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Management, Economics and Industrial Engineering

Business game design for lean product and process development (Lean PPD)

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José Luís Almenara Ariza

Cristina Castaño Fuentes
Dedication

To my mother M Angeles, my father Alejandro, and my brothers and sister, Alejandro, M Angeles and Francisco Javier, who gave me peace to this work and help me to advance in life.

Cristina Castaño Fuentes

To my parents Horacio and Josefa and my brother Horacio, who gave me education, discipline and love to stay here.

José Luis Almenara Ariza
### Table of contexts

<table>
<thead>
<tr>
<th>Acknowledgement</th>
<th>Dedication</th>
<th>Table of contexts</th>
<th>Table of figures</th>
<th>Table of tables</th>
<th>Abbreviations</th>
<th>Abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

### Chapter 1

**New Product Development Process & Lean Thinking**

1.1 New product development .......................... 15

1.2 Various types of new product development process models .......... 18

1.3 Lean thinking ................................... 25

### Chapter 2

**Lean new product development** .................................................. 30

2.1 New Product Development at Toyota ................................... 31

2.2 Concurrent Engineering and Lean Product Development .................. 32

2.3 Lean New Product Development: state of the art .......................... 37

2.3.1 Lean principles applied to the New Product Development process .... 44

### Chapter 3

**State of art of serious games** .................................................. 55

3.1 E-Learning concept ............................................... 55

3.1.1 The context of e-learning ...................................... 56

3.1.2 The strategic importance of e-learning ........................ 57

3.1.3 Organisational culture: a key to successful and sustainable e-learning .......... 59

3.2 Trainer and Learner Roles ......................................... 60

3.2.1 The trainer’s roles in e-learning era .......................... 60

3.2.2 The learner’s roles in e-learning era ........................... 61

3.3 Serious Games ......................................................... 64

3.3.1 Definition ......................................................... 64

3.3.2 Challenges of Serious Gaming .................................. 65

3.3.3 Serious Games versus Traditional Games .......................... 67
3.3.4 Advantages of serious games ................................................................. 68
3.4 Analysis of Serious Games in the market ..................................................... 71
3.4.1 Compilation of various Educational Games ............................................. 72
3.4.2 Overall Analysis of Educational Games .................................................. 72

Chapter 4
Research domains ................................................................................................. 77
4.1 Goal of the LeanPPD Game ........................................................................... 77
4.2 Researches of Process and Product ............................................................... 78
  4.2.1 Research of the New Product Development model ................................... 79
  4.2.2 Research of the product ......................................................................... 83
  4.2.3 Transformation of the process through the product .................................... 83
4.3 LeanPPD game Overview ............................................................................... 89
  4.3.1 Approach to the LeanPPD game ............................................................... 89
  4.3.2 Role of the player ................................................................................... 91
  4.3.3 Approaching the lean tools ...................................................................... 92

Chapter 5
LeanPPD Game .................................................................................................... 100
5.1 Qualitative model of the LeanPPD Game ...................................................... 100
  5.1.1 Customer’s requirements ...................................................................... 100
  5.1.2 The airplane .......................................................................................... 102
  5.1.3 The design table .................................................................................... 106
  5.1.4 Test phase ............................................................................................. 108
  5.1.5 Design time .......................................................................................... 109
5.2 Quantitative model of the LeanPPD Game .................................................... 110
  5.2.1 General equations of the model ............................................................... 110
  5.2.2 Definition of the customer’s requirements ............................................. 116
  5.2.3 Design phase ......................................................................................... 127
5.3 Flow of the game ............................................................................................ 131
  5.3.1 Stage 1 .................................................................................................. 131
  5.3.2 Stage 2 .................................................................................................. 134
  5.3.3 Evaluation of the game interface ............................................................. 144
5.4 Performances .................................................................................................. 145
Chapter 6
Validation of the LeanPPD game................................................................................................................. 149
6.1 Validation mode........................................................................................................................................... 149
6.2 Segmentation of the players ......................................................................................................................... 153
   6.2.1 Players with Skill and Technical Knowledge ....................................................................................... 153
   6.2.2 Player with skill but without Technical Knowledge .............................................................................. 153
   6.2.3 Players without skills and without technical knowledge........................................................................ 154
6.3 Conclusions of the validation......................................................................................................................... 154

Chapter 7
Conclusions and Future improvements............................................................................................................... 157
7.1 Future Improvements................................................................................................................................... 157
   7.1.1 Interface of the game.............................................................................................................................. 157
   7.1.2 New Lean enablers................................................................................................................................ 157
   7.1.3 Create a Database.................................................................................................................................. 159
   7.1.4 Put the game on-line.............................................................................................................................. 159
7.2 Conclusions................................................................................................................................................... 159

8 Annexes......................................................................................................................................................... 163
8.1 Annexe I: Visual Basic code.......................................................................................................................... 163
8.2 Annexe II: Helps of the game......................................................................................................................... 192
   8.2.1 General Instructions................................................................................................................................. 192
   8.2.2 Customer’s requirements instructions.................................................................................................... 196
   8.2.3 Lean Instructions...................................................................................................................................... 197
8.3 Annexe III: Standardization enable................................................................................................................. 202
8.4 Annexe IV: Front loading models................................................................................................................. 204
9 Bibliography...................................................................................................................................................... 208
Table of figures:

Figure 1 – Automotive industry NPD process (Hong B., 2006) .................................................. 18
Figure 2 – The Product Development Process (Ulrich and Eppinger 2000) ................................. 19
Figure 3 – The Front-end Activities Comprising the Concept Development Phase .................. 20
Figure 4 – Steps of the Planning and Design Process (Phal and Beitz, 1996) ............................ 21
Figure 5 – Spiral Development is a Series of “Build-Test-Feedback-Revise” Iterations .............. 22
Figure 6 – Toyota’s Overall Cost Advantage (Hoover's Company Profiles, 2007) ..................... 31
Figure 7 – Example of QFD (Schilling, 1996) ........................................................................ 34
Figure 8 – Concurrent Technology Transfer (Cusumano and Nobeoka, 1998) ......................... 35
Figure 9 – Product Strategy (Vaugh, 2002) .......................................................................... 36
Figure 10 – Lean Integration Tools on Aircraft Structure Development (McManus, 2005) .... 45
Figure 11 – Production Labour Before and After Lean Engineering (McManus, 2005) .......... 46
Figure 12 – Results of Applying Lean to Engineering Processes (McManus, 2005) ............... 46
Figure 13 – Material and Information Flow (Rother and Shook, 1999) .................................... 48
Figure 14 – Liker’s 13 Principles in NPD (Liker, 2006) ............................................................... 50
Figure 15 – Methods of E-Learning (Back et al, 2001) ............................................................... 56
Figure 16 – Innovation cycle (Knight, 2002) ........................................................................... 57
Figure 17 – Kolb’s Learning Cycle and Learning Styles (Kolb and Chapman 2005) ............. 61
Figure 18 – Position of serious game in e-learning tools (Alfamicro, PRIME Version 8.0) .... 64
Figure 19 – Challenges of a serious game (Stokes, 2005) .......................................................... 66
Figure 20 – The Product Development Process (Ulrich and Eppinger 2000) ......................... 79
Figure 21 – Current State of the first model .............................................................................. 81
Figure 22 – Future State of the first model ................................................................................ 82
Figure 23 – Front view .............................................................................................................. 85
Figure 24 – Lateral view .......................................................................................................... 85
Figure 25 – Top view ................................................................................................................ 85
Figure 26 – Final model .......................................................................................................... 88
Figure 27 – Example of Trade-off curve .................................................................................... 98
Figure 28 – Screen of customer’s requirements ....................................................................... 101
Figure 29 – Parts of the airplane ............................................................................................. 102
Figure 30 – Basic shapes to build the airplane ....................................................................... 103
LeanPPD Game

Figure 31 – Supplier’s catalogue

Figure 32 – Design table

Figure 33 – Matrix of design

Figure 34 – Screen of the clock

Figure 35 – Flow of the equations

Figure 36 – Wingspan and length of an airplane

Figure 37 – Ratio of power

Figure 38 – Flow of the Game

Figure 39 – Screen of the Lean Enablers

Figure 40 – Interface of the Stage 1 of the game

Figure 41 – Screen of chief engineer

Figure 42 – Screen of previous knowledge

Figure 43 – Screen of standardization of the cockpit

Figure 44 – Screen of guest supplier

Figure 45 – Screen of cross-functional teams

Figure 46 – Screen of front loading model 1

Figure 47 – Screen of trade-off curves: speed versus weight

Figure 48 – Screen of trade-off curves: Km of travel versus wing surface

Figure 49 – Example of the lean score

Figure 50 – Validation template of the LeanPPD game

Figure 51 – Results of the validation

Figure 52 – Screen of general instructions

Figure 53 – Screen of goal of the game

Figure 54 – Screen of how to play?

Figure 55 – Screen of general airplane’s knowledge

Figure 56 – Screen of customer requirement instructions

Figure 57 – Screen of lean instructions

Figure 58 – Screen of chief engineer help

Figure 59 – Screen of guest supplier help

Figure 60 – Screen of previous knowledge help

Figure 61 – Screen of front loading help

Figure 62 – Screen of cross-functional teams help

José Luis Almenara Ariza

Cristina Castaño Fuentes

DATE September 2011
Figure 63 – Screen of standardization help................................................................. 200
Figure 64 – Screen of trade-off curves help.................................................................. 201
Figure 65 – Screen of standardization of the cockpit....................................................... 202
Figure 66 – Screen of standardization of the tail ............................................................. 202
Figure 67 – Screen of standardization of the wing............................................................ 203
Figure 68 – Screen of front loading model 1. .................................................................. 204
Figure 69 – Screen of front loading model 2 .................................................................... 204
Figure 70 – Screen of front loading model 3. ................................................................. 205
Figure 71 – Screen of front loading model 4. ................................................................. 205
Figure 72 – Screen of front loading model 5. ................................................................. 206
Table of tables:

Table 1 - The Generic Product Development Process (Ulrich and Eppinger, 2000) .................... 22
Table 2 - Functional Activities under Cross-Functional Integration ........................................ 23
Table 3 - The Differences between CE and Lean Philosophy (Haque, 2008) .......................... 37
Table 4 - Comparison of Conversion, Flow, and Value Generation Views (Ballard and Koske, 1998) ..................................................................................................................... 38
Table 5 - Differences between Production and Product Development (Oppenheim, 2004) ...... 39
Table 6 - Definition of Lean Engineering (Murman, 2008) .................................................................. 43
Table 7 - Key Elements of NPD Derived From the Literature .................................................... 45
Table 8 - Womack and Jones’ Five Lean Principles Translation (McManus, 2005) ............... 47
Table 9 - Comparison of classical e-Learning with Educational Games (Alfamicro, PRIME Version 8.0) .......................................................... 68
Table 10 - Comparison of Education Games (Alfamicro, PRIME Version 8.0) ....................... 74
Table 11 - 13 principles of Liker ........................................................................................................... 94
Table 12 - Different types of cockpits ................................................................................................. 118
Table 13 - Different types of wings ..................................................................................................... 119
Table 14 - Different types of tails ....................................................................................................... 122
Table 15 - Study of the variance ....................................................................................................... 145
Table 16 - Lean scores ....................................................................................................................... 147
Table 17 - Performances of the players ........................................................................................... 152
Abbreviations:

\( n_{s,b} \)  number of squares in the body
\( n_{t,b} \)  number of triangles in the body
\( n_{bt,b} \)  number of big triangles in the body
\( n_{s,w} \)  number of squares in the wings
\( n_{t,w} \)  number of triangles in the wings
\( n_{bt,w} \)  number of big triangles in the wings
\( n_{s,t} \)  number of squares in the tail
\( n_{t,t} \)  number of triangles in the tail
\( n_{bt,t} \)  number of big triangles in the tail
\( n_{s,c} \)  number of squares in the cockpit
\( n_{t,c} \)  number of triangles in the cockpit
\( n_{bt,c} \)  number of big triangles in the cockpit
\( n_{i,j} \)  number of pieces \( i \) located in the part \( j \) of the plane, where \( i = s, t, bt \) and \( j = b, w, t, c \)
\( Np \)  number of passenger
\( n_e \)  number of engines
\( cap_i \)  number of passenger of the piece \( i \) in the body
\( w_{ij} \)  weight of the piece \( i \) located in the part \( j \) of the plane
\( a_i \)  area of the piece \( i \)
\( w_e \)  weight of the engine
\( p_e \)  power of the engine
\( ROP \)  ratio of power
\( W \)  weight of the plane
\( KmT \)  kilometers of travel or max range of the plane
\( L \)  length of the airplane
\( ws \)  wingspan
\( c_{i,j} \)  cost of the piece \( i \) located in the part \( j \) of the plane
\( c_e \)  cost of the engine
\( t_{s_{i,j}} \)  
Supplier time of the piece \( i \) located in the part \( j \) of the plane

\( t_{a_{i,j}} \)  
Assembly time of the piece \( i \) located in the part \( j \) of the plane

\( t_d \)  
Design time, adding the normal time and the extra time in the design phase

\( t_{d,normal} \)  
Minutes of design during the first thirty minutes

\( t_{d,extra} \)  
Minutes of design once overpassed the first thirty minutes

\( t_t \)  
Test time

\( D_t \)  
Delivery time

\( D_{t_c} \)  
Delivery time required by the customer

\( l_{y_j} \)  
Length of the part \( j \) of the airplane in the \( y \) axis

\( l_{x_j} \)  
Length of the part \( j \) of the airplane in the \( x \) axis

\( C \)  
Total cost
Abstract

Companies have to constantly innovate and introduce new products to the market to win the current pressure they are facing in the globalization era. New Product Development (NPD) Process is becoming crucial, and its performances determine the success of the whole enterprise. Most efforts have been dedicated to improve the phase using different tools and methodologies. Particularly some are trying to apply lean product development to foster the efficiency and effectiveness of their NPD. Though literatures show its success, its implementation is complex and asks for relevant efforts to get benefits out of it.

