poor design	Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements	33	10	72
Unused Employee Creativity	Bad knowledge managed	Communications failure and non-conformance	36	11	72
Unused Employee Creativity	Bad knowledge managed	Inability to reuse previous knowledge	37	12	72
Waiting	Waiting to process information	Time spent (without adding value) waiting to process information	7	13	64
Waiting	Waiting for information	Waiting for decisions, people, resources, data, information, documents	8	14	64
Correction (Reworks / Defective)	Poor design	Reworks and revisions derived from Scarce integration between Product and Service	35	15	64
Motion	Travel	Unneeded travels might be done for visit customers	27	16	54
Over Producing / Engineering	Over specification	Specifications not needed and/or not implemented are formulated	1	17	48
Over Producing / Engineering	Over designed	Projects not needed and/or not convenient are studied	4	18	36
Processing (Over / Inappropriate)	Inappropriate process	Unnecessary, not useful, not appropriate, immature, not error-free technologies are used	19	19	36
Processing (Over / Inappropriate)	Inappropriate process	Time is spent for reworks and revisions due to changing priorities, information, data, requirements	22	20	36
Processing (Over / Inappropriate)	Inappropriate process	The development process is performed in different ways, depending by customers / suppliers / others	24	21	36
Inventory	Bad accumulation	Batches of projects remain untouched	26	22	36
Over Producing / Engineering	Over information	Design data and info are formulated with too much details and/or too much earlier (for the specific NPD phase)	5	23	32
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unneeded and not useful activities are performed along the development phase	14	24	32
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unnecessary and not useful tests are performed	15	25	24
Processing (Over / Inappropriate)	Inappropriate process	Development of changes not asked or not needed	20	26	24
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Development of parts / components / products already designed and existing, without re-using previous works and projects	17	27	18
Over Producing / Engineering	Over designed	Product functionalities not asked / needed are implemented	3	28	12
Motion	Travel	Unneeded travels might be done for managing projects and teams	28	29	12
Waiting	Too many steps	Long times to get access to the service because steps to get to it are too difficult/burdensome	9	30	8
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Too many authorizations / controls are needed to perform an activity	18	31	8
Conveyance/ Transportation	Bad resource allocation	Uneasy communication between user and business	13	32	6

Over Producing / Engineering	Over specification	Specifications are formulated with too much details and/or too much earlier (for the specific NPD phase)	2	33	4
Processing (Over / Inappropriate)	Unnecessary / Excessive activities	Unnecessary and not needed tolerances are included	16	34	4
Processing (Over / Inappropriate)	Inappropriate process	Time spent for bad definition of priorities	21	35	4
Motion	Meeting	Unneeded and useless meetings are continuously organized with customers	29	36	4
Motion	Meeting	Unneeded and useless meetings are continuously organized inside the company	30	37	4
Motion	Undefined path	Unnecessary movements to get to the service	31	38	4

Table 4.7: Waste list ordered by Priority Index number

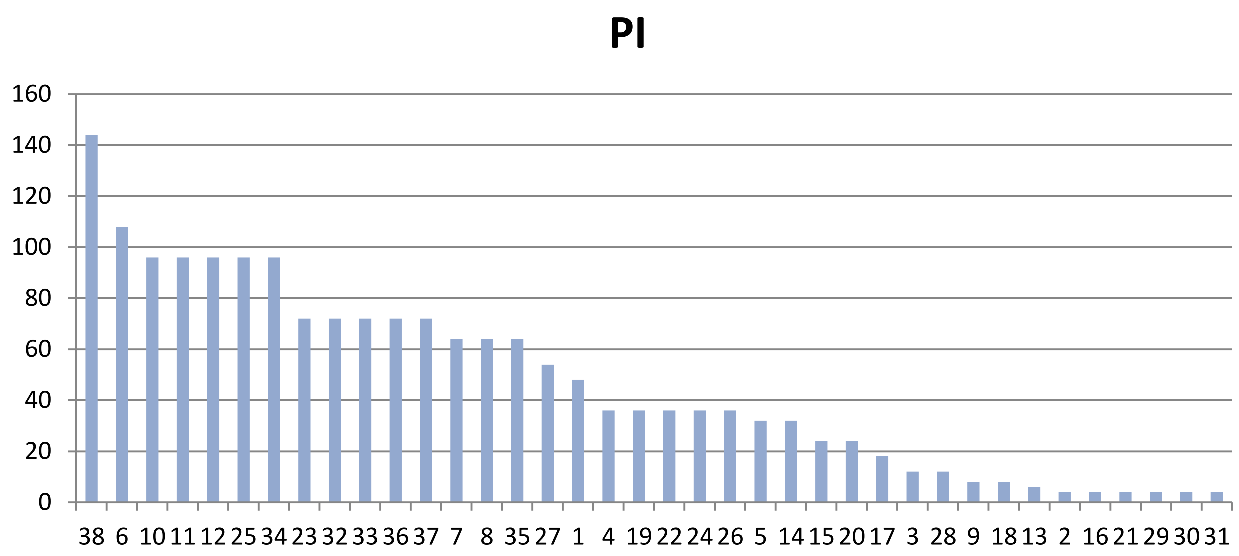


Figure 4.16: Bar chart of the ADF prioritization

These are the results of the first two phases of the Methodology. By observing them, it is easy to realize that there is one waste clearly more dangerous than the others and then there are 6 more which have a very similar PI. As in the above previously developed business case, the number of wastes to study it is incumbent upon who carries out the analysis. In this first application of the Methodology it has been decided simply to take the top seven wastes, which are:

- **38**_*Unused Employee Creativity; Bad knowledge managed;* New employees cannot retrieve company knowledge easily.
- **6**_*Over producing/Engineering; Over components;* components/materials not needed are used in the product.
- **10**_*Conveyance/Transportation; Information systems;* Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate.
- **11**_ *Conveyance/Transportation; Manual transcodification*; Information might be manually retyped from one process / system to another.

12_ *Conveyance/Transportation; Inappropriate tech choice;* inappropriate communication platform.

25_*Inventory; Bad accumulation;* Designs wait for the next available resources.

34_ *Correction (Reworks / Defective); Poor product;* Reworks and revisions derived from not successful products.

After examining these wastes it can be seen that half of them are related to not having all the information in a clear and easy way or not having it at all (#38, #10, #11 & #12). These initial ones all cause a waste in time and also coincide in the fact that they will origin future errors due to mistakes repetition. All this because changes cannot be traced, there is not a common database and the IT system is not structured as the main causes. The remaining ones are connected to making mistakes when using the resources available in the manufacturing process. They reflect the rise in costs and the delay generated in the process both caused by low resources & bad knowledge transfer.

Before going to the next phases of the methodology the second step was completed by asking the designers to think about some potential detection way and corrective actions for these seven main wastes. To support them the check lists shown in the Figure 4.17 below were given.

Waste macro-category	Detection way	Corrective actions
1. Over Producing/Engineering	□Post project review or ―Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □More collaboration among departments	□ LAMDA process □ QFD_ Quality function deployment □ Design for X □ Check sheet □ Value analysis □ Six Sigma □Product architecture formalization □ Chief engineer
3. Conveyance/ Transportation	□Post project review or ―Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □ Standard information's format
5. Inventory	□Post project review or ―Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to designers	□ LAMDA process □ Zero buffer/ inventory □ Initial scheduling of available resources □Chief engineer □ A-3 Reports
7. Correction	□Post project review or ―Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Customer satisfaction control	□ LAMDA process □ Check sheets □ Staff training □Chief engineer □Use modularity

		□Obeya □Centralized and structured database □Quality control activities □All the activities in order to understand a product failure □Knowledge sharing system
8. Unused employee creativity	□Post project review or ―Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to employees	□ LAMDA process □ Multifunctional teams □ Introduction program □Centralized and structured database □Knowledge sharing system

Figure 4.17: Check list of the ADF selected wastes and their detection way and corrective actions

The results of this task are reported in the Table 4.8 below.

# waste	Detection way	Corrective actions
38	□Post project review or ―Lessons Learned □BPR _ Business Process Reengineering	□ Introduction program □Centralized and structured database □Knowledge sharing system
6	□Work Sampling	□ LAMDA process □ Design for X (DFMA)
10	□BPR _ Business Process Reengineering	□ Centralized and structured database □ Knowledge sharing system □ Standard information's format
11	□BPR _ Business Process Reengineering	□ Centralized and structured database □ Knowledge sharing system □ Standard information's format
12	□BPR _ Business Process Reengineering	□ Centralized and structured database □ Knowledge sharing system □ Standard information's format
25	□Set of indicators	□ Initial scheduling of available resources □Chief engineer
34	□Post project review or ―Lessons Learned □BPR _ Business Process Reengineering	□ Check sheets □ Staff training □Obeya □Centralized and structured database

Table 4.8: Possible detection ways and corrective actions selected for the ADF analysis

- ***Third meeting: sub process identification and analysis & corrective actions choice***

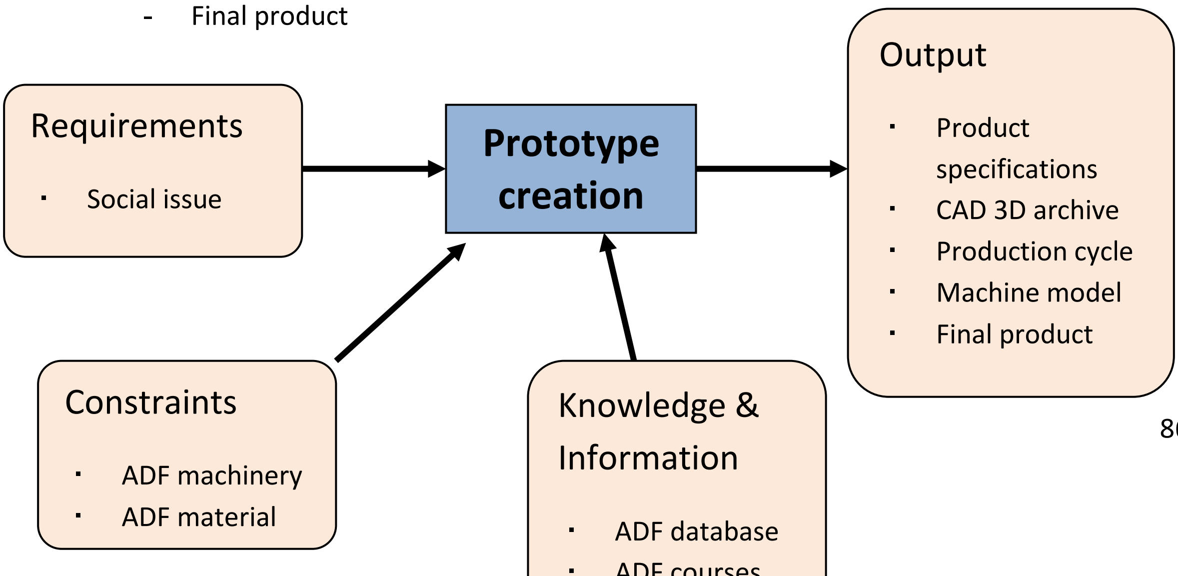
After identifying the top seven wastes it was asked to think about a sub process in which these waste were likely to be found. Moreover it was suggested them to find a sub process in which at least a few of them were directly involved in order to have a deep knowledge of all the activity and features. As a result they come to the conclusion that it was better to analyze the whole process in which the customer is involved instead of analyzing just a sub process that wouldn't have too many aspect to go in depth. The first thing made has been to analyze briefly this process by doing two activities:

1. Delineate the boundaries of the process by specifying: the process owner, who is the responsible; the requirements to perform the sub process; knowledge and information needed; the constraints to be taken into account and finally the expected output.
2. Map the sub process using the VSM logic, symbols and language.

The result of the first activity listed above is shown in Figure 4.18.

First of all, the process boundaries definition was made, specifying, as always, requirements, information and knowledge, constraints and output of the process.

- Requirements:
  - The idea needs to be social oriented
- Constraints:
  - All the ADF available Machinery & material
- Knowledge & Information:
  - ADF database
  - ADF courses
  - ADF operators.
- Output:
  - product specifications
  - CAD 3D
  - production cycle with its matching machine model
  - Final product



After that the Value Stream Map was made. Within each activity the minimum and maximum processing time is specified, while between the activities the minimum and maximum waiting time is indicated, if any.

The selected process starts when the customer has an idea and decides to develop it in the Ateneu of Digital Fabrication. The next step is to contact with the ADF via e-mail explaining the initial thought. Since ADF is funded by the Barcelona council, all projects entering the sequence must fulfil one important requirement, to have a social aspect. According to this, the first filter is for ADF to evaluate if a project has this social purpose. If not, the customer needs to refocus the idea into a more social one. Once the essential requirement is achieved, the customer enters the ADF's database looking for designs already made that are similar to the one he/she is planning to develop to improve his/her own idea. After that, the concept must start to have form and to do so the requirements definition must be done. At the end of this activity the product specification should be completed. Then, the ADF's operators explain to the costumer the available technologies that the project could use in the centre. If the user does not know how to use them there are weekly courses which explain how to use them. In addition, if he/she just needs some advice the staff themselves can provide the help needed. Afterwards, the client has everything needed to create the 3D model simulation and then the feasibility analysis with an ADF operator. At this point, the CAD file should be finished and the product development phase should begin. In this step the user together with an operator design how the prototype is going to be manufactured and which resources are going to be used in the process. Finally, the production phase starts and the model of the final product is made.

In this case study, because of the data unavailability and also because of time, it was decided to take into account only two kinds of time:

- The processing time, which in the Current State Map is indicated with 'T' and 't' (maximum and minimum) and stands for the value added time within each activity, so the effective time in which the designer has worked on the project;
- The waiting time between sequential activities, indicated with 'W' and 'w', in which the designer had to wait before starting to perform a new activity.