The application of lean thinking in NPD though simple in the theory, it is subtle in practice and need a constant effort for pursuing perfection. The subtlety comes with the nature of a product design process. NPD is characterized by innovation process, where new ideas come to reality having a complex interaction between multiple stockholders. Moreover, at the early phase of product design customer requirements are ambiguous, manufacturing constraints and opportunities are not evident, and supplier’s capabilities are not accessible to designers. Taking the complexities of NPD, the application of lean thinking based on the Toyota’s way of product development (lean product development) need a hand on experience to let NPD practitioners and academician understand the principles of lean product development. Such a hand on experience needs to be simple enough to translate the main concepts of lean thinking in NPD. This thesis is therefore aimed at designing a computer based business game, in entertaining and simple manner, to translate the basic principles of lean product development.

An EU funded project called LeanPPD (www.leanppd.org) is addressing the application of lean product development in European manufacturing companies. The project involves 12 academic and industrial partners. In the project, a novel approach for designing new products is under development based on lean thinking. In addition, this business game is initiated in the project to translate the main principles of lean thinking in NPD through a simplified and entertaining game. So that, industrial partners in the project as well as other interested groups can grasp the concepts easily.

To understand the game, it is necessary to understand the concepts behind it. These concepts are the NPD and the lean philosophy. The chapter one gives an overview about the New Product Development. It explains what it is understood under this term, and it shows different models of NPD process. Also, this chapter explains the history and bases of the lean thinking. How Toyota is the example to follow by the most company what tries to adopt the lean system, and how lean can be applied in any field of research or in any field in the life.

The chapter two joins the two previous ideas explained in the chapter one. It mixed the NPD with the lean philosophy, generating the Lean New Product Development. The ideas of lean applied in NPD create a list of activities and tools that make the lean NPD an important weapon for the companies. With this process companies can launch to the market very high quality
products in a short period of time at a low cost. Here is the key of why the lean NPD is so important currently.

To create an effective serious game, it is necessary to follow some rules and answer some question. All that things are explained in the chapter 3, where the state-of-art of serious games in NPD is given. The entire bases for a good serious game are explained.

All the ideas behind the game, what are taken from the chapter 1, chapter 2 and chapter 3, are explained in the chapter 4. This chapter explains how the game has been developed: first a NPD model is taken in the first part of the chapter one; then some lean principles and activities are applied to the NPD process selected; finally, a lean NPD is defined. To get this final process the player has to meet the role of a designer and some time the role of a manager, implementing lean tools to improve the process. The product selected for the game is explained too.

All the ideas explained in the chapter 4 adopt shape in the chapter 5. The chapter 5 shows how the game is. The game is explained in a qualitative and in a quantitative way. It explains what the player has to do, what are the goals, the penalizations, the score system and the rules in the game. All the equations are explained to get a clearer way of how the game has been developed.

Finally, the chapter 6 and 7 shows the validation of the game and the future improvements.
Chapter 1

New product development & Lean thinking
1 New Product Development Process & Lean Thinking

The directions that guide the literary review of this section are mainly two: the first deals with NPD process and the second with Lean thinking.

In literature a wide number of alternative terms are used to describe NPD process so it is necessary to clearly establish what is intended with NPD process within this research. The definition of a Lean NPD process cannot be leave aside from the understanding of the Lean concept in manufacturing industry. The aim of this chapter is to achieve an exhaustive knowledge of a Lean NPD process which is the starting point for the development of the model within this research.

The aim of the research presented in this Chapter is to establish the state-of-art concerning the application of Lean thinking to product design and development. To achieve this, a review of the literature in this field has been carried out analysing the publications dealing with lean and product development.

The initial approach to this study has been done to consider some key points related to the process of product development itself, to what is commonly meant by the term Lean in manufacturing and then to the application of the principles of Lean to NPD process.

1.1 New product development

First of all some definitions of the term “new product development” are given here below. It must be underlined that speaking about New Product Development (NPD) necessarily includes talking about the process because they are strictly correlated.

- In business and engineering, new product development is the term used to describe the complete process of bringing a new product or service to market. There are two parallel paths involved in the NPD process: one involves the idea generation, product design, and detail engineering; the other involves market research and marketing analysis. Companies typically see new product development as the first stage in generating and commercializing new products within the overall strategic process of product life cycle management used to maintain or grow their market share.

  (Wikipedia definition)

- Process: “A series of actions or steps towards achieving a particular end”

  (Oxford dictionary)

- A business process can be described as “a number of interrelated activities needed to accomplish a specific task”

  (Garside, 1998).
New Product Development (NPD): The overall process of strategy, organization, concept generation, product and marketing plan creation and evaluation, and commercialization of a new product. Also frequently referred to just as "product development.

(PDMA)

New Product Introduction (NPI): The launch or commercialization of a new product into the marketplace. Takes place at the end of a successful product development project.

(PDMA)

New Product Development Process (NPD Process): A disciplined and defined set of tasks and steps that describe the normal means by which a company repetitively converts embryonic ideas into saleable products or services.

(PDMA)

A new product development is an integral part of a healthy, growing economy and it contributes by generating revenue and profits to a corporation that otherwise would not have been generated.

(Annacchino, 2006)

In the book “The pursuit of new product development” (Annacchino, 2006) different types of New Product Development in existence today are described. Each one is used for a different reason, and each one has its own objectives and dynamics for execution. The following is a common list of the different types of possible developed products with their attributes and contributions:

- “New to the world” products: these products are somewhat revolutionary in the marketplace; they generally create entire new markets that never before existed. An example would be the cellular phone which has revolutionized person-to-person communications in modern-day society.

- New product lines: these new categories of products allow entry into newer markets not previously participated in by the manufacturer. The new product lines generate incremental revenue to the manufacturer by leveraging the market’s familiarity with the manufacturer into new categories of products. In many cases, the market familiarity with the manufacturer paves the way for new categories of products. Sometimes these products go into new markets, but can also be an alternative to existing ones.

- Additions to existing product lines: these efforts support existing product lines by creating line completers to extend the influence of the original products’ brand to larger audiences or extending range, power and scope. An example of this type of
product would be tomato sauce versions- hearty, traditional, roasted garlic. By taking the basic product and modifying it, a wider market share is realized. The addition to existing lines has a similar effect on the company’s revenue as the new product lines. They generate incremental revenue by leveraging the existing product familiarity rather than the company familiarity. These programs generate incremental improvement in the economy, but generally fall short of the contribution made by the totally new products.

- **Improvements and revisions of existing products:** as time advances, customers have higher expectations of products and the competition adds features to their offering. It becomes necessary to improve a company’s offering to increase market share or to retain it. By redesigning the product or repackaging it, a company can offer a greater value or satisfaction to the customer. An example of this type of product development is the automotive companies adding features to their basis models each year as standard. Generally, the improvements to existing products do not generate additional revenue.

- **Repositioning:** it is another way of increasing or maintaining market share. Repositioning is an exercise in changing the perception in the mind of the consumer. It generally can happen with products that are lower in value or the consumer spends little time evaluating the actual data. It is truly a marketing activity rather than a development activity, and it is another stop gap measure for generating revenue from an existing product.

In general, a Product Development (PD) process is defined as a set of activities involved in taking a design problem during product development from setting initial specifications to producing a finished artefact that meets specifications (Johnson, Brockman, Vigeland, 1996). It has a large number of decision-making activities that combine creative thinking, experience, intuition, and quantitative analysis, the characteristics of which are iterative, cooperative, evolutionary, and uncertain. These characteristics make the PD process complex. It involves thousands of decisions, sometimes over a period of years, with numerous interdependencies, and under a highly uncertain environment. A large number of participants are involved, such as architects, project managers, discipline engineers, service engineers, and market consultants. Each category of professionals has a different background, culture, and learning style (Formoso et al., 1998). Trade-offs between multiple, competing design criteria must be made throughout the design process, often with inadequate information and under intense budget and schedule pressure. Early design stages are notoriously hard to evaluate and control against progress milestones; lacking physical deliverables such as drawings, it is difficult to measure the amount of work completed and remaining on any given task, and consequently in the project as a whole. Moreover, feedback from the production and building operation stage takes a long time to be obtained, and tends to be ineffective. To make matters worse, projects are increasingly subject to uncertainty because of the pace of technological change, the rapid shifting of market
opportunities, and the inability to keep pace with relentless pressure to reduce time and cost (Ballard and Koskela 1998).

![Diagram of NPD process]

**Figure 1 – Automotive industry NPD process (Hong B., 2006)**

As shown in the figure above there are several activities and functions involved in NPD and above all there are several iterations among them which complicate the process.

According to Ulrich and Eppinger (1995) NPD is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product. It is used to indicate the complete business process of introducing new products to market. It spans the entire product life-cycle from initial identification of market/technology opportunity, conception, design and development through to production, market launch, support, enhancement and retirement.

### 1.2 Various types of new product development process models

After having listed some generic definitions of new NPD and NPD process, this section will present in detail different new product introduction process models.

The most common NPD process models mentioned in literature are: Departmental-stage models, Activity-stage models, and Decision-stage models (Saren, 1984).

The Departmental-stage models are the oldest and are characterized by the ‘functional’, ‘sequential’ and ‘over the wall’ approach for NPI. The focus is on the functions (departments) that are responsible to carry out each stage. Product development is a reactive process by its
nature (Kennedy, 2003); the design teams naturally react to what is learnt in the previous step. In other words, it is not unusual that the results from one step drive the actions of the next step, which may suggest that this process is appropriate. The literature suggests that these models are out-dated and should be discarded.

The Activity-stage models of NPD offer a better view of the process since they focus on the activities that are carried out. Activity-stage models and their extension, Decision-stage models, are the models that have been most rigorously investigated and used. One of the first examples of activity-stage model was described by Booz, Allen and Hamilton (1968, quoted in Ehmke and Boehlje, 2005).

The Decision-stage models have various names in practice: Phased Project Planning, Gating System, Stage-Gate Systems or Phase-Gate Systems. Their characteristic is that the process consists of Stages (where the activity takes place) which are always followed by Gates (which are review points with specific input, exit criteria and a go/kill/hold/reiterate decision as output).

Garside describes a Stage-Gate model with formal reviews and overlapping activities, which is applicable to an engineering business. The model is based upon four interconnected stages: product and process design and development; concept validation; process implementation and verification; and manufacturing support (Garside, 1998). Garside defines the starting point of the NPI process just after a Bid, which is after the Opportunity Evaluation Phase (i.e. bid and proposal phase).

The product development process is also defined, as already written above, as “the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product” (Ulrich and Eppinger, 1995). In Figure 2 a general product development process is represented: according to Ulrich and Eppinger the New Product Development is a stage-gate process composed of six phases. Each phase comprises of a series of activities and feedback processes. For instance, Ulrich and Eppinger (2000) present the front-end activities comprising the concept development phase.
Phal and Beitz (1996) propose, though using terms in a different way, a very similar approach as it can be seen in Figure 4.

These approaches, however, do not show what functional department should be involved with each step. In other words, organizational issues are excluded in the presentation of the product development procedures. Therefore, Ulrich and Eppinger (2000), and Wheelwright and Clark (1992), add organizational information to the procedural models.

They are shown in Table 1 and Table 2 respectively showing the general activities to be taken by each functional department during each phase of product development.
Figure 4 – Steps of the Planning and Design Process (Phal and Beitz, 1996)
### Planning

<table>
<thead>
<tr>
<th>Marketing</th>
<th>Concept Development</th>
<th>System Level design</th>
<th>Detail design</th>
<th>Testing and refinement</th>
<th>Production Ramp up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect customer needs. Identify lead users. Identify competitive products.</td>
<td>Develop plan for product options and extended product family.</td>
<td>Develop marketing plan.</td>
<td>Develop promotion and launch materials. Facilitate field testing.</td>
<td>Place early introduction with key customer.</td>
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</tbody>
</table>

### Design

<table>
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<tr>
<th>Design</th>
<th>Concept Development</th>
<th>System Level design</th>
<th>Detail design</th>
<th>Testing and refinement</th>
<th>Production Ramp up</th>
</tr>
</thead>
</table>

### Manufacturing

<table>
<thead>
<tr>
<th>Manufacturing</th>
<th>Concept Development</th>
<th>System Level design</th>
<th>Detail design</th>
<th>Testing and refinement</th>
<th>Production Ramp up</th>
</tr>
</thead>
</table>

**Table 1 - The Generic Product Development Process (Ulrich and Eppinger, 2000)**
<table>
<thead>
<tr>
<th>Functional Activities</th>
<th>Concept Development</th>
<th>Product Planning</th>
<th>Detailed design and development</th>
<th>Commercial preparation</th>
<th>Market Introduction</th>
</tr>
</thead>
</table>

Table 2 - Functional Activities under Cross-Functional Integration

(Wheel Wright and Clark, 1992)

Recently Cooper has further evolved the Stage-Gate vision introducing “Spiral Development” (Cooper, 2008) which is explained in the following scheme.
Customers or users really don’t know what they want until they see it, especially in case of very innovative products. Get something in front of the user fast, something the customer can see, feel, touch, is useful to respond to his expectations.

Spiral development does this: it deals with the need to get mock-ups or prototypes in front of customers early in the process, and seek fast feedback. Spiral development also allows for smart-and-fast failures; these spirals are relatively inexpensive, and often the first few spirals result in negative responses. Cooper also suggests that negatives responses are not a problem: it should be very important to revise, rebuild and test again via the next spiral. Spiral development also bridges the gap between the need for sharp, early and fact-based product definition before development begins and the need to be flexible, agile and to adjust the product’s design to new information and fluid market conditions as development proceeds.

Cooper notes that these loops or spirals are deliberately built in from the front-end stages through the development stage and into the testing stage; he suggested that the number of required spirals depends on the type of product to develop. The spiral model visibly resembles Deming’s “Plan, Do, Check, Act” cycle and it combines the features of the prototyping model and waterfall model that is a typical sequential software development process.

The first loop or spiral should be the voice-of-customer study undertaken early in Stage 2, where project team members visit customers to better understand their unmet and unspoken needs, problems and benefits sought in the new product. At this point, the project team probably has very little to show the customer; and that’s the way it should be: the purpose of this visit is to listen and watch, not to “show and tell.”

The second spiral, labelled “full proposition concept test” in the exhibit, should be where the project team presents a representation of the proposed product. Depending on the type of product and industry, this representation can be a computer-generated virtual prototype, a handmade model or mock-up, a very crude prototype, or even a few computer screens for new
software. The product obviously does not work at this early stage, and in some presentations is only two-dimensional. But it is enough to give the customer a feel for what the product will be and do. Interest, liking, preference and purchase intent are thus established even before the project is a formal development project. Feedback is sought, and the needed product revisions are made.

Moving into the Development Stage within weeks the project team produces the next and more complete version of the product, perhaps a crude model or a rapid prototype. Designers test this with customers, and again seek feedback, which they use to rapidly revise and build the first-working prototype, and then to Spiral #3, #4 and so on. In this way each successive version of the product get closer to the final product, and at the same time, closer to the customer’s ideal. These loops resemble spirals, hence the name “spiral development.” Cooper isn’t the first who talks about spiral development. This term comes from software development world even since 1988. This approach is usually used in design and development process by software house that use beta tests, prototypes and provisional versions of the product in order to involve customers. Users’ feedbacks are then used to improve process and its output.

1.3 Lean thinking

Lean Thinking has its origin after World War II when the management of Toyota Motor Company needed to invent different manufacturing techniques than the mass production systems that were widespread in the West because of the very limited financial resources of the company and the difficulties of the local market which was small and fragmented with scarce natural and human resource. Eiji Toyoda and chief engineer Taiichi Ohno managed to delineate and apply the concept of the Toyota Production System (TPS) by the 1960s. Thanks to TPS Toyota, which despite 1973 oil crisis increased its earnings, was able to continue increasing its market share and performed better than western competitors.

Over the last two decades, many researchers have studied TPS and have documented various principles and practices used by Toyota (Womack and Jones, 1994; Liker, 1998; Adler, 1993, Spear and Bowen, 1999; Sobek et al. 1998). The total approach was termed as “lean manufacturing” because of its ability to attain and realize so much more in terms of final outcomes with the deployment of fewer resources.

In reality the principles behind Lean are not in themselves new; they can be traced back to the work of pioneers such as Deming, Taylor, Skinner in which they talk about continuous improvement, Total Quality Management, cost reduction etc.

The famous book “The Machine that Changed the World” (Womack, Jones and Ross, 1990) details the progress of the Japanese automobile industry (Toyota) and compares its production model to the traditional mass production model common in the United States. The Lean Toyota model has been associated since the beginning with the practice of identifying the value added
activities from those that are waste ("muda" in Japanese) in an organization and its supply chain. Taichi Ohno suggested “Waste accounts for nearly 95 percent of all costs”. These common wastes are:

1. Product defects;
2. Overproduction;
3. Semi-finished goods in warehouses waiting for further work;
4. Unnecessary production;
5. Unnecessary people location;
6. Unnecessary transport of goods;
7. Waiting time: workers or machines awaiting the conclusion of an upstream activity.

Womack and Jones (1990) add an eighth one:

8. Design and production that do not meet customer needs.

Womack and Jones (1996) explain that Lean “provides a way to specify value, line up value-creating action in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more effectively. In short, Lean thinking is ‘Lean’ because it provides a way to do more with less – less human effort, less equipment, less time, and less space – while coming closer and closer to providing customers with what they really want”.

The core of Lean thinking philosophy is constituted by the five principles which are suggested for disposing of waste. Here below a brief description is given:

1. Specify value: define value precisely from the perspective of the end customer in terms of a specific product with specific capabilities offered at a specific price and time;
2. Identify the value stream: identify the entire value stream for each product or product family and eliminate waste. All activities can be classified into 3 groups: activities that create value; activities which do not create value, but they cannot be removed under current conditions (for example: the quality control); activities which do not create value and can be removed (for example, any internal transportation which is not strictly necessary). Flow mapping (materials and information) is the tool used to identify the value stream;
3. Make the value flow: make the remaining value creating steps flow. The common work organization is distributed by functions and departments; thus it is thought that a greater control and efficiency are achieved. But this structure damages the continuity of flow. Continuous flow is achieved mainly through interventions that enable radical change in a short period of time. To achieve this maybe only some little actions are necessary: for example (Bonfiglioli, 2001) with small “continuous improvement teams” (kaizen) very good results could be achieved. Also the organization chart should change;
4. Let the customer pull the process: design and provide what the customer wants only when the customer wants it;

5. Pursue perfection: strive for perfection by continually removing successive layers of waste as they are uncovered. The perfection is an unachievable concept. Seeking perfection refers to a process of continuous improvement. The lean management is not a process with a beginning and an end, its implementation necessarily involves the continual search for improvement; even more in the current environment, since the life cycles of products are remarkably short and technology is moving fast. Product teams are, in this sense, very useful. If they are in direct contact with the customer, they can quickly understand the value for them and promote the continuous improvement process (Bonfiglioli, 2001). It is necessary to form multi-skilled employees and also to form them in lean thinking. Hence, it is important to invest in the employees, not only in the machines. (Bonfiglioli, 2001).

Lean Thinking is often seen as a set of tools. Rather than embracing one or two isolated tools companies should practice most, if not all, of them. A list of the most common tools is presented here below:

- Continuous improvement/kaizen. It refers to activities that continually improve all functions of a business, from manufacturing to management and from the CEO to the assembly line workers. By improving standardized activities and processes, Kaizen aims to eliminate waste;
- Group Technology or Cellular Manufacturing. A production which is focused on a component or on a product part allows to reduce transport, waiting and process time;
- Kanban. It is Japanese term that literally means label. It enables to synchronize product flow among cells through a label system that authorizes withdraw and production;
- Labour balancing, Production smoothing and Takt Analysis are useful in order to obtain a good trade-off between throughput time in the cell and delivery time of the product. Takt time is substantially the production rhythm (Net available time to work/ Total demand) and production flow should be follow it because takt time represents the maximum time available to produce a piece in order to satisfy the demand. It is a tool to control that it is being produced only what is asked for.
- Single Minute Exchange of Dies (SMED). It is a tool used to reach a Quick Changeover (QCO), thus eliminate delays in change-over times on machines in order to reduce the lead-time and improve flows;
- Step change/kaikaku. It is a radical overhaul on an activity to eliminate all waste and create a greater value, it is also called breakthrough kaizen;
- Poka-yoke. It aims to get a zero-defects process and eliminate quality inspections. Poka-yoke means “mistake proofing” and it is a technique that frees employees’ mind and
time in order to pay more attention on value added activities rather than monitoring ones;

- Supplier development. Organization need to actively develop links with suppliers and working closely with them for mutual benefit as intimated by Bicheno (1999) and Henderson et al. (1999);

- Supplier base reduction. Further attempting to reduce the number of suppliers an organization engages with;

- Five S and general visual management. It is used to reduce the clutter and inefficiency of any typical production and office environment. The five Ss (seiri, seiton, seiso, seiketsu, and shitsuke) are:
  1. Sort-Sort through items and keep only what is needed while disposing of what is not;
  2. Straighten (orderliness) - A place for everything and everything in its place;
  3. Shine (cleanliness) - The cleaning process often acts as a form of inspection that exposes abnormal and pre-failure conditions that could hurt quality or cause machine failure;
  4. Standardize (create rules) - Develop systems and procedures to maintain and monitor the first three S's;
  5. Sustain (self-discipline) - Maintaining a stabilized workplace is an ongoing process of continuous improvement;

- Value Stream Mapping (VSM). It consists of two maps: current state map and future state map. The main aims are: visualize the material flow and information flow, highlight where wastes are and consequently remove them, and identify the priority of interventions to improve the flow. It will be better explained in the next Chapter;

- Total Productive Maintenance (TPM). This is aimed at improving the reliability, consistency and capacity of machines through maintenance regimes as dwelled on originally by Ohno (1988).

All tools listed above are commonly mentioned in most of the literature and it has heard about them since Lean thinking was born.
Chapter 2

Lean New Product Development
2 Lean new product development

In the automotive industry, lean manufacturing has become so effective that every automobile company has developed a lean manufacturing strategy and many have been quite successful. Likewise, many companies in other industries have developed lean strategies.

Today lean manufacturing is no longer the exclusive competitive advantage of organizations: in the automobile industry, the number of vehicle models available to North American consumers has increased dramatically. Conversely, the number of unique vehicle platforms has decreased substantially. Consequently, to be successful and remain competitive, automakers must now offer a much wider variety of vehicles and introduce new vehicles more often while using fewer platforms (Liker, 2006). As a result, most consumer-driven companies must work to meet consumer demand by accelerating product development and bringing to market the products that customers want when they want them.

According to a Merrill Lynch analysis in the automotive industry, new model introductions over the last five years have grown at a tremendous pace, with more than 60 new vehicles being introduced each year in the United States between 2003 and 2005. Dealing with this trend, many industries have been moving to platform engineering. For example, Intel recently made this a strategic priority, moving to platform of integrated chip sets to provide for different customer segment.

In today’s competitive market, excellence in product development is rapidly becoming more of a strategic differentiator than manufacturing capability. According to Liker (2006), the reason for this is simple: there is much more opportunity for competitive advantage in product development than anywhere else. Two underlying factors support this premise. First, whereas the performance gap in manufacturing is closing, the gap between best-in-class and the rest of whatever industry in product development is increasing. Secondly, as Toyota have clearly demonstrated, though manufacturing capability is paramount, it is only one functional discipline: while a strong manufacturing system can affect quality and productivity, the ability to impact customer defined-value and variable costs is clearly much greater in product development process and decreases as the development program proceeds toward launch.

It can be easily derived that developing new products faster than competitors do is a formidable strategic weapon to succeed in increasingly turbulent markets. Although the techniques used to accomplish such high product development performance have existed for some time, they were later drawn together under a common heading: the concept of Lean product development.
2.1 New Product Development at Toyota

The underlying philosophy of the Toyota way (Liker, 2004) led to parallel evolutionary paths in three core competencies (manufacturing, sales and product development). Liker stated that although not as broadly understood as Toyota’s production system, Toyota’s product development system is equally powerful. The company consistently developed higher quality vehicles faster than its competitors, for less costs and at a greater profit. It also launches more new vehicles annually than most of its competitors, creating a steady flow of high quality new products to meet consumer demand. This has fuelled industry leading profits, reaching a Japanese record of 10.9 billion dollars by 2005, a market capitalization greater than that of GM and Ford combined and a continuing growth in market share (Liker, 2006). Toyota is the lowest in the ratio of R&D to sales. According to Liker, by combining its lean production capabilities with common architecture strategies, standard process and component sharing, Toyota achieved an incredible overall cost advantage. It achieved speed and quality by minimizing variation and increasing the potential for predictable outcomes in an unpredictable environment (Figure 6).

The traditional product development process consists of iterations on one initial good concept; that is making modifications-improvements in series, until an acceptable design emerges (Ward et al., 1995). This design practice works perfectly with the ‘over the wall’ NPD process. What is more, it is considered a ‘good’ practice to freeze the specifications as early as possible, as it is recognized that time to market is critical.
According to Sobek (1999), although Toyota is the founder of Lean production, its product development processes do not seem to follow all the Lean principles in the same sense or rigor as their manufacturing processes. For instance, as opposed to selecting one design concept/solution and optimizing it, it applies set-based Concurrent Engineering (Sobek et al., 1999). Set-based Concurrent Engineering demands the generation of a wide range of alternative designs of related product components/subsystems that are developed and prototyped simultaneously, while being gradually refined or eliminated through a process of intersection of feasible regions. They begin by broadly considering sets of possible solutions (in parallel and relatively independently) and gradually narrow the set of possibilities to converge on a final solution, overlapping development problems solving activities and leading to shorter lead times (Clark and Fujimoto, 1989). This results in lots of information being generated and then discarded. However, this information is seen as knowledge and is recorded in a way that can be re-used, a ‘value adding waste’ that adds no direct value to the final product but the knowledge acquired may add value to future products. It seems that at Toyota NPD processes need ‘value adding waste’ to enhance value and not restrain creativity, whilst traditional Lean practice is applied in the appropriate transactional processes, bringing balance to the ‘added’ waste. The authors who support the Toyota view have coined the phrase “right on time”, not right first time, as the important measure in the NPD process where time to market is key (Parry, Graves, Moore, 2008).