As the exact time values were not available, the best and the worst cases had been considered. As said before, in the next page the Current State Map Visio version is available (Figure 4.19), it follows a label in order to read and understand it.

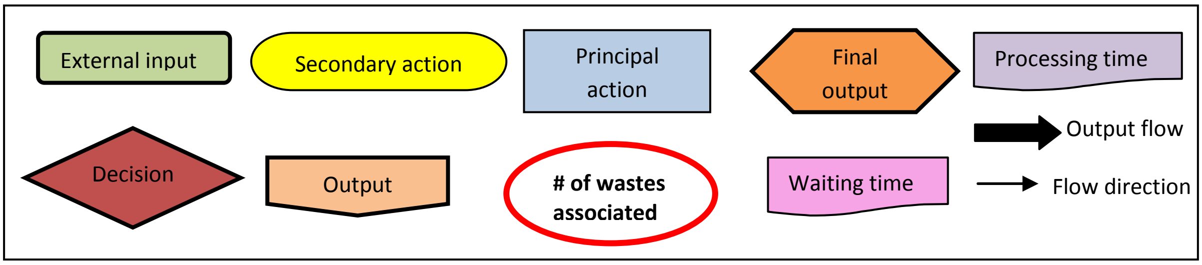


Figure 4.19: Vale Stream Map labels definition

Once the VSM was made it was also asked to locate the wastes in the activities where they could be found. According to the collaborators tips, a table has been made connecting the wastes with their possible location in the process (table 4.9):

# Waste	Possible location
38	□Improve initial design □Initiation in the ADF available & suitable technologies □Feasibility analysis □Product manufacturing
6	□Product development □Product manufacturing
10	□Improve the initial design □Requirements definition □3D model simulation
11	□Initial feasibility check with ADF □Improve initial design
12	□Feasibility analysis
25	□Product manufacturing
34	□Feasibility analysis

Table 4.9: Potential wastes and their possible location in the ADF VSM

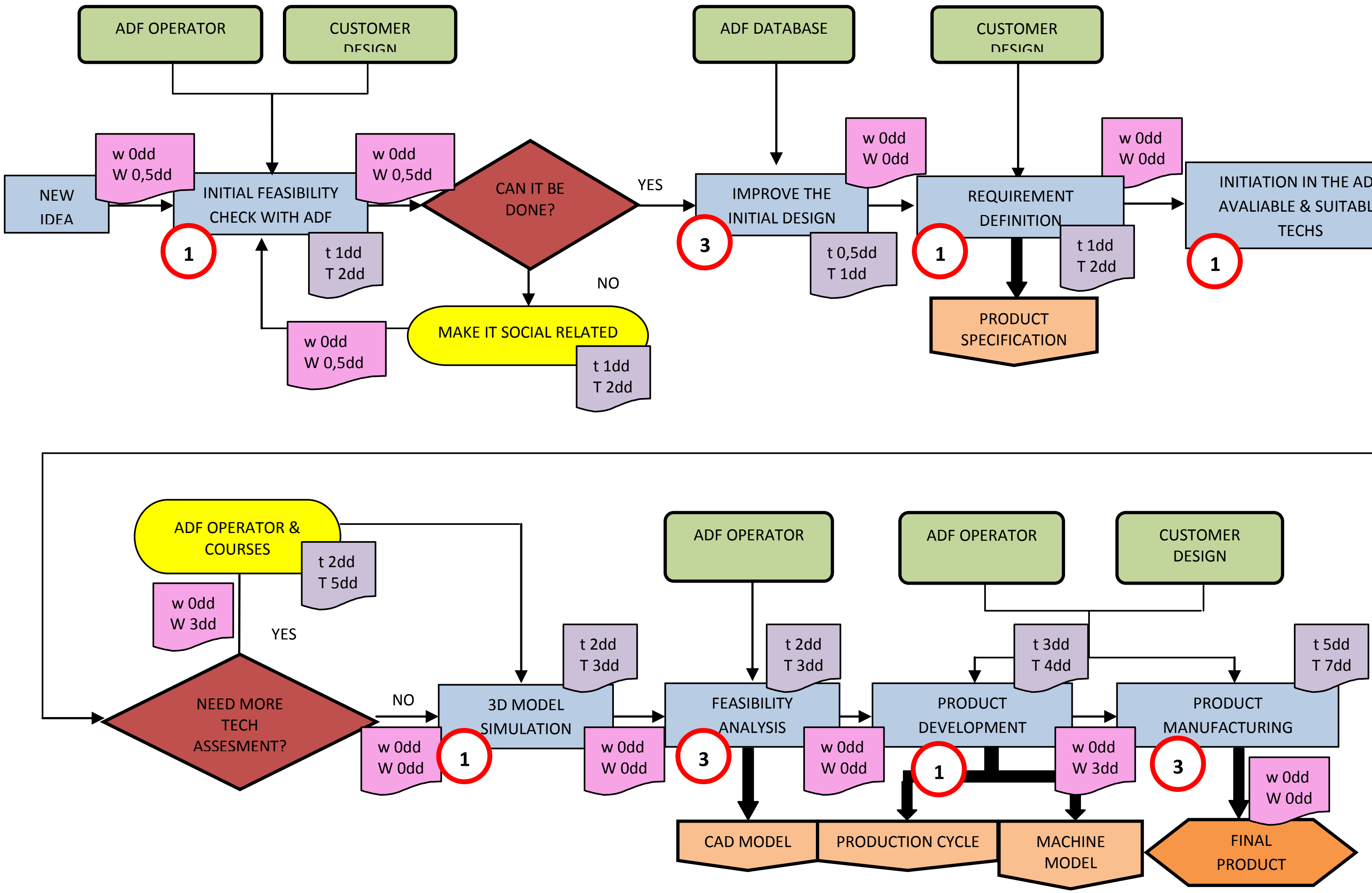


Figure 4.20: Prototype creation Current State Map

Figure 4.20 is the current state map of the prototype creation process. The following phases consist on locating the waste and, after that, implement the corrective actions to remove them and, therefore, improve the process.

Analyzing the CSM some considerations came up:

1. The longest waiting times are found when the customer needs to learn, assimilate or even master the technologies available in the Ateneu and when the resources in the production phase are not available.
2. The recirculations are mostly because of the low awareness that the client has on what he/she has to do. The thing is that, in the first one, (make it social) the client does not remember the essential requirement or because he/she oversights it.
3. All the activities are sequential which means that it cannot begin one until the previous is concluded.

Moreover by the time calculation exposed in Appendix B it can be noticed that there is a huge difference between the worst (37,5 days) and the best (15 days) case scenario. The waiting time on the worst case is a 20% of the lead time and it is negligible on the best case.

Finally, from the observations exposed above and the time calculation results, some improving hypotheses have been made.