Nevertheless at the same time they are very waste conscious in the way they communicate design problems that require cross-functional coordination. All engineers must prepare written reports on only one side of A3 paper, which follow a standard format (Sobek et al. 1998), differently from most Western companies where design issues are normally communicated through lengthy reports.

Sobek et al. (1998, 1999) have identified that Toyota maintains a functionally based organization but with impressive integration. Toyota’s managerial practices can be divided into six organizational mechanisms: three primarily social processes (mutual adjustment, close supervision, and integrative leadership); and three forms of standardization (standard skills, standard work processes, and standard designs). The key aspect is that all are in place together, and that knowledge is shared across projects so that all can learn. Another key aspect of Toyota’s success is that they manage product development as a system. The two key elements of the system are the chief engineer (providing essentially the leadership) and the functional engineer (providing the expertise). These are supported and influenced by the three forms of standardization and a strong focus on the customer.

### 2.2 Concurrent Engineering and Lean Product Development

As previously mentioned, Set-Based Concurrent Engineering (as practiced by Toyota) is suggested in the literature as the preferred approach to Lean PD. Set-Based Concurrent
Engineering imposes agreed constraints across different functions to ensure that a final subsystem solution, chosen from a set of alternatives from a particular function will work with convergent solutions from all other functions. During the design process as each alternative is evaluated, trade-offs are made, weaker solutions are eliminated, and new ones are created, often by combining components in new ways. Instead of being designed from the top down, the system configuration ‘evolves’ from creative combinations of multiple solution sets.

Techniques such as Concurrent Engineering (CE) have been implemented and have been quite successful in improving NPD in terms of time, cost, quality, or a combination of these three; key features of concurrency which strongly relate it to NPD are the parallel scheduling of design and development activities and project-oriented organizational structures with strong cross-functional co-ordination (Abetti, 1994; Galbraith and Kazanjian, 1986). But CE is a much broader concept, developed in Western product development environments, which encompass all functions in the product development life cycle, not just engineering (Fleischer and Liker 1997). One of the original and most quoted definitions of CE is that provided by the Institute of Defense Analysis (Winner et al. 1988):

Concurrent Engineering is a systematic approach to the integrated concurrent design of products and their related processes including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life from conception through disposal including quality, cost, schedule and user requirement.

The focus of the definition is on improving integration and collaboration, process compression, and optimization: CE refers to the product and its flow thus including suppliers, marketing personnel, service and support personnel, the activities of design and engineering and of course the customers.

The CE philosophy focused on developing organizational mechanisms to facilitate integration of the different functions that had to come together to develop and introduce a product to market (Haque, 2006). This was achieved through overlapping sequential activities, and early involvement of all enterprise functions that contribute towards a successful product. Integration was achieved at different levels:

- people via multifunctional teams: a cross-functional team should develop the process since NPD is a complex business-wide concern that impacts many functional areas within the organization, and both their input and experience should be useful. The use of cross-functional product development teams should minimize miscommunication and informal communication can be encouraged; teams with different backgrounds could provide a broader knowledge base and allow the project to draw on more information sources, ensuring a wide variety of them. Multifunctional teams should also help in understanding the strengths and weakness of the current NPD process, since the team can critically assess what is and is not working in current approaches.

- processes via formal methods such as Quality Function Deployment (QFD) (Figure 7): QFD or, equally the House of Quality, is a matrix that maps customer requirements against
product attributes. It involves the conversion of the “voice of the customer” into a set of characteristics which the organization can use to assign priorities and make objective trade-off decisions. Generally the requirements are weight in terms of their relative importance from a customer’s perspectives. Once this has done, the team needs to identify the engineering attributes that drive the performance of the product.

Figure 7 – Example of QFD (Schilling, 1996)

- Design for X (DFx): under the label Design for X a wide collection of specific design guidelines are summarized. Each design guideline addresses a particular issue that is caused by, or affects the characteristics of a product. The design guidelines itself propose usually an approach and corresponding methods that may help to generate and apply technical knowledge in order to control, improve, or even to invent particular characteristics of a product; from knowledge-based view, the design guidelines represents an explicit form of knowledge. The main ways in which DFx find expressions are:
  - Design for manufacturability (DFM) is the general engineering art of designing products in such a way that they are easy to manufacture
  - Design for Assembly (DFA) is a process by which products are designed with ease of assembly in mind. If a product contains fewer parts it will take less time to assemble, thereby reducing assembly costs. In addition, if the parts are provided with features which make it easier to grasp, move, orient and insert them, this will also reduce assembly time and assembly costs. The reduction of the number of parts in an assembly has the added benefit of generally reducing the total cost of parts in the assembly.
- systems via technology: rapid advances in computer technology have enabled the development of low priced and high powered graphics-based workstation, by which prototypes can be build and tested in a virtual reality (Computer Aided Design, CAD). It provides the ability to edit parametric and non-parametric geometry without the need to understand or undo the design intent history of the geometry by use of direct
modeling functionality. This ability may also include the additional ability to infer the correct relationships between selected geometry (e.g., tangency, concentricity) which makes the editing process less time and labor intensive. In doing so, cycle time and costs can be reduced by deleting the need for physical model building.

In order to decrease the risk associated with technical mistakes, Cusumano and Nobeoka (1998) extended the concept of CE, suggesting that the competitive advantage achieved through Concurrent Engineering is fading to be replaced by competitive advantage through Concurrent Technology Transfer across projects (Figure 8). Deriving evidence from the automotive sector, they show that Concurrent Technology Transfer (i.e. transferring knowledge between projects whilst the projects are still running) is the most effective strategy for developing fast-to-market projects with the minimum of engineering design hours and maximum corporate sales growth. They suggest that such inter-project sharing can lead to considerable advantage by mutual adjusting between projects teams, sharing tasks and sharing resources for larger technical problems or designs; the role of project managers is particularly important in ensuring that CTT occurred effectively.

![Figure 8 – Concurrent Technology Transfer (Cusumano and Nobeoka, 1998)](image)

Vaugh et al (2002) give emphasis on the collaboration between all the function involved in NPD process; particularly they refer to the relationship between marketing, manufacturing and product design which should lead to an understanding of the true customer needs and technical feasibility of those needs. They expand the definition of CE into a wider one, Concurrent Product Design, Manufacturing, Supplier and Marketing Activities, in order to try to be aligned to the Product Strategy.
Figure 9 – Product Strategy (Vaugh, 2002)

Although CE and the following techniques which derive from it contribute very much towards a leaner process and product, the focus is on improving integration and collaboration, process compression, and optimization. According to Haque (2008), the concept of CE clearly states ‘what’ to do, and ‘why’ in terms of quality, cost, and delivery, but not ‘how’ and in ‘what’ context (i.e. value identification was not explicitly promoted).

The paradigm pays less attention to identifying ‘value’ and eliminating ‘waste’, two of the main constituents of lean. Lean, on the other hand, is a wider rather high-level philosophy, focused on waste elimination and flow of value. As customer value had not been identified CE did not enable benefits to be obtained from the viewpoint of product effectiveness, nor as internal value had not been defined were any benefits obtained in improving process effectiveness. Regarding wastes, CE does eliminate the waste caused by a sequential operation but there are many other wastes within the system that need identifying and eradicating in a systematic manner. So there are still process efficiency issues that have not been fully addressed. Table 3 attempts to clarify the differences between the two paradigms.

The Lean concept does not provide the details needed to improve NPI (i.e. it lacks depth found in CE); instead, it provides a high-level contextualized (in terms of value) approach to process improvement. According to Haque (2008), both approaches are complementary; CE, even if really improved NPD process and provided some of the necessary tools, has some shortfalls which could be overcome by the application of the lean principles to NPD.
Table 3 - The Differences between CE and Lean Philosophy (Haque, 2008)

<table>
<thead>
<tr>
<th>CE philosophy</th>
<th>Lean Philosophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacks an enterprise wide common strategic direction or statement for implementation. It is naturally geared towards improving the NPD process and thus promotes specialized tools such as the Design for x tools etc.</td>
<td>Lean is by definition an enterprise initiative with a common format for all business processes with the single strategic goal of eliminating waste and improving the flow of value</td>
</tr>
<tr>
<td>Lacks a life-cycle approach; that is, does not answer the question: where do I start and how do I sustain the movement? The focus is on the what to do and not the how to</td>
<td>Provides a lifecycle approach with both the what and how to, starting and ending with the customer with a continuous drive for waste elimination</td>
</tr>
<tr>
<td>Liable to different interpretations and definitions</td>
<td>Value and Waste as main factors</td>
</tr>
<tr>
<td>Does not classify and contextualize waste. Waste elimination is a by-product of CE activities</td>
<td>Wastes identified, classified and contextualized within given value stream</td>
</tr>
<tr>
<td>Promotes customer focus and improvement of information flow but does not explicitly define a systematic approach</td>
<td>Explicitly promotes creation of value stream maps based on customer demands</td>
</tr>
<tr>
<td>It promotes overlapping of activities and hence the flow of partial information based on downstream process needs.</td>
<td>Promotes the concepts of takt time, single piece flow</td>
</tr>
</tbody>
</table>

2.3  Lean New Product Development: state of the art

Most of the literature about the application of Lean to New Product Development starts with the comparison between manufacturing process and New Product Development process, analysing both analogies and contrast.

Huovila et al. (1997) proposes a conceptual framework for translating the design process into a manufacturing one; three different views of this process are considered:

1. design as a conversion of inputs to outputs;
2. design as a flow of information;
3. design as a value generation process for the clients.

Huovila concludes that what is needed is a management philosophy and tools that fully integrate the conversion, flow, and value views (Table 4).
LeanPPD Game
José Luis Almenara Ariza
Cristina Castaño Fuentes

<table>
<thead>
<tr>
<th></th>
<th>Conversion</th>
<th>Flow</th>
<th>Value Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conceptualization of engineering</strong></td>
<td>As a conversion of requirements into product design</td>
<td>As a flow of information composed of conversion, inspection, moving and waiting</td>
<td>As a process where value for the customer is created through fulfilment of his requirements</td>
</tr>
<tr>
<td><strong>Main principles</strong></td>
<td>Hierarchical decomposition, control and optimization of decomposed activities</td>
<td>Elimination of waste, time reduction</td>
<td>Elimination of value loss, (achieved value in relation to the best possible value)</td>
</tr>
<tr>
<td><strong>Practical contribution</strong></td>
<td>Taking care of what has to be done</td>
<td>Taking care that what is unnecessary is done as little as possible</td>
<td>Taking care that customer requirements are met in the best possible manner</td>
</tr>
<tr>
<td><strong>View</strong></td>
<td>Task management</td>
<td>Flow management</td>
<td>Value management</td>
</tr>
</tbody>
</table>

Table 4 - Comparison of Conversion, Flow, and Value Generation Views (Ballard and Koske, 1998)

Javier and Alarcon (2002) focus on the last two perspectives previously mentioned and illustrate the relationship existing between them. The process of product development can be conceptualized as a flow of information; the principle of waste elimination translated into the design process lends to waste reduction through minimizing the amount of time before information is used. Value generation arises from capturing the customer’s requirements and transmitting these accurately in the overall design process. Haque (2003) suggests a further refinement of this comparison, underlying the analogy between the role of information in the product development value stream and material in manufacturing. This explains his recommendation that engineers should focus on the identification and enhancement of value.

Liker (2006) considers that lean manufacturing can be described as a set of tools (e.g. kanban) that eliminates waste and creates flow of materials through a transformation process; lean product development can be easily described in the same way. Moreover, moving on another layer, both lean manufacturing and lean product development are based on the importance of appropriately integrating people, processes, tools and technology to add value to the customer.

Besides these analogies through which the application of Lean principles to New Product Development is possible, Mc Manus (2005) points out that product development processes differ in fundamental ways from factory processes. Most of the differences are driven by the fundamental uncertainty of product development processes: at the beginning of the process, the
exact content of the output is not known. This is in stark contrast to factory operations, where
the ideal is to make a part precisely the same as the last one.

The product development process is also acting upon information more than physical material
(the ultimate output is the specification of a product rather than the product itself). Finally, most
product development processes are acting on a mix of jobs, of greater or lesser difficulty or
complication. This is not a fundamental difference; it is analogous to a factory working on
mixed-model production.

Referring to the Table 5 (Oppenheim, 2004), manufacturing deals principally with real matter
rather than with ideas and so it is more suitable for applying a repeating serial process as the
production one.

The differences are substantial as manufacturing is a repetitive, sequential, bounded activity that
produces physical objects whereas NPD is a non-repetitive, non-sequential, unbounded activity
that produces information. Risk-taking and ‘good variability’ are important for adding value in
NPI and unlike manufacturing a NPD process doesn’t add value if it does exactly the same thing
twice. While in manufacturing cycle time is measured in days or weeks, in New Product
Development cycle time is measured in months or years; moreover the part flow is generally
more defined and stable than the information flow because of the nature of the design process.
In fact it involves thousands of decisions sometimes over a period of years, with numerous
interdependencies and under a highly uncertain environment, and a large number of participants
are involved. According to Oppenheim (2004) these differences complicate the application of
lean philosophy but can be easily overcome.

<table>
<thead>
<tr>
<th></th>
<th>Manufacturing</th>
<th>Product Development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focus</strong></td>
<td>Costs</td>
<td>Timelines</td>
</tr>
<tr>
<td><strong>Type of process</strong></td>
<td>Repetitive, linear, stable</td>
<td>Uncertainty</td>
</tr>
<tr>
<td><strong>Type of waste</strong></td>
<td>Time and material</td>
<td>Time and opportunity</td>
</tr>
<tr>
<td><strong>Raw material</strong></td>
<td>Supplied material</td>
<td>Knowledge and experience</td>
</tr>
<tr>
<td><strong>Inventory</strong></td>
<td>WIP buffers, Finished goods</td>
<td>All released 3D models and text</td>
</tr>
<tr>
<td><strong>Time measure</strong></td>
<td>Days/weeks</td>
<td>Months/years</td>
</tr>
</tbody>
</table>

Table 5 - Differences between Production and Product Development (Oppenheim, 2004)

Extending lean manufacture concepts across the enterprise, the concept of Lean product
development was first introduced in The Machine That Changed the World (Womack et al.
1990). Although the focus of the book was still on manufacturing and assembly processes, Womack discussed Lean product development in terms of a number of techniques previously known. Womack refers principally to the presence of a strong project leader with total control over functional resources, since the allocation of human and capital resources to the development effort can be facilitated. The presence of a project leader can also stimulate communication and cooperation between the different functional groups involved in the development process. The author suggests also that cross-functional teams should be created because product development is a complex business-wide concern that impacts many functional areas within the organization; in so doing early and controlled communication is made more easily, and simultaneous development can be introduced.

Smith and Reinertsen (1991) identified the application of just-in-time (JIT) manufacturing philosophy in the NPD process. In fact, JIT is the manufacturing analogy of the kind of improvement that the NPD process is trying to achieve: the pull concept of JIT can be related to the use of partial information in NPD. In a manufacturing pull system, the downstream process calls for the parts when they are ready for them. Similarly, in NPD, they state that if the information is pulled it will go faster to the entity requiring it and will be done in the form of small batches, this will also be more applicable and more recipient oriented, and will compress the whole development cycle. From day 1 each department should have the responsibility of identifying what information they need and asking for it. The ‘pull’ approach is established in a development team by making it clear that it is the responsibility of the downstream person to ask for whatever information they need. By making this the standard operating procedure, the downstream tasks will naturally get started sooner, compressing the whole development cycle.

Karlsson and Ahlstrom (1996), based on their observations of a company over a 2.5-year period, conceptualized lean product development as composed by the following elements:

- cross-functional teams: teams consisting of members from different functional areas in the company to integrate all functional aspects in the product already from the beginning;
- simultaneous engineering: with this term they mean overlapping of activities or processes. Different activities in the development effort are performed in parallel;
- a focus on integration of activities instead of co-ordination: the team is integrated as a result of the physical proximity that arises when individuals are working together in developing a new product;
- strategic management: visions and objectives instead of detailed specifications, including commitment to the project;

Karlsson and Ahlstrom emphasize that a company does not achieve lean product development simply by implementing some of these techniques. They state that a successful move towards lean product development requires approaching these interrelated techniques as elements of a coherent whole. They make also a consideration comparing product development to lean manufacturing: if removing buffers can reveal hidden problems and help-provoke solution in
manufacturing, with lean NPD buffers, in terms of time left to deadline, should be removed so that heavy pressure is put on the project and the results improve. Despite covering a number of practices conducive to lean, Karlsson and Ahlstrom had not explicitly looked at identification of ‘value’ in neither product development, nor the application of the seven Toyota Production System wastes to product development. They also had not considered the application of value stream mapping (Hines and Rich 1997, Rother and Shook 1998) to product development processes.

The subject of buffers in lean NPD has also been discussed by Goldratt (1997). Goldratt states that the critical task must be protected by putting just enough buffers before it and only one contingency buffer must be made, calculated to protect the whole project. Among the three outputs of NPD, quality, cost and time, Goldratt believes that time is the most critical. He identified the root cause of the delays in time-to-market. First, it is a common belief that the only way to protect the whole project is by protecting the completion date of each step. Second, a margin of safety is put into the estimations of each step mainly because the time estimates are based on pessimistic experience and, the larger the number of management levels involved, the higher the total estimation because each level adds its own margin.

Reinertsen (1997) initially presented an application of manufacturing principles in NPD with an emphasis on tools, rather than rules. He gives details on batch size, capacity utilization, queue and information theory. In 2005, Reinertsen published an article covering issues similar to those discussed in the previous work, this time utilising the term Lean (Reinertsen and Shaeffer, 2005). For managing NPD, Reinertsen (1997) suggests a number of steps which have been already discussed by Womack (1990, 1996) in the lean manufacturing perspective.

Reinertsen also introduced the term DIP [design-in-process] inventory. He explains that it’s not uncommon to find phased development systems where 100 per cent of work is transferred to the next phase on a single day. Until that day, the work done is waiting, like physical inventory waits in a warehouse. Like the level of WIP the level of DIP is a sign of the health of the NPD process. In fact, Reinertsen argues that DIP-costs are much larger than WIP-costs. Reinertsen proposes modularity, and the decision to make the product modular or not is complex, and it interacts with organisational structure and NPD process design.

Mikulina (1998) identified that the key elements of ‘demand flow manufacturing’ can be applied to the NPD in the area of ‘relationship with suppliers’. Vendors that become supplier partners are responsible for the management of component supply, and supply them ‘on demand’. When this happens, information flows freely across the two companies. This information is related to the characteristics, specifications, costs and quality level of the parts to be supplied. Therefore, the final decision of where to buy the components from will not be made just according to the price, but to the total cost, including impact on production, operating cost, quality, delivery and inspection.

The fact that the inspection is now done by the supplier, and no longer by the manufacturer can be applied also when talking about internal suppliers (i.e. the internal functions of a company
that contribute to NPD by providing mainly information or knowledge). Mikulina (1998) also states that each of the participants on the NPD process should work only when and on what is needed, or in other words ‘in demand’, so re-work and time can be saved. He also says that the NPD process can be such that there is no need to ‘send a purchase order’ to ask for the services of the supplier because the communication with the supplier is so direct that there is no need of it. This approach can be applied to both internal and external customers. According to the Product Development Institute (1999) a good balance of the work-load in the NPD process facilitates the flow of value. If there are not enough projects, highly paid engineers and developers will be waiting for activities to do. Therefore the marketing process has to be able to generate far more project ideas than the development process can realize. However, it is necessary to count on an effective flow control mechanism to avoid a level of multi-tasking that affects the termination of the products in the time required.

According to Howell and Ballard (1998), flow in manufacturing is regulated by the routing of intermediate products through a sequence of machining operations or assembly steps. In NPD the routings are organized through planning and control systems, with little reliance on the physical layout of work stations or the sequence and timing control of assembly lines, so the formulation of the assignments is vital.

Establishing common platforms via modular designs, and late point differentiation enabling mass customization, has been proposed by a number of researchers (Lean Enterprise Resource Centre 2000, Cloke 2000) as being conducive to Lean. This means to develop families of products based on certain product platforms and then differentiate the products as late as possible in the NPD process. The design must allow future 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. It is also helpful to include elements already commercially available or easy to be outsourced. This strategy can be used to simplify the NPD process and therefore to facilitate the flow of ‘value’; it is popular mainly in the automobile and electronics industries but can be applied in other industries as well. Modular designs that maximize re-use of standard parts and flexible manufacturing systems and technologies support the implementation of Lean in the NPD process.

To facilitate the flow and pull approach, several information system tools have been developed and are used in organizations. Information systems can play a key role in supporting lean New Product Development and coordination is achieved through a global database with appropriate control mechanisms to access information in such a database. Schilling (1998) considers that rapid advances in computer technologies have enabled the development of low priced and high powered graphics-based workstations, adding the possibility to build and test prototypes manipulating a 3D model.

Several of the studies previously mentioned suggest that Lean product development should not be confused with its techniques (Karlsson and Ahlstrom, 1996; Reinertsen, 1997; Reinertsen and Shaeffer, 2005). Thus, implementing one or a few of the techniques contained in the total
concept is not sufficient for achieving Lean product development. However, since some of the techniques included in Lean product development have been known before the invention of the concept, confusion concerning definitions is likely to arise.

The Lean Aerospace Initiative reaches a consensus on what Lean means in the product development context. The term used for these efforts by most industry members is Lean Engineering and it represents three very different areas of process improvement. They are:

- creating the right products: creating product architectures, families, and designs that increase value for all enterprise stakeholders;
- effective lifecycle and enterprise integration: using lean engineering to create value throughout the product lifecycle and the enterprise;
- efficient engineering processes: applying lean thinking to eliminate wastes and improve cycle time and quality in engineering.

Liker (2006) describes Lean Product Development as an asset that can be created, implemented and improved in any company; it refers to people, process and technology and its application requires an integrated effort among sales, marketing, design, purchasing, engineering, manufacturing and supplier.

Murman (2008) describes lean engineering as framework that needs to be tailored to fit the activities involved in the NPD process and addresses several different engineering applications. The possible lean engineering approaches are shown in the Table 6.

Freire (2009) focuses on lean design, which he defines as the application of lean production principles, which promote the elimination of waste and non–value adding activities in processes, to engineering and design, in order to reduce costs and time of these two activities.

<table>
<thead>
<tr>
<th>Program Type</th>
<th>Possible Lean Engineering Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance R&amp;D</td>
<td>Small focused co-located team; useful tools for the application are rapid design, risk reduction, lifecycle experience</td>
</tr>
<tr>
<td>New Product Development</td>
<td>Direct involvement of customer throughout design; strong focus on lifecycle value and lessons learned from past programs</td>
</tr>
<tr>
<td>Engineering Testing and Support</td>
<td>More standardized tasks and continuous improvement through Value Stream Mapping and Analysis</td>
</tr>
</tbody>
</table>

Table 6 - Definition of Lean Engineering (Murman, 2008)
M. Lind, Aras Corporation and PDMA (2008) state that there are numerous perspectives on exactly what lean in product development and engineering constitutes. Fundamentally they identify three different approaches:

- lean engineering, focused on the application of Lean principles to engineering; value flow, pull, standardized work, takt time, and other lean principles through common lean techniques and tools used in operations;
- lean design, which is the equivalent of set-based concurrent engineering;
- lean development, which refers to the relationship existing between NPD process and the lean manufacturing environment and lean supply chain requirements.

The latest direction of literature research focuses principally on the concept of value and waste, and clearly refers to the application of the principles prescribed by Womack and Jones (1990) to NPD process. As already mentioned in the section below, the principle are briefly “specific value”, “identify the value stream and eliminate waste”, “make the value flow”, “let the customer pull the process”, and “pursue perfection” e they will be better explained in the next section. The Table 7 summarizes the key elements that emerge from the literature review and the relationship with Womack and Jones’ principles.

2.3.1 Lean principles applied to the New Product Development process

McManus (2002) first tries to apply some Lean techniques to New Product Development, and summarizes the results he has obtained. He notes that using lean tools such as changes in knowledge management and process changes enabled by the application of 3D solid geometry, the integration of the engineering process into the product lifecycle has had dramatic results. Figure 10 illustrates the impact of lean engineering on labour and cycle time for development of four generations of comparable forward fuselage configurations. Results show a reduction of approximately 50% in cycle time and 80% in maximum staffing levels. Figure 11 shows the effects of the same tools on the manufacturing labour as a function of unit number, again for forward fuselages. Two comparable products are shown; one developed using the lean tools, and one without. The manufacturing labour content is show as a function of the unit number. The lean techniques not only reduce the stable work content by 48%, they also have a dramatic effect on the learning curve. The virtual experience gained using manufacturing simulation was the equivalent of 9 units of actual production.

1 Aras Corporation is the Microsoft enterprise open source software solution provider for companies; it is specialized in solutions that supplies key strategies to implement lean development and the synergies with advanced product quality planning.

2 The results showed in this paragraph comes from applications on aerospace industry, in collaboration with LAI. They are summarized in McManus (2005).
### Table 7 - Key Elements of NPD Derived From the Literature

<table>
<thead>
<tr>
<th>Characteristic, techniques or tool</th>
<th>Associated Lean Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE and partial information; downstream departmental responsibility for requesting information</td>
<td>Pull and waste elimination</td>
</tr>
<tr>
<td>Strong supplier involvement in developing modules</td>
<td>Waste elimination, flow and pull</td>
</tr>
<tr>
<td>Focus on integration rather than coordination</td>
<td>Value stream identification and waste elimination</td>
</tr>
<tr>
<td>Set based Concurrent Engineering</td>
<td>Value creation</td>
</tr>
<tr>
<td>Strategic management: visions and objectives</td>
<td>Value stream identification and waste elimination</td>
</tr>
<tr>
<td>Common platform and modular design</td>
<td>Flow</td>
</tr>
<tr>
<td>Leadership and cross-functional teams</td>
<td>Flow and pull</td>
</tr>
<tr>
<td>Standard operating procedures, standard skills</td>
<td>Waste elimination, flow and pull</td>
</tr>
</tbody>
</table>

**Figure 10 – Lean Integration Tools on Aircraft Structure Development (McManus, 2005)**
McManus also clearly analyses a drawing release process, characterized by very long, and extremely variable, cycle times. He notes that by using lean techniques such as work cells and single piece flow, average cycle time was drastically reduced. More importantly was the variation in cycle time: with a short, predictable cycle time, the release of drawings could be scheduled with confidence, enabling the application of lean to other processes dependent on the drawings. As an additional benefit, it was found that the standardized process also drastically reduced drawing errors, without any additional work or inspection (Figure 12).
Starting from these considerations, McManus considers Womack and Jones’ 5 steps to Lean (previously mentioned) applied to NPD process (Table 8):

- precisely specify value by specific product;
- identify the value stream for each product;
- make value flow without interruptions;
- let the customer pull value from the producer;
- pursue perfection.