Waste 38, *"New employees cannot retrieve company knowledge easily"*, which is the one that is the most damaging and also the one that is present in more activities. For this waste, the chosen corrective action it has been to incorporate a centralized and structured database which will also let the company staff and users to share their knowledge in order not to repeat previous mistakes. For that purpose, a common platform should be designed. Another possibility is to create an introduction program for new employees so as to prepare them for the job before they begin working in the ADF.

Wastes 10 (Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) cannot interoperate), 11 (Information might be manually retyped from one process / system to another), 12 (inappropriate communication platform) will also be corrected using the platform previously mentioned which will standardize the format in which data is stored too.

This platform will also reduce waste 34 (Reworks and revisions derived from not successful products) because it will allow store all the errors committed in previous manufactures for not repeating the same mistakes, which is something that usually happens in an ADF. The staff training would be also a good manner to reduce this kind of waste.

The LAMDA action and the Design for Manufacturing and Assembly are both chosen to moderate the effects of using components/materials not needed in the product (waste 6). This will be achieved using a manufacturing simulator (*g code analyzer*) that permits to see how a 3D printer is going to manufacture a product.

Finally, the last solution will be to include in the ADF's website the availability of each resource and the possibility to book them for a limited period of time. The website will follow the red/green classic system and therefore the customer and the ADF staff will not waste their time waiting for a resource to be accessible or to be underused (waste 25).

The next step is to decide which of these solutions implement following the PICK matrix method.

The most difficult alternative is to create a platform that will solve lots of problems. The fact that it has to include a wide amount of processes and actions increases its complexity. However, achieving this goal would diminish most of the problems in that surge during the process. For this reasons, it is a Challenge. This said it is important to underline that *Fundació CIM* is already involved in the Manutelligence consortium, which it has been explained above, so as to put in place this platform in the *Ateneus of Digital Fabrication.*

The LAMDA and DFMA solution has a very beneficial result and they are not very complex actions. That means that without too much effort the income would be really high. In consequence, the decision is to *Implement* them.
The last corrective action involved to add the resource availability system to the website which nowadays it is easy to do but the benefit would not be really high (Possible in the PICK method).
All of them were proposed to the Fundació Cim and from this point it was left to them which solution use, taking into account that one is already in motion.

Chapter 5

5. Conclusions

This is the closing Chapter in which, on the first part, a brief interpretation of the research is made. Then, the Methodology comments and impressions risen up are pointed out. On the final part, the limits of the research and some suggestions for future researches and developments are explained.

5.1. Discussion and Results

Customers are always demanding new products every few time; moreover, this customer also wants it at a low price. However, nowadays, they also want an extra, that “bonus” for the consumer that gives a better user experience which the product cannot give by itself. Therefore, the concept of Product-Service arises and with it, new techniques to model it and to improve it.

In the past 10-15 years, studies and research on this topic have been conducted, with the aim to find tools and techniques which provide Companies a support. Not all of them have focused on Lean Thinking application, yet ideas related with it have been used. Lean techniques are known to provide speed, efficiency and effectiveness in manufacturing and in the Product Development field and now there is the need to include the service part in them.

The contribution this thesis wanted to evolve a simple already existing Methodology to encompass the new requirements of the market. This methodology, together with other tools and methods, is meant to assist Companies not only to be Lean with the product part, also to integrate the services offered in it.

As it has been previously discussed in the course of the thesis exposition, the Methodology arose from the study of literature and the current industrial context exploration. In fact, thanks to the Politecnico di Milano participation Manutelligence Project a wider view and understanding have been obtained. Moreover, it has been very useful to apply the Methodology steps to both the car2go and the Ateneus of Digital Fabrication Cases to realize there are many different types of PSS with different levels of servitization. It has also realized that even with all these different levels and also in the case that the product seems to be the main part, the final offer is the whole value perceived by the customer. These activities have also allowed to have a general assessment of the Methodology, by collecting Industrial subject’s opinions and feelings, after testing it.

Below there is a list of observations that point out the methodology qualities:

- The Methodology is intuitive and easy to deploy. It is not necessary to be an expert in Lean principles and tools to implement it. It is enough to have a brief training on the basic Lean issues and on the Methodology phases. It can be easy to carry out by users under the guidance of a responsible for continuous improvement.

- The questionnaire that includes the first two phases of the methodology is exhaustive and time saving thanks to the support check, wastes, causes, effects, corrective actions and detection ways lists.
- The Methodology steps are just a guide, in fact internally several alternative techniques and tools are proposed, but the decision maker is not bound in their application. For instance, the subprocess to be analyzed choice the choice is left to the decision maker. Likewise, numerous analysis methods are proposed still the decision maker is free to apply what he reckons to be more appropriate. To sum up, the Methodology gives aid on how to proceed and which options could be followed, but the decision maker remains the one that defines the final path.
- The Methodology is adaptable, that is to say that it can be applied in all the industrial sectors, to all kinds of products & services in order to ease the obtaining of an integrated PSS.
- It can be applied as an improvement tool or a monitoring one.
- Helps to involve all the stakeholders by debating and participating in the Product-Service Development process. Consequently, each one of them is informed about how is the process analysis and improvement going and it helps to establish a teamwork atmosphere.
- By involving all the members affected by the product-service it also helps all of them to understand a bit more the viewpoint of their colleagues, suppliers and clients.

5.2. Limits and Further Researches

The Empirical Research performed has some limits. One of them is the amount of information gathered which it was enough to perform the analysis given the time available. Because of this, the new wastes added have been tested just in two cases and some of them have not appeared as a problem in any case. So the methodology should be retested in other Product-Service business types which have different level of service or product focus. After doing that, new wastes could come up and some of the newly added could be redefined or deleted.

Concerning the Methodology steps, the waste identification one, it could be influenced by the personal opinion and feelings of the people who fill it. In order to reduce this influence, the questionnaire should be passed to a suitable number of people to acquire a more accurate knowledge. One way of doing it is to change the manner of filling it. If the questionnaire was electronic, the first two steps would have been much faster and could have been filled by more people. As a result, the process is highly optimized an automated.

Carrying on with the methodology phases, the last one is applied in a qualitative way, so it could be improved by adding objective parameters as, for instance, expenditure and time needed for each available action. With these parameters it would be easier to define a more accurate position of each action in the PICK matrix.

Another application could be for comparing your own company with your competitors in order to find a benchmark or to examine existing similar PSSs to identify wastes that maybe have not appeared yet but they could do so in the future.

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APPENDIX A

Waste	Waste potential effect	Waste potential cause	Probability	Severity	Detection	Avoidable	Detection way	Corrective action
1. Over specification Specifications not needed and/or not implemented are formulated	□ Rise of development times □Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Reduced reliability □ Increase of the critical of project □ Wrong estimates of costs/sales □Waste of design □Staff discontent □Stressful work conditions □____________________	□ Limited knowledge of the market □ Inability/impossibility to translate requirements into technical specifications □ No analysis of customer's needs □Copy of existing products □Imitation rather than innovation □ Obsolete rules □ Rules are too general □ Lack of control by top management □Try to innovate □Lack of coordination/planning □____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □More collaboration among departments □____________________	□ LAMDA process □ QFD_ Quality function deployment □ Design for X □ Check sheet □ Value analysis □ Six Sigma □ Chief engineer □Product architecture formalization □____________________
1. Over specification Specifications are formulated with too much details and/or too much earlier (for the specific NPD phase)	□ Rise of development times □Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction	□ Limited knowledge of the market □ Inability/impossibility to translate requirements into technical specifications □ No analysis of customer's needs □Copy of existing products	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □More collaboration among departments	□ LAMDA process □ QFD_ Quality function deployment □ Design for X □ Check sheet □ Value analysis

	□ Reduced reliability □ Increase of the critical of project □ Wrong estimates of costs/sales □Waste of design □Staff discontent □Stressful work conditions □____________________	□Imitation rather than innovation □ Obsolete rules □ Rules are too general □ Lack of control by top management □Try to innovate □Lack of coordination/planning □____________________					□____________________	□ Six Sigma □ Chief engineer □Product architecture formalization □____________________
1. Over specification Product functionalities not asked / needed are implemented	□ Rise of development times □Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Reduced reliability □ Increase of the critical of project □ Wrong estimates of costs/sales □Waste of design □Staff discontent □Stressful work conditions □____________________	□ Limited knowledge of the market □ Inability/impossibility to translate requirements into technical specifications □ No analysis of customer's needs □Copy of existing products □Imitation rather than innovation □ Obsolete rules □ Rules are too general □ Lack of control by top management □Try to innovate □Lack of coordination/planning □____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □More collaboration among departments □____________________	□ LAMDA process □ QFD_ Quality function deployment □ Design for X □ Check sheet □ Value analysis □ Six Sigma □ Chief engineer □Product architecture formalization □____________________
1. Over specification Projects not needed and/or not convenient	□ Rise of development times □Delays generation	□ Limited knowledge of the market □ Inability/impossibility to translate	□Never/rarely_1 □Sometimes_2	□Unimportant_1 □A little_2	□Very easy_1 □Easy enough_2	□Avoidable waste_4 □Not so avoidable waste_3	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering	□ LAMDA process □ QFD_ Quality function deployment

are studied	□ Rise of development costs □ Rise of product costs □ Productivity reduction □ Reduced reliability □ Increase of the critical of project □ Wrong estimates of costs/sales □Waste of design □Staff discontent □Stressful work conditions □____________________	requirements into technical specifications □ No analysis of customer's needs □Copy of existing products □Imitation rather than innovation □ Obsolete rules □ Rules are too general □ Lack of control by top management □Try to innovate □Lack of coordination/planning □____________________	□Enough_3 □Very much_4	□Enough_3 □Very much_4	□Hard enough_3 □Impossible_4	□Difficult to avoid waste_2 □Not avoidable waste_1	□Work Sampling □Set of indicators □More collaboration among departments □____________________	□ Design for X □ Check sheet □ Value analysis □ Six Sigma □ Chief engineer □Product architecture formalization □____________________
1. Over specification Design data and info are formulated with too much details and/or too much earlier (for the specific NPD phase)	□ Rise of development times □Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Reduced reliability □ Increase of the critical of project □ Wrong estimates of costs/sales □Waste of design □Staff discontent □Stressful work conditions	□ Limited knowledge of the market □ Inability/impossibility to translate requirements into technical specifications □ No analysis of customer's needs □Copy of existing products □Imitation rather than innovation □ Obsolete rules □ Rules are too general □ Lack of control by top management □Try to innovate □Lack of coordination/planning	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □More collaboration among departments □____________________	□ LAMDA process □ QFD_ Quality function deployment □ Design for X □ Check sheet □ Value analysis □ Six Sigma □ Chief engineer □Product architecture formalization □____________________

	□____________________	□____________________						
1. Over specification Components / materials not needed are used in the product	□ Rise of development times □Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Reduced reliability □ Increase of the critical of project □ Wrong estimates of costs/sales □Waste of design □Staff discontent □Stressful work conditions □____________________	□ Limited knowledge of the market □ Inability/impossibility to translate requirements into technical specifications □ No analysis of customer's needs □Copy of existing products □Imitation rather than innovation □ Obsolete rules □ Rules are too general □ Lack of control by top management □Try to innovate □Lack of coordination/planning □____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □More collaboration among departments □____________________	□ LAMDA process □ QFD_ Quality function deployment □ Design for X □ Check sheet □ Value analysis □ Six Sigma □ Chief engineer □Product architecture formalization □____________________
2. Waiting Time spent (without adding value) waiting to process information	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □Difficulties on managing a multi projects environment	□ Scarce resources □ Inefficient management and allocation of resources □ No scheduling of competing facilities □ Sequential activities □ No knowledge sharing system □ Inappropriate communication	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □High project control □____________________	□ LAMDA process □ Concurrent engineering □ Supplier involvement □ Initial schedule of available resources □ Knowledge sharing system □ Standard information's format □ Visual planning

	□Stressful work conditions □Communication between different department □____________________	□ Incompatibility format of the information □Lack of tools to support productivity and design, that allow a fast implementation of standard activities □Outdated information Low level employees' commitment □____________________						□ CAD/CAM Technologies □ Balance of the work load □Implementation of ICT technologies □A more clear role definition □Correct level of delegation □____________________
2. Waiting Waiting for decisions, people, resources, data, information, documents	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □Difficulties on managing a multi projects environment □Stressful work conditions □Communication between different department □____________________	□ Scarce resources □ Inefficient management and allocation of resources □ No scheduling of competing facilities □ Sequential activities □ No knowledge sharing system □ Inappropriate communication □ Incompatibility format of the information □Lack of tools to support productivity and design, that allow a fast implementation of standard activities □Outdated information Low level employees' commitment □____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □High project control □____________________	□ LAMDA process □ Concurrent engineering □ Supplier involvement □ Initial schedule of available resources □ Knowledge sharing system □ Standard information's format □ Visual planning □ CAD/CAM Technologies □ Balance of the work load □Implementation of ICT technologies □A more clear role definition □Correct level of delegation □____________________

2. Waiting Long times to get access to the service because steps to get to it are too difficult/burden some	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □Difficulties on managing a multi projects environment □Stressful work conditions □Communication between different department □____________________	□ Scarce resources □ Inefficient management and allocation of resources □ No scheduling of competing facilities □ Sequential activities □ No knowledge sharing system □ Inappropriate communication □ Incompatibility format of the information □Lack of tools to support productivity and design, that allow a fast implementation of standard activities □Outdated information Low level employees' commitment □____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □High project control □____________________	□ LAMDA process □ Concurrent engineering □ Supplier involvement □ Initial schedule of available resources □ Knowledge sharing system □ Standard information's format □ Visual planning □ CAD/CAM Technologies □ Balance of the work load □Implementation of ICT technologies □A more clear role definition □Correct level of delegation □____________________
3.Conveyance/ Transportation Information are available in different formats and ICT systems (e.g. CAD, PDM, ERP) can't interoperate	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □____________________	□ Unstructured information system □ No common database □Too many interfaces required for the activity of product realization, low integration, long times □ No culture of sharing □ Data flow not clearly defined	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □____________________	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □ Standard information's format □____________________