<table>
<thead>
<tr>
<th></th>
<th>Manufacturing</th>
<th>Product Development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Value</strong></td>
<td>Visible at each step, defined goal Harder to see, emergent goals</td>
<td>Harder to see, emergent goals</td>
</tr>
<tr>
<td><strong>Value Stream</strong></td>
<td>Parts and material Information and knowledge</td>
<td>Information and knowledge</td>
</tr>
<tr>
<td><strong>Flow</strong></td>
<td>Iterations are waste Planned iterations must be efficient</td>
<td>Planned iterations must be efficient</td>
</tr>
<tr>
<td><strong>Pull</strong></td>
<td>Driven by takt time Driven by needs of enterprise</td>
<td>Driven by needs of enterprise</td>
</tr>
<tr>
<td><strong>Perfection</strong></td>
<td>Process repeatable without errors</td>
<td>Process enables enterprise improvement</td>
</tr>
</tbody>
</table>

Table 8 - Womack and Jones’ Five Lean Principles Translation (McManus, 2005)

Value, especially as the process is underway, is harder to see, and the definition of value-added is more complex. The value stream consists of information and knowledge, not the easy-to-track material flows of the factory. As used in Rother and Shook (1999) the term “information flow” refers to both the flow of control information backing up the stream, and to management or schedule information imposed externally. Figure 13 shows the use of this terminology.
In product development, all the flows are essentially information flows, so it would be better distinguishing the different types. In Figure 13, the design package or other “product” information flows in the direction of the value stream; feedback, iterations, and perhaps control information flows “upstream,” and management information is exchanged with the process.

The “pull” to which the system should respond is also rarely a simple customer demand that can be used to calculate a takt time; the demand arises from both external customers (the end customer) and internal customers, who ask for what they need when they need (McManus compares this concept to a metronome-like beat that paces the process; at each beat a product is created). Product development operations are usually intermediate steps in an overall enterprise effort to create value. Finally, perfection is even harder to reach, as simply doing the process very fast and perfectly with minimal resource used is not the final goal; efficient product development process is simply an enabler of better enterprise performance and better products.

Haque and Moore (2004) give further refinements of the definition and characteristics of a Lean product development system based on Womack and Jones’ 5 principles.

- Value: they started from the definition of specifying value from the perspective of the ultimate customer as well as the internal and external stakeholders in terms of specific products, information, and services with specific capabilities or applications offered at a specific price or cost and time.
- Identify the value stream and eliminate waste: an ideal NPD system should be able to satisfy what Haque and Moore call the ‘specific value’ principles; these principles are listed here below:
  - the NPD process requires some activities to identify the right customer, market, product and margins;
  - the customer needs should be identified in terms of performance (results), quality, price, timing, desirability, and options;
  - the right information should be delivered at the right time, and at targeted cost to downstream processes/customers, where it can be quantified by form, fit, function;
o the right product should be delivered at the right time, and at the right price to the customer;
o a NPD organization should have people adequately trained, equipped and motivated; this can be achieved adopting an optimized range of standard tools that will be deployed by an integrated team for problem-solving, risk mitigation, supply chain capability, etc.

- Make the value flow: as already mentioned, the key product of NPD activities is information. To implement the principle of ‘flow’ in NPD, an organization should be able to control information flow. The aim should be to reduce delay, to encourage process information in parallel wherever possible, to continuously add information value as activities progress from one to the next, and eliminate non-value added information. To satisfy the “flow of value” principle, process and organization structure should focus on improving integration of NPD functions as opposed to just co-ordination; in this way, effective communication and data flow of multifunctional information are made easier. The allocation of resources to the projects should be effective and made by a responsive system for program planning and control.

- Let the customer pull: according to Haque and Moore (2004), these principles can be achieved by producing a program plan in which activities, their workload and objectives are based on the needs of the downstream activities. The key issue is the effective control of the rate of information production based on downstream or ‘customer’ needs, so that information could be available and accessible as and when desired. To achieve this, the program plan (including resource plan, communication plan, work breakdown structures, and organization breakdown structure) should be managed by a strong leader and developed with the involvement of all the teams that are critical to the milestones achievement. In so doing, upstream activities should produce and decide only that information that is requested by downstream.

- Pursue perfection (continuously improve): continuous improvement can be achieved by continually identifying ways to increase value provision, reduce the costs of non-value adding but necessary activities, and remove successive layers of waste, as they are uncovered in existing activities. The key issue is the ability to continuously identify and eliminate waste through a visible quantitative measurement system. Having the right benchmarks in place based upon a thorough analysis of the needs and capability, both present and desired, of the organization and its systems is required. Useful actions to undertake the direction of continuous improvement can be:
  1. the continuous review of the implementation of all lean principles;
  2. the consideration of both radical change and incremental change;
  3. the improvements must be sustainable in order to be embedded into the day-to-day routines.
All the listed principles include some common factors in the achievement of their purpose: the presence of a project manager and team working, an accurate management of the flow of information and the use of technology as an enabler.

Liker (2006) looks for further refinement following this direction; though sharing Haque and Moore’s principles, he suggests that even though value, waste and their identification are the core of a lean NPD system, there are multiple interdependent parts that interact to create a whole and cannot be fully understood by looking at individual parts. What is more, what makes lean product development truly powerful is the whole system of mutually supportive tools, processes and human system working in harmony. Only by studying people and equipment working together it is possible to see how the whole functions. In this way, it is possible to consider also dynamics, because the system changes over time in response to changes in the environment concerning the interaction between what is inside the organization and the outside environment.

Liker suggests that a Lean Product Development System (LPDS) has three primary subsystems: process, people, tools and technology, which should be interrelated and interdependent and affect an organization’s ability to achieve its internal purpose.

5. Develop a Chief Engineer System to Integrate Development from Start to Finish.
7. Develop Towering Technical Competence in all Engineers.
8. Fully Integrate Suppliers into the Product Development System.
9. Build in Learning and Continuous Improvement.
10. Build a Culture to Support Excellence and Relentless Improvement.
11. Adapt Technology to Fit your People and Process.

1. Establish Customer-Defined Value to Separate Value-Added from Waste.
2. Front-Load the PD Process to Explore Thoroughly Alternative Solutions while there is Maximum Design Space
3. Create a Leveled Product Development Process Flow
4. Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes.

Figure 14 – Liker’s 13 Principles in NPD (Liker, 2006)
The first subsystem Liker analyses is Processes, which comprises all the tasks and the sequence of tasks required to bring a product from concept to start of production. It is a value stream map from raw materials (customer need, past product characteristics, competitive product data, engineering principles) to finished goods. The most of the attention should be put on the day-by-day activities by which information flows, design evolves, tests are completed, prototypes built and finally a finished product emerges. The principles belonging to this class are the following ones:

1. Establish customer defined Value to separate Value Activity from Waste. The customer is always the starting point in a lean system, so defining waste starts with defining what a customer (both internal and external one) values. Simply put any activity that takes time and money but does not add value from the customer’s perspective is waste. Liker (2006) notes that in product development there are two broad categories of waste:
   - Waste created by poor engineering that result in low levels of products or process performance. The best antidote to this category of waste is a deep and concrete knowledge of how to create customer-defined value at each level of the organization (a hierarchy of value).
   - Waste in the product development itself. Product Development VSM can contribute to eliminate these wastes.

2. Front load the Product Development process to explore thoroughly alternative solutions while there is maximum design space. The greatest opportunity to explore alternatives is early in the product development program. It can be useful using integrated cross-functional engineering resources challenges while the maximum possible options are still available; the aim is to keep the “design space” as open as long as possible before making critical decisions to address uncertainty.

3. Create a levelled product development process flow. Once value has been defined, lean product development requires a waste-free process to speed the product to market. Rework should be reduced to a minimum and activities synchronized across functional department.

4. Utilize rigorous standardization to reduce variation and create flexibility and predictable outcomes. The aim of this principle is to reduce variation in product development while preserving creativity (for example, Toyota creates higher level flexibility by standardizing lower-level tasks). Liker (2006) reminds that there are three broad categories of standardization at Toyota:
   - Design standardization: common architecture, modularity and reusable or shared components;
   - Process standardization in order to reduce variability found in having many non-standard low levels tasks;
   - Engineering skill set standardization to make easier knowledge modelling and knowledge representation.
The following six principles belong to the People Subsystem. It covers recruiting, selecting and training engineers, organizational structure and learning patterns; considering the degree to which an organization truly shares these things across its membership and with the partners, this subsystem could be considered a measure of the strength of the culture of lean thinking.

5. Develop a chief engineer system to integrate development from start to finish. In many companies there are so many functional departments responsible for different pieces of product development that nobody is responsible. Try to identify exactly what the status of the project is or when decisions are made could be very difficult. Liker (2006) points out that the solution to this problem is a chief engineer: not just a project manager who is able to manage only people and time, but also a leader and technical system integrator.

6. Organize to balance functional expertise and cross functional integration. One of the more difficult tasks in developing a high-performance product development system is striking a balance between functional excellences within specific disciplines while achieving the seamless integration of those experts across departments.

7. Develop towering technical competence in all engineers. Technical excellence in engineering and design resources is fundamental to lean product development.

8. Fully integrate suppliers into the product development system. Company should manage and nurture their supplier in the same way they manage engineering resources and internal manufacturing; suppliers should be valued for both their technical expertise and their parts-making capabilities. Pre-sourcing arrangements get them on board from the start so that they are involved in the earliest stages in concept development of a product.

9. Build in learning and continuous improvement. The ability to learn and improve may well be the most sustainable competitive advantage of an organization. Toyota is a leader in gathering, diffusing and applying performance-enhancing information.

10. Build a culture to support excellence and relentless improvement. Toyota’s culture supports excellence with explicitly defined values and an adherence to core beliefs by leader and team members. All of the other principles work because the culture itself makes the principles a living part of how Toyota gets things done.

The third subsystem considers Tools and Technologies in order to bring a product into being. This subsystem includes not only CAD systems, machine technology, digital manufacturing but also soft tools that support the effort of people involved in the development project, whether it is for problem solving, learning or standardizing best practices.

11. Adapt technology to fit people and process. Many companies try to achieve high levels of performance in product development by using technology; the correct approach to adopt a new technology is to consider how this technology will impact current processes or people. Toyota recognizes that technology seldom represent a meaningful competitive advantage, partly because it can be replicated elsewhere. It is much more
important to take the time and effort to make sure that the technology fits and enhanced already disciplined processes and highly skilled and organized people. In an effective product development system, people and process subsystems come first; technological accelerators that leverage opportunities follow.

12. Align organization through simple visual communication. Toyota uses very simple, visual methods for communicating information, often limiting it to one side of one sheet of paper; this report has four variations for proposals, problem solving, status updates and competitive analysis.

13. Use powerful tools for standardization and organizational learning. A well-known principle of kaizen is that it is not possible to have continuous improvement without standardization. Toyota has created some powerful tools that standardize learning from program to program; this occurs at a macro level of learning (how a design process is shared among program managers) and at a detailed technical component level, captured in engineering checklists.

A number of activities, tools and techniques that are conducive to lean New Product Development have been put forward in this paragraph. The analysis of the application of lean to NPD has identified that while Womack and Jones’s five principles are all relevant and applicable to NPD, a certain degree of tailoring is required. Considering the nature of the process of New Product Development, value can be achieved by increasing innovation and risk mitigation and that demands abundance of information.

Toyota has demonstrated this through their application of set-based CE, which involves expensive, multiple prototyping on systems that require cross-functional development. Strategies geared towards ‘abundance of information’ seem to give competitive advantage in the long run, both from the perspective of innovation in design and velocity (the correct speed in the correct direction) in NPD (Haque and Moore, 2004). Information technology should play a strong role in achieving flow and pull, but not before the correct process, data, and human resource infrastructure are in place.

Concluding, Haque and Moore’s five principles require process, people and technology (Liker’s subsystem) working as a coherent whole to be applied; Liker’s thirteen principles are a series of step which should all be implemented to identify waste and enhance value, as specified in Haque and Moore. For these reason, these two kinds of principles are consequent and complementary: Liker points out in detail what should be done in order to make the value flow, let the customer pull and pursue perfection.

These Lean complementary principles and the knowledge acquired from the literature analysis of Lean in NPD process contribute at the definition of requirements of the model which is proposed in Chapter 4.
Chapter 3

State of art of serious Games
3 State of art of serious games

This Chapter presents the state of the art of serious games in the context of the e-Learning environment including the models, the processes and the pedagogical methodologies.

It starts with a definition of e-Learning and progresses with its evolution along time. The terminology used in the e-Learning context is confused as well as the usage being made of current technologies and methodologies.

The chapter continues describing the role of the trainer- the one that develops the contents of e-Learning. This is followed by an overview of the Kolb learning model which is also confronted with alternative learning models.

A clear comparison is made for the traditional e-Learning and Serious Games approaches which are still quite often confused.

This chapter ends with a detailed analysis of serious games and the positioning of the LeanPPD Game between them.

3.1 E-Learning concept

Combining the new technologies with play, the e-learning concept is given. By e-learning it understood the virtual education using ICT. E-learning comprises all form of electronically supported learning and teaching

(Wikipedia definition)

E-Learning is the employment of technology to aid and enhance learning. It can be as simple as High School students watching a video documentary during a class or as complex as an entire university course provided online. e-Learning began decades ago with the introduction of televisions and over-head projectors in classrooms and has advanced to include interactive computer programmes, 3D simulations, video and telephone conferencing and real-time online discussion groups comprised of students from all over the world. As technology advances, so does e-learning, making the possibilities endless (Dewath 2004).

The methods of e-Learning can be further be classified into (Figure 15)

- Serious Games, which corresponds to digital games to support learning in a particular domain
- Distance Learning, Virtual Learning, Tele Learning, which includes e.g. correspondence courses and Sat-TV courses.
- Online Learning, which employs network based online resources (e.g. video communications) resulting in Tele Teaching, Tele Tutoring and Virtual Collaboration.
- Web-based Training (WBT)
- Computer-based Training (CBT)
• Blended Learning is the combination of traditional learning methods with e-Learning. Face to face and group tuition is still considered extremely important

![Diagram of E-Learning methods]

**Figure 15 – Methods of E-Learning (Back et al, 2001)**

Educational Games can roughly be divided into computer based and traditional educational games. The computer based educational games can be seen as part of CBT and/or WBT depending on whether they make use of the web or not. This kind of view puts the view of using ICT to deliver the game, but there are also non computer based educational games on the market, which – per definition – do not belong to the e-Learning sector. Sometimes educational games are also called edutainment (this artificial word combines the terms education and entertainment). The main principle behind edutainment is the mediation of knowledge combining it with entertainment.

### 3.1.1 The context of e-learning

The economic, social and technological dynamics associated with the transition to the knowledge-driven economy continue to change the global economy, and established practices in organizations and the world. The knowledge within an organization is clearly evident in the products or/and services that are offered to the market. As depicted in Figure 16, knowledge drives innovation, but human capital is an essential resource that requires lifelong learning.
The essence of the “core competence” argument is that an organization needs to invest in their knowledge resources. As a result, there is a growing need for continuous education and training. The movement to lifelong learning and the changing demographic balances in most advanced economies mean that the demand for higher education, especially professionally related course and non-traditional delivery modes, is increasing. However, while demand is growing, the capacity of the public sector to satisfy the demand is being challenged. This is due to budget limitations, the changing role of government, and increased emphasis on market economy and privatization.

At the same time, innovations in ICT are providing alternative and virtual ways to facilitate learning. New types of providers such as corporate universities, for profit educational specialist institutions, consultancy firms, and media companies are emerging. This scenario is changing further by providers – public and private, new and traditional – delivering education services across national borders to meet training and education needs in other countries. (Knight, 2002).

### 3.1.2 The strategic importance of e-learning

The transformations associated with the transition to the knowledge-driven economy have increased the strategic importance of the intangible assets of organisations, especially their organisational learning capabilities. In this context e-learning has emerged as a strategic issue for organisations because of its potential to enhance their learning abilities.

The increase in complexity and velocity of the work environment brought about by technological and economic changes are also major forces that have fuelled the demand for e-
learning. The shift from the industrial to the knowledge-driven era, rapid technological change, the ever shortening product developmental cycles, lack of skilled personnel, enterprise resource planning, the migration towards value chain integration and the extended enterprise are also prominent drivers of e-learning (Mcrea, Gay and Bacon, 2000).

The trends discussed above have given rise to several business issues that need to be addressed if companies are to retain their competitive edge. Research indicates that ICT-enhanced and supported business strategies must be anchored on the following forces: First, the redefinition of value must be addressed because wealth creation, communication, commerce and distribution converge on common digital, networked platforms. Industry boundaries blur, causing providers to rethink the composition of value creation processes. Second, digital knowledge economics must be understood well because hoarding knowledge is proving to be counterproductive. In the digital economy knowledge must be shared. Third, information technology is driving change everywhere. Thus, every executive, in every industry, must embrace the pace and dynamics ICT. Fourth, jobs, business processes, companies, and even entire industries face elimination or digital transformation. Lastly, the digital implosion drives disaggregation and specialisation, undermining the economic rationality of the vertically or horizontally integrated firm. Digital knowledge reduces the time and financial costs of information and coordination. It is now economically feasible for large and diverse sets of people to have the information they need to make decisions in near real time. Thus, companies can increase wealth by adding knowledge value to a product through innovation, enhancement, cost reduction, or customisation at each step in its life cycle (Ticoll, Lowy and Kalakota, 1998, Castells, 2001, Drucker, 2001).

The business forces discussed above have set the stage for the ascendance of e-learning to an issue of strategic importance for organisations. As companies digitally transform their businesses, knowledge and training become rapidly obsolete. As a result, “just-in-time” training becomes a basic survival need, and identification of cost-effective ways of reaching a diverse global workforce becomes critical (Urdan and Weggen, 2000).

Parallel to these business forces there are several additional factors that account for the strategic importance of e-learning. Internet access, for example, is becoming a given at home and work. Second, advances in digital technologies continue to enrich the interactivity and media content of the web. Third, increasing bandwidth and better delivery platforms make e-learning feasible and attractive. Fourth, a growing selection of high-quality e-learning products and services is now available. Lastly, technology standards, which facilitate compatibility, and usability of e-learning products are emerging (Urdan and Weggen, 2000). The Internet and its distributive architecture will, for the first time, give organisations the power to combine a series of discrete, unlinked and unmeasured activities into an enterprise-wide process of continuous and globally distributed learning that directly links business goals and individual learning outcomes (Mcrea, Gay and Bacon, 2000). The projected benefits are highly attractive. They include: accessibility of courses via Intranets and Internet, training can be self-paced, availability of training at any
time and place, training being less expensive, and reduced or eliminated travel time (Hall and Karon, 2000).

Nevertheless, if the benefits of e-learning are obvious organisations are far from achieving the strategic importance of the digital economy and digital learning. The current organisation of training is based to a large extent on off-site classroom based on “just in case” learning, misalignment with business objectives and outcomes, unknown competency gaps, ‘one size fits all’ philosophy and the training department is in the back office, mean that corporate entities are far from achieving the benefits promised by e-learning (Urdan and Weggen, 2000). Their organisational culture is in desperate need of change.

3.1.3 Organisational culture: a key to successful and sustainable e-learning

Organisational culture is critical to the inception, growth and success of e-learning in any organisation. Organisational culture can be thought of as having several levels that differ in terms of their visibility and their resistance to change. At the deeper less visible level, culture refers to values that are shared by people in a group and tend to persist over time even when group membership changes. At the more visible level, culture represents the behaviour patterns or style of an organisation that employees are automatically encouraged to follow by their fellow employees. Notions of what is important in companies vary considerably. Kotter and Heskett (1992) have identified money, technological innovation and employee wellbeing as values that may underlie organisations. Nahavandi and Malekzadeh (1993) have identified assumptions as being additional level of culture. This level is composed of basic assumptions resulting from an organisation’s success and failures in dealing with the environment. These assumptions encompass an organisation’s basic philosophy and worldview, and they shape the way the environment and all other events are perceived and interpreted. Values, behaviour and assumptions combined with organisational leadership nurture the bond and identity that unites the members of organisations.

Research shows that becoming a knowledge organisation is not easy. It requires new types of investments, new systems of reward and the adoption of new philosophies of management, especially regarding employees and customers. Risks are proportionate to rewards in such cases. The most serious risk for corporate leaders is not to make decisions that will move their organisations to become knowledge generating applying entities (Huseman and Goodman, 1999). Harreld (1998), for instance, has argued that imposing new technologies and management processes on a culture that is not prepared to embrace them is futile. Knowledge management and e-learning processes require people to behave in some fairly counter-cultural ways such as, sharing their know-how with everyone else, making mistakes public and spending a lot of time exchanging information in collaborative processes.

Khajanchi and Kanfer (2000) in their review of knowledge management practices have found that in creating an environment that encourages knowledge sharing the most important key is
creating processes and an organizational culture. Creating such an environment would require careful integration of culture and incentive systems with business strategies. However, each business organisation may require a unique solution depending on its history, identity, business needs and present environment. In conclusion, organisational culture in the sense discussed here is a critical mediating factor for the success or failure of knowledge management and e-learning initiatives.

3.2 Trainer and Learner Roles

3.2.1 The trainer’s roles in e-learning era

The role of the trainer – the one that develops the content of e-learning – remains critical in e-learning. The traditional questions ‘who educates the teacher’ and ‘what makes a good teacher’ apply with equal force in e-learning as they have always applied in traditional learning environments. Many researchers agree that technology will never replace the trainer or instructional designers. However, technology brings with it more demands for teamwork and collaboration among a diverse group of workers (Wagner, and Reddy, 1999). Trainers, in particular, will need to take on new roles as their work design and environment changes.

The traditional trainer roles include instructional designer, instructional developer, trainer, and materials supporter. As an instructional designer, the trainer performs the initial analysis and instructional design tasks. He or she also advises on course exercises and revision. As an instructional developer, the trainer writes course materials, exercises, and auxiliary materials and develops overheads. A trainer also does course development, becomes familiar with course flow, and learns how to use the technology. As a materials supporter the trainer produces the training materials, manuals, overheads, graphics, exercises, and so forth (Abernathy, 1998). Lastly, a trainer also facilitates.

In addition to their existing roles, trainers are now involved in technology support, facility support, and distant-site facilitating (Chute, Sayers, Gardner, 1999). In performing technology support, the trainer may choose the technology and help install the equipment. Trainers may also learn how to use the technology. As technology supporter, the trainer may also coordinate technology issues with the facility supporter and distant site facilitators. As facility supporter, the trainer may ensure that distant sites are set up and operable. The trainer, as distant-site facilitator, coordinates all distant-site set-up and ensures that the technology works, welcomes students to class, and is available to students in case there are problems.

It is important to give learners more control of the learning process and it does not mean losing value of corporate education. Instead, it indicates that when a trainer can sit at a computer and publish a course with the help of an authoring tool and a public portal, the role of the trainer is changing. Leonard (1996) describes the new trainer’s roles as someone who facilitates mentors and guides employers and employees to use the best and most timely training available. The goal of the corporate trainer is to find, interpret and assess a wide range of information and
technologically sophisticated products. Even though trainers are expected to play multiple roles, they cannot do e-learning alone. E-learning is labour-intensive and is dependent on an array of skills. Thus, a team approach is a requirement for the institutionalisation of an e-learning program. Team members could include graphic designers, network managers, server installers, end-user support personnel, programmers, instructional designers, and content experts (Driscoll, 1998).

3.2.2 The learner’s roles in e-learning era

Like trainers, the role of the learner is changing in ICT-enabled learning environments. In traditional learning environments students meet instructors face-to-face in a physical setting, while e-learning, students meet instructors virtually via electronic media. Certain learner-related issues must be considered when considering an e-learning platform in any organisation.

Keefe (1979) has defined learning style as “the characteristic behaviours of learners that serve as relatively stable indicators of how they perceive, interact with, and respond to the learning environment.” There are many learning style theories and measurement. They focus on different aspects of an individual’s learning characteristics.

One well-known instrument is David Kolb’s Learning Style Inventory (LSI) (Kolb, 1976, 1985). Social interaction, the third layer, addresses how students interact in the classroom. The Grasha-Reich Mann Student Learning Style Scale (LSS) (Grashna, 1972) analyses this layer. The LSS asked students questions concerning their attitudes toward learning, their views of the instructor and/or peers, and reactions to classroom procedures, revealing three contrasting styles: dependent-independent; competitive-collaborative, and avoid an participant. Finally, the outer layer of the onion is concerned with instructional preference and the individual’s preferred environment for learning. Canfield’s Learning Style Inventory (1980) is such an example.

Kolb’s (1984) experiential learning theory conceives of learning as a four-state cycle starting with concrete experience, which forms the basis for observation and reflection upon experiences. These observations are assimilated into concepts and generalisations about experiences, which, in turn, guide new experiences and interactions with the world. This model reflects two independent dimensions: Concrete Experience (CE) – Abstract Conceptualisation (AC); and Active Experimentation (AE) – Reflective Observation (RO). These can be seen in the Figure 17.
Each of the four Kolb learning styles (Kolb and Chapman 2005) can be briefly described as:

- **Diverging (feeling and watching - CE/RO)** - These people are able to look at things from different perspectives. They are sensitive. They prefer to watch rather than do, tending to gather information and use imagination to solve problems. They are best at viewing concrete situations several different viewpoints. Kolb called this style 'Diverging' because these people perform better in situations that require ideas-generation, for example, brainstorming. People with a Diverging learning style have broad cultural interests and like to gather information. They are interested in people, tend to be imaginative and emotional, and tend to be strong in the arts. People with the Diverging style prefer to work in groups, to listen with an open mind and to receive personal feedback.