		□ ____________________						
3.Conveyance/ Transportation Information might be manually retyped from one process / system to another	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ ____________________	□ Unstructured information system □ No common database □Too many interfaces required for the activity of product realization, low integration, long times □ No culture of sharing □ Data flow not clearly defined □ ____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □ ____________________	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □ Standard information's format □ ____________________
3.Conveyance/ Transportation Inappropriate communication platform	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ ____________________	□ Unstructured information system □ No common database □Too many interfaces required for the activity of product realization, low integration, long times □ No culture of sharing □ Data flow not clearly defined □ ____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □ ____________________	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □ Standard information's format □ ____________________
3.Conveyance/ Transportation Uneasy communication between user and business	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction	□ Unstructured information system □ No common database □Too many interfaces required for the activity of product realization, low integration, long times □ No culture of sharing	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □ ____________________	□ LAMDA process □ Centralized and structured database □ Knowledge sharing system □ Standard information's format □ ____________________

	□____________________	□ Data flow not clearly defined □_________________________						
4.Processing (Over / Inappropriate) Unneeded and not useful activities are performed along the development phase	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □_________________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________
4.Processing	□ Rise of development times	□No analysis of costumer's needs	□Never/rarely_1	□Unimportant_1	□Very easy_1	□Avoidable waste_4	□Post project review or —Lessons Learned	□ LAMDA process

(Over / Inappropriate) Unnecessary and not useful tests are performed	□ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□The costumer doesn’t specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □________________________	□Sometimes_2 □Enough_3 □Very much_4	□A little_2 □Enough_3 □Very much_4	□Easy enough_2 □Hard enough_3 □Impossible_4	□Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________
4.Processing (Over / Inappropriate) Unnecessary and not needed tolerances are	□ Rise of development times □ Delays generation □ Rise of development costs	□No analysis of costumer’s needs □The costumer doesn’t specify the initial requirements	□Never/rarely_1 □Sometimes_2 □Enough_3	□Unimportant_1 □A little_2 □Enough_3	□Very easy_1 □Easy enough_2 □Hard enough_3	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling	□ LAMDA process □ Multi functional teams □ Chief engineer

included	□ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □________________________	□Very much_4	□Very much_4	□Impossible_4	□Not avoidable waste_1	□Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________
4.Processing (Over / Inappropriate) Development of parts / components / products already designed and existing,	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring

without re-using previous works and projects	□ Waste of resources □____________________	beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □_________________________					□Process delays monitoring □____________________	□ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________
4.Processing (Over / Inappropriate) Too many authorizations / controls are needed to perform an activity	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system

		□ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □_________________________						□ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________
4.Processing (Over / Inappropriate) Unnecessary, not useful, not appropriate, immature, not error-free technologies are used	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members

		□ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □_______________________						□Redefinition of decisional processes and decision making activities □New technologies implementation □____________________
4.Processing (Over / Inappropriate) Development of changes not asked or not needed	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies

		□Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □________________________						implementation □____________________
4.Processing (Over / Inappropriate) Time spent for bad definition of priorities	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________

		□ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □________________________						
4.Processing (Over / Inappropriate) Time is spent for reworks and revisions due to changing priorities, information, data, requirements	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________

		□ Inappropriate business practices □_________________________						
4.Processing (Over / Inappropriate) Time is spent working with incomplete / incorrect / inappropriate / not reliable information, data, requirements are performed	□ Rise of development times □ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □_____________________	□No analysis of costumer's needs □The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □_________________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □_____________________	□ LAMDA process □ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □_____________________
4.Processing	□ Rise of development times	□No analysis of costumer's needs	□Never/rarely_1	□Unimportant_1	□Very easy_1	□Avoidable waste_4	□Post project review or —Lessons Learned	□ LAMDA process

(Over / Inappropriate) The development process is performed in different ways, depending by customers / suppliers / others	□ Delays generation □ Rise of development costs □ Rise of product costs □ Productivity reduction □ Waste of resources □____________________	□The costumer doesn't specify the initial requirements □ Requirements change ongoing □ Decision making is not concentrated at the beginning □ No common definition of priorities □ No clear definition of the objectives □ Ineffective role of the PM □ PM is not a reference and integration figure also from a technical point of view □ Lack of communication □Wrong communication □ No inter functional teams □ Training and motivating staff's problems □ Ineffective social mechanisms □ Inappropriate archives □ Inappropriate business practices □________________________	□Sometimes_2 □Enough_3 □Very much_4	□A little_2 □Enough_3 □Very much_4	□Easy enough_2 □Hard enough_3 □Impossible_4	□Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Anonymous surveys or questionnaires □Process delays monitoring □____________________	□ Multi functional teams □ Chief engineer □ Use modularity □Mentoring □ Centralized and structured database □ Knowledge sharing system □ Visual planning □More coordination among team members □Redefinition of decisional processes and decision making activities □New technologies implementation □____________________
5. Inventory Designs wait for the next available resources	□ Delays generation □ Inefficiencies generation □Designers' discontent	□ Scarce resources □ Inefficient management and allocation of resources □ No scheduling of competing facilities	□Never/rarely_1 □Sometimes_2 □Enough_3	□Unimportant_1 □A little_2 □Enough_3	□Very easy_1 □Easy enough_2 □Hard enough_3	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling	□ LAMDA process □ Zero buffer/ inventory □ Initial scheduling of available resources

	□Inefficient multi-project environment □____________________	□Inefficient project activities management □Lack of clear priorities definition □Lack of correct decision making activities □____________________	□Very much_4	□Very much_4	□Impossible_ 4	□Not avoidable waste_1	□Set of indicators □Surveys or questionnaires to designers □____________________	□ A-3 Reports □Chief engineer □____________________
5. Inventory Batches of projects remain untouched	□ Delays generation □ Inefficiencies generation □Designers' discontent □Inefficient multi-project environment □____________________	□ Scarce resources □ Inefficient management and allocation of resources □ No scheduling of competing facilities □Inefficient project activities management □Lack of clear priorities definition □Lack of correct decision making activities □____________________	□Never/rarely_ 1 □Sometimes_2 □Enough_3 □Very much_4	□Unimporta nt_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_ 4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to designers □____________________	□ LAMDA process □ Zero buffer/ inventory □ Initial scheduling of available resources □ A-3 Reports □Chief engineer □____________________
6. Motion Unneeded travels might be done for visit customers	□ Rise of development times □ Delays generation □ Rise of development costs □ Productivity reduction □Inefficiencies generation □Stressful and inefficient work conditions □____________________	□ No initial Project Review □ Work is not structured in a systematic way □ Decision making is not concentrated at the beginning □ Priorities change ongoing □ Requirements change ongoing □ Inappropriate communication □ The team's components are situated in	□Never/rarely_ 1 □Sometimes_2 □Enough_3 □Very much_4	□Unimporta nt_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_ 4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to employees □____________________	□ LAMDA process □ Effective management of meetings □ Team integration □Implementation of ICT technologies □Effective project management □Effective costumers management by characterizing and classifying their needs □____________________

		different areas □ Lack of a communication and sharing remote system □Ineffective role of PM □PM is not a reference and integration figure also from a technical point of view □_____________________						
6. Motion Unneeded travels might be done for managing projects and teams	□ Rise of development times □ Delays generation □ Rise of development costs □ Productivity reduction □Inefficiencies generation □Stressful and inefficient work conditions □_____________________	□ No initial Project Review □ Work is not structured in a systematic way □ Decision making is not concentrated at the beginning □ Priorities change ongoing □ Requirements change ongoing □ Inappropriate communication □ The team's components are situated in different areas □ Lack of a communication and sharing remote system □Ineffective role of PM □PM is not a reference and integration figure also from a technical point of view	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to employees □_____________________	□ LAMDA process □ Effective management of meetings □ Team integration □Implementation of ICT technologies □Effective project management □Effective costumers management by characterizing and classifying their needs □_____________________

		□____________________						
6. Motion Unneeded and useless meetings are continuously organized with customers	□ Rise of development times □ Delays generation □ Rise of development costs □ Productivity reduction □Inefficiencies generation □Stressful and inefficient work conditions □____________________	□ No initial Project Review □ Work is not structured in a systematic way □ Decision making is not concentrated at the beginning □ Priorities change ongoing □ Requirements change ongoing □ Inappropriate communication □ The team's components are situated in different areas □ Lack of a communication and sharing remote system □Ineffective role of PM □PM is not a reference and integration figure also from a technical point of view □____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to employees □____________________	□ LAMDA process □ Effective management of meetings □ Team integration □Implementation of ICT technologies □Effective project management □Effective costumers management by characterizing and classifying their needs □____________________
6. Motion Unneeded and useless meetings are continuously organized inside the company	□ Rise of development times □ Delays generation □ Rise of development costs □ Productivity reduction	□ No initial Project Review □ Work is not structured in a systematic way □ Decision making is not concentrated at the beginning	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators	□ LAMDA process □ Effective management of meetings □ Team integration □Implementation of ICT technologies

	□Inefficiencies generation □Stressful and inefficient work conditions □____________________	□ Priorities change ongoing □ Requirements change ongoing □ Inappropriate communication □ The team's components are situated in different areas □ Lack of a communication and sharing remote system □Ineffective role of PM □PM is not a reference and integration figure also from a technical point of view □____________________					□Surveys or questionnaires to employees □____________________	□Effective project management □Effective costumers management by characterizing and classifying their needs □____________________
6. Motion Unnecessary movements to get to the service	□ Rise of development times □ Delays generation □ Rise of development costs □ Productivity reduction □Inefficiencies generation □Stressful and inefficient work conditions □____________________	□ No initial Project Review □ Work is not structured in a systematic way □ Decision making is not concentrated at the beginning □ Priorities change ongoing □ Requirements change ongoing □ Inappropriate communication □ The team's components are situated in different areas □ Lack of a communication and	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to employees □____________________	□ LAMDA process □ Effective management of meetings □ Team integration □Implementation of ICT technologies □Effective project management □Effective costumers management by characterizing and classifying their needs □____________________

		sharing remote system □Ineffective role of PM □PM is not a reference and integration figure also from a technical point of view □____________________						
7.Correction (Reworks / Defective) Reworks and revisions derived by poor-quality products	□ Delays generation □ Inefficiencies generation □ Rise of development costs □ People move away from core activities □Rise of product costs □Stressful work conditions □Project review corrections □Reduction in costumer satisfaction □Reduction of market share □Reduction in employees' commitment □____________________	□ Failure to understand customer needs □ Copy of existing products □ No project review □ Wrong communication □ No culture of sharing □ Training and motivating staff's problems □ PM doesn't evaluate feedback □ PM is not a reference and integration figure also from a technical point of view □Unstructured information system □Problems discovered during the development process □Too much cost reduction objectives □Lack of control on last steps of the project □Changes ongoing	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Costumer satisfaction control □____________________	□ LAMDA process □ Check sheets □ Staff training □Chief engineer □Use modularity □Obeya □Centralized and structured database □Knowledge sharing system □Quality control activities □All the activities in order to understand a product failure □____________________

		□Limited knowledge of the market □Lack of correct decision making mechanisms □Inappropriate technical team □____________________						
7.Correction (Reworks / Defective) Reworks and revisions due to incomplete / incorrect / inappropriate / not reliable (of suspect quality) information, data, requirements	□ Delays generation □ Inefficiencies generation □ Rise of development costs □ People move away from core activities □Rise of product costs □Stressful work conditions □Project review corrections □Reduction in costumer satisfaction □Reduction of market share □Reduction in employees' commitment □____________________	□ Failure to understand customer needs □ Copy of existing products □ No project review □ Wrong communication □ No culture of sharing □ Training and motivating staff's problems □ PM doesn't evaluate feedback □ PM is not a reference and integration figure also from a technical point of view □Unstructured information system □Problems discovered during the development process □Too much cost reduction objectives □Lack of control on last steps of the project □Changes ongoing □Limited knowledge of the market □Lack of correct decision making mechanisms	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Costumer satisfaction control □____________________	□ LAMDA process □ Check sheets □ Staff training □Chief engineer □Use modularity □Obeya □Centralized and structured database □Knowledge sharing system □Quality control activities □All the activities in order to understand a product failure □____________________

		□Inappropriate technical team □_____________________						
7.Correction (Reworks / Defective) Reworks and revisions derived from not successful products	□ Delays generation □ Inefficiencies generation □ Rise of development costs □ People move away from core activities □Rise of product costs □Stressful work conditions □Project review corrections □Reduction in costumer satisfaction □Reduction of market share □Reduction in employees' commitment □_____________________	□ Failure to understand customer needs □ Copy of existing products □ No project review □ Wrong communication □ No culture of sharing □ Training and motivating staff's problems □ PM doesn't evaluate feedback □ PM is not a reference and integration figure also from a technical point of view □Unstructured information system □Problems discovered during the development process □Too much cost reduction objectives □Lack of control on last steps of the project □Changes ongoing □Limited knowledge of the market □Lack of correct decision making mechanisms □Inappropriate technical team □_____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Costumer satisfaction control □_____________________	□ LAMDA process □ Check sheets □ Staff training □Chief engineer □Use modularity □Obeya □Centralized and structured database □Knowledge sharing system □Quality control activities □All the activities in order to understand a product failure □_____________________
7.Correction	□ Delays generation	□ Failure to understand customer	□Never/rarely_	□Unimporta	□Very	□Avoidable	□Post project review or	□ LAMDA process

(Reworks / Defective) Reworks and revisions derived from Scarce integration between Product and Service	□ Inefficiencies generation □ Rise of development costs □ People move away from core activities □Rise of product costs □Stressful work conditions □Project review corrections □Reduction in costumer satisfaction □Reduction of market share □Reduction in employees' commitment □_____________________	needs □ Copy of existing products □ No project review □ Wrong communication □ No culture of sharing □ Training and motivating staff's problems □ PM doesn't evaluate feedback □ PM is not a reference and integration figure also from a technical point of view □Unstructured information system □Problems discovered during the development process □Too much cost reduction objectives □Lack of control on last steps of the project □Changes ongoing □Limited knowledge of the market □Lack of correct decision making mechanisms □Inappropriate technical team □_____________________	1 □Sometimes_2 □Enough_3 □Very much_4	nt_1 □A little_2 □Enough_3 □Very much_4	easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	—Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Costumer satisfaction control □_____________________	□ Check sheets □ Staff training □Chief engineer □Use modularity □Obeya □Centralized and structured database □Knowledge sharing system □Quality control activities □All the activities in order to understand a product failure □_____________________
8. Unused Employee Creativity Communication	□ Delays generation □ Inefficiencies generation	□ Focus on local optimization of costs □ High variability of the product range	□Never/rarely_1 □Sometimes_2	□Unimportant_1 □A little_2	□Very easy_1 □Easy enough_2	□Avoidable waste_4 □Not so avoidable waste_3	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering	□ LAMDA process □ Multifunctional teams

s failure and non-conformance	□ Unnecessary test and checks are performed □ Mistakes repetition □Imitation rather than innovation □Risk of team frustration □Low products' standardization □Reduction of perceived quality □Products with reduced innovative content □____________________	□ Lack of communication □ No culture of sharing □ Knowledge confined to the single individual or team □No inter functional teams □ No culture of reuse □Unstructured information system □No common database □Job rotation □____________________	□Enough_3 □Very much_4	□Enough_3 □Very much_4	□Hard enough_3 □Impossible_4	□Difficult to avoid waste_2 □Not avoidable waste_1	□Work Sampling □Set of indicators □Surveys or questionnaires to employees □____________________	□ Introduction program □Centralized and structured database □Knowledge sharing system □____________________
8. Unused Employee Creativity Inability to reuse previous knowledge	□ Delays generation □ Inefficiencies generation □ Unnecessary test and checks are performed □ Mistakes repetition □Imitation rather than innovation □Risk of team frustration □Low products' standardization □Reduction of perceived quality □Products with reduced innovative content	□ Focus on local optimization of costs □ High variability of the product range □ Lack of communication □ No culture of sharing □ Knowledge confined to the single individual or team □No inter functional teams □ No culture of reuse □Unstructured information system	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to employees □____________________	□ LAMDA process □ Multifunctional teams □ Introduction program □Centralized and structured database □Knowledge sharing system □____________________

	□____________________	□No common database □Job rotation □____________________						
8. Unused Employee Creativity New employees cannot retrieve company knowledge easily	□ Delays generation □ Inefficiencies generation □ Unnecessary test and checks are performed □ Mistakes repetition □Imitation rather than innovation □Risk of team frustration □Low products' standardization □Reduction of perceived quality □Products with reduced innovative content □____________________	□ Focus on local optimization of costs □ High variability of the product range □ Lack of communication □ No culture of sharing □ Knowledge confined to the single individual or team □No inter functional teams □ No culture of reuse □Unstructured information system □No common database □Job rotation □____________________	□Never/rarely_1 □Sometimes_2 □Enough_3 □Very much_4	□Unimportant_1 □A little_2 □Enough_3 □Very much_4	□Very easy_1 □Easy enough_2 □Hard enough_3 □Impossible_4	□Avoidable waste_4 □Not so avoidable waste_3 □Difficult to avoid waste_2 □Not avoidable waste_1	□Post project review or —Lessons Learned □BPR _ Business Process Reengineering □Work Sampling □Set of indicators □Surveys or questionnaires to employees □____________________	□ LAMDA process □ Multifunctional teams □ Introduction program □Centralized and structured database □Knowledge sharing system □____________________

APPENDIX B

Car2go Time calculations

PHASE	Activity	Waiting time		Processing time	
		w(s)	W(s)	t(s)	T(s)
RESERVATION PHASE	RUN APP	0	0	5	15
	FIND A CAR NEAR YOUR LOCATION	5	15	45	70
	LOG IN	5	15	30	50
	CHANGE PASSWORD*	5	30	60	40
	RETRY*	5	10	15	50
	BOOK THE CAR	0	0	18	30
CAR FINDING PHASE	GET TO THE CAR	0	0	360	600
	LAUNCH THE APP TO SEE WHERE THE CAR IS*	4	7	45	70
	GET TO THE CAR	0	0	360	600
	OPEN THE CAR	0	0	9	13
	RETRY*	5	10	9	13
CAR RUN	INSERT CAR STATUS	2	4	3	7
	INSERT PERSONAL CODE	2	4	3	7
	RETRY*	20	35	10	24
	START THE TRIP	5	10	7	13
TOTAL BEST CASE SCENARIO TIME (Recirculations excluded)		37(0,62min)	-	482(8,03min)	-
TOTAL WORST CASE SCENARIO TIME		-	140(2,33min)	-	1602(26,7min)
CAR NOT REACHABLE SCENARIO		63(1,05min)	155(2,58min)	1389(23,15min)	2287(38,12min)

ADF Time calculations

PHASE	Activity	Waiting time		Processing time	
		w(days)	W(days)	t(days)	T(days)
CONCEPT PHASE	INITIAL FEASIBILITY CHECK WITH ADF	0	0,5	1	2
	MAKE IT SOCIAL RELATED*	0	0,5	1	2
DESIGN	IMPROVE THE INITIAL DESIGN	0	0,5	0,5	1

PHASE	REQUIREMENT DEFINITION	0	0	1	2
	INITIATION IN THE ADF AVALIABLE & SUITABLE TECHS	0	0	0,5	1
	ADF OPERATOR & COURSES*	0	3	2	5
	3D MODEL SIMULATION	0	0	2	3
PRODUCTION PHASE	FEASIBILITY ANALYSIS	0	0	2	3
	PRODUCT DEVELOPMENT	0	0	3	4
	PRODUCT MANUFACTURING	0	3	5	7
TOTAL BEST CASE SCENARIO TIME (Recirculations excluded)		**0**	**-**	**15**	**-**
TOTAL WORST CASE SCENARIO TIME		**-**	**7,5**	**-**	**30**

The worst case scenario is when the customer does both recirculations and the waiting and the processing times are W and T respectively. Moreover, the best case scenario is when there are no recirculations and the processing time is t and the waiting time w. This takes us to the final Lead Time in each scenario. For the first it is 15 days and, for the second, 37,5 days.