- **Assimilating (watching and thinking - AC/RO)** - The Assimilating learning preference is for a concise, logical approach. Ideas and concepts are more important than people. These type of learners require good clear explanation rather than practical opportunity. They excel at understanding wide-ranging information and organising it a clear logical format. People with an Assimilating learning style are less focused on people and more interested in ideas and abstract concepts. People with this style are more attracted to logically sound theories than approaches based on practical value. These learning style people are important for effectiveness in information and science careers. In formal
learning situations, people with this style prefer readings, lectures, exploring analytical models, and having time to think things through.

- **Converging (doing and thinking - AC/AE)** - People with a Converging learning style can solve problems and will use their learning to find solutions to practical issues. They prefer technical tasks, and are less concerned with people and interpersonal aspects. People with a Converging learning style are best at finding practical uses for ideas and theories. They can solve problems and make decisions by finding solutions to questions and problems. People with a Converging learning style are more attracted to technical tasks and problems than social or interpersonal issues. A Converging learning style enables specialist and technology abilities. People with a Converging style like to experiment with new ideas, to simulate, and to work with practical applications.

- **Accommodating (doing and feeling - CE/AE)** - The Accommodating learning style is 'hands-on', and relies on intuition rather than logic. These people use other people's analysis, and prefer to take a practical, experiential approach. They are attracted to new challenges and experiences, and to carrying out plans. They commonly act on 'gut' instinct rather than logical analysis. People with an Accommodating learning style will tend to rely on others for information than carry out their own analysis. This learning style is prevalent and useful in roles requiring action and initiative. People with an Accommodating learning style prefer to work in teams to complete tasks. They set targets and actively work in the field trying different ways to achieve an objective.

By adapting Kolb’s experimental learning theory and LSI, Gunawardena and Boverie (1993) have studied the interaction between adult learning style and computer-mediated classes compared with non-equivalent traditional classes. Their study focuses on the interaction between learning styles and the media, methods of instruction and group functioning in a distance learning class using audio-graphics and computer-mediated communication. They find that learning styles do not impact how students interact with media and methods of instruction, but do affect satisfaction with other learners; Accommodators being the most satisfied and the Divergers the least satisfied with class discussions and group activities. In 1991, Sein and Robey also used Kolb’s LSI to study the interaction between learning style and efficacy of computer training methods. They concluded that Converger subjects who combine active experimentation and abstract conceptualisation perform better than subjects with other learning styles. This suggests that students’ learning outcomes when using computer application software may be affected by the style of the learner, regardless of the training methods. However, in an endeavour to seek the relationships between learning style preference and the effectiveness and acceptance of Interactive Video Instruction, Larsen (1992) finds no significant differences between learning style groups and suggests that both effectiveness and satisfaction are independent of students learning style preference.
3.3 Serious Games

In the knowledge society, lifelong learning is essential for knowledge workers in their work processes. All learning tools, methodologies and content that mainly consists on digital support is considered as e-learning, those Information Technology (IT) is the seed enabler as reflected in F.X. The advent of communication technology (ICT) permitted for the support of both distance and collaborative learning.

![Diagram of e-Learning, Simulation, CBT, ICT, IT, Serious Games, Edutainment, WBT](image)

**Figure 18 – Position of serious game in e-learning tools (Alfamicro, PRIME Version 8.0)**

Serious games are considered as the next evolutionary generation of learning tools, which address some of the short-comings of its predecessors.

3.3.1 Definition

A formal definition for serious games does not exist, but the original proponents, Ben Sawyer and David Rejeski, propose the following description:

Serious Games: Entertaining games with non-entertainment goals.

Such a broad definition does not properly capture the tacit understanding of what qualifies as a serious game. In fact, this is reflected by the contradictory perspectives between an observer and a user of a serious game:

- **Observer.** The user is playing a game.
- **User.** They are engaged in a serious learning activity that is fundamental to their productivity in the work environment.

Although a clear definition does not exist, it is important to state that a serious game is not a simulation. Probably the most distinguishing factor is the ability to successfully engage the user, such that they are completely immersed in the environment portrayed in the application. Another important factor is the artificial conflict generated to raise challenges to the user, but done with the correct balance to ensure satisfaction whilst avoiding frustration.
An important characteristic of a simulation is the sophistication and realism of the supporting model, whereas in a serious game the focus is on the overall user experience, thus realism is many times is sacrificed. In fact, a serious game prefers a low fidelity simulation with only a few critical elements are modelled in detail.

3.3.2 Challenges of Serious Gaming

The research community claims that most people learn most effectively through experience. This premise is reflected in the collective wisdom of humankind, as clearly captured by the Confucius saying:

I hear, I forget
I see, I remember
I do, I understand

The serious games field is still a relatively new one and is facing challenges which range from the selection of a suitable topic to the method of assessment used. Many of these challenges require interdisciplinary approaches to address them appropriately which correspondingly requires collaboration between professionals from different disciplines (e.g. subject matter, game design, game development, and instructional design) and this is in itself has been described as an awkward problem (Stokes, 2005) (Figure 19). The challenges can be as follow:

The first challenge: Why Use a Serious Game?

The first challenge in designing and developing any serious game is to justify its need by examining the suitability of the topic, by identifying the instructional problems, and by finding out why a serious game may be more effective than other training methods. With regards to the topic selection, Thaigi and Prensky agree on the possibility of using games to teach anything to anyone at any time (Nichani, 2001). However, Prensky raised some concerns of its worthiness considering the time and cost involved and suggests the power of games should be reserved for material the learners do not want and even resist to learn because it is boring (e.g. policies) or complicated (e.g. complex software).

The Second Challenge: Learning

Once the instructional problems and learning objectives are identified the next challenge is to integrate them into the serious game in a way that goes beyond making the game a sugarcoating for educational purposes, which was how edutainment was perceived (Kirriemuir & McFarlane, 2004). Egenfeldt-Nielsen (Egenfeldt-Nielsen, 2005) describes the problem as the lack of connection between the learning and the game play which very often limits the use of games as a reward for learning.
Figure 19 – Challenges of a serious game (Stokes, 2005)

The Third Challenge: Assessment

The assessment of learning in serious games presents another challenge that has to be addressed. The future growth of the serious games industry depends on it according to Kevin Corti of PIXELearning (Chen & Michael, 2005). Researchers have identified a number of assessment issues facing serious games. One of these issues arose because serious games rely less on memorization of facts and therefore traditional methods may not appropriately reflect the learning gained (Chen & Michael, 2005). The other issue concerns the wide range of possible solutions due to the open-ended nature of serious games which entail different levels of knowledge transfer (Iuppa & Borst, 2007; Chen & Michael, 2005). Iuppa & Borst also described the issue of measuring the improvements of abstract skills such as teamwork and leadership. Chen & Michael added the problem of identifying what is cheating in the context of serious games. To meet these issues three main types of assessments have been used by serious games developers (Chen & Michael, 2005): completion assessment, in-process assessment, and teacher evaluation.

The Fourth Challenge: Development

After the serious game is designed the next challenge becomes the development. The two main development options are either to build from scratch or to reuse game engines. The advantage of the first option is that the team has full control over the source code. The disadvantage, and
what has been argued as being a prohibiting factor, is cost (Gaudiosi, 2005). Cost can also be an issue with the second option. However, the wide range of game engines available means the cost range varies from free to six figures plus royalties. The other factors pushing towards the second option are: the graphics capability, the availability of scripting, the small learning curve, physics and networking.

### 3.3.3 Serious Games versus Traditional Games

The following table summarizes similarities and differences when comparing the traditional e-Learning approaches to the serious gaming approach.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>E-Learning</th>
<th>Serious Game</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Is always based on ICT.</td>
<td>Can be based on ICT, but is not restricted to.</td>
</tr>
<tr>
<td>Motivation</td>
<td>Mostly extrinsic. Learners learn because others want it. Sometimes intrinsic (auto didactic)</td>
<td>Intrinsic, because gaming is fun.</td>
</tr>
<tr>
<td>Usage Mode</td>
<td>Mostly Single-User</td>
<td>Mostly Multi-User</td>
</tr>
<tr>
<td>Tutorial Support</td>
<td>Some forms are with tutorial support, others without</td>
<td>Most cases include tutorial support</td>
</tr>
<tr>
<td>Learning Environment</td>
<td>Can be anywhere with computer access</td>
<td>Can be anywhere in case of computer-based or computer-supported educational games. Non computer-based games are normally played in one room.</td>
</tr>
<tr>
<td>Virtual World Model</td>
<td>Mostly learning about the world as an abstract item</td>
<td>Learning within the (virtual) world with the need to act</td>
</tr>
<tr>
<td>Pedagogical Model</td>
<td>Mostly behaviouristic</td>
<td>Mostly constructivist</td>
</tr>
<tr>
<td>Diverging Learning Style</td>
<td>Medium support of the needs of diverging style learners; most restrictive is the pre-programmed content of the learning medium</td>
<td>Good support of the needs of diverging style learners because games allow to develop and test new ideas</td>
</tr>
</tbody>
</table>
### 3.3.4 Advantages of serious games

- **Experiential learning**

According to Raybourn, Deagle, Mendini and Heneghan (2005) well designed ‘serious games provide the opportunity for experiential learning and they provide an environment for active, critical learning’. Experiential learning opportunities enable game players to ‘learn from contextual information embedded in the dynamics of the game, and through the risks, benefits, costs, outcomes and rewards of alternative strategies that result from decision making’ (Raybourn et al, 2005 and Caird-Daley, A, 2009). Experience in game will positively influence perceptions of subject matter areas and increase interest in portrayed areas because person is assuming a role within the game that they identify with and want to emulate. Yee and Bailenson (2007) have shown that an experience as an avatar can change a person’s real life perceptions and behaviours. James Paul Gee, states that no deep learning takes place unless an extended commitment of self is made for the long haul. Good video games capture players through identify. Players either inherit a strongly formed and appealing character or they get to build a
character from the ground up. Players become committed to the new virtual world in which they will learn and act. (Kaplan Edu Neering., 2010)

- Higher levels of declarative & procedural knowledge retention of material

Sitzmann and Ely (2010) in a meta-analysis found that learners participating in simulation game learning experiences have 11% higher declarative knowledge, 14% higher procedural knowledge and 9% higher retention of training material than those trainees participating in more traditional learning experiences. Increase in learner knowledge, recall and retention of content of due to increased frequency of interacting within a game due to motivational factors and due to the fact that the learning takes place in a realistic environment. (Kaplan EduNeering. 2010)

- Active Learning

Unlike some classroom based ‘chalk and talk’ training sessions, serious games ensure that learning is an active rather than a passive process. According to Gee (2004) good learning requires that learners feel like active agents (producers) not just passive recipients (consumers) Training games (i.e. serious games) allow learners to actively engage in the content they are learning, which is likely to produce positive learning outcomes’ (Belanich, Mullin and Dressel). Put very simply, serious games require players to participate in the action. Games do nothing until a player acts and then the game responds, presenting the player with feedback and new decision making events. (Gee, 2005).

- High Motivation

Learning happens when people are self-motivated to learn. Serious games can be highly motivating, and as such encourage players to commit time and effort to a game. According to Abt (1987, cited in Michael and Chen, 2006) ‘Games are effective teaching and training devices for students of all ages and in many situations because they are highly motivating, and because they communicate very efficiently the concepts and facts of many subjects’.

Intrinsic motivation appears to be increased as games encourage curiosity and competition, or as Gee (2005) suggests, motivation comes from being challenged by a game.

- Strategies Thinking & Ability to learn through repeated failure

Serious games may encourage exploring and trying new things (Gee, 2005). According to the design of a game, serious games enable learners to explore the solution space, i.e. they enable players to actively explore alternative decision making strategies, and to learn from experiencing the outcome of their decisions. Design advantages encourage wider and repeated use, and amplify strategic thinking and learning opportunities among users.
➢ **Timely feedback**

Belanich et al (2004) identified that the ability to provide feedback to students about their performance was important and should be provided according to the learners’ needs and the task at hand. An advantage of using serious games for training is the ability to provide this timely feedback.

In addition to being able to leverage the properties of games and digital games for learning serious games also possess many of the properties of simulator based training devices. For example, serious games may provide the opportunity for after action review, either by being designed to collect objective data, such as the route taken in executing a task, which can then be benchmarked against an optimal course of action, or by means of a replay of action from either a first person or bird’s eye view. (Caird-Daley, A, 2009)

➢ **Increase in learner’s self-efficacy, self-regulatory and self-observational**

The confidence to perform the task for which they trained, increased ability to solve problems and to work with others. Bandura’s (1986) social learning theory, Sitzmann and Ely (2010) found post-training self-efficacy was 20% higher with simulation games than comparison groups in meta-analysis. They state that confidence to perform the task for which they trained, increased ability to solve problems and to work with others are outcomes of serious gaming.

Sitzmann and Ely (2010) found that learners gained more knowledge when simulation games conveyed course material actively rather than passively and well-designed simulation games are active. Means et. Al (2009) in a US DOE meta-analysis of studies comparing online and face-to-face instruction found that online learner activity and self-reflection are key factors in increasing learning outcomes. (Kaplan EduNeering. 2010)

➢ **Elimination of risks and danger**

In military training, Serious games also provide students with a safe benign learning environment which enables students to explore decision making under a range of hazards and in dangerous activities and to learn from the outcomes of their actions without risk to life or equipment. (Caird-Daley, A (2009))

➢ **Anytime, anywhere access to learning content**

They enable training to take place 24 hours a day, seven days a week regardless of weather conditions; and without damage to the environment (Rolfe and Staples, 1986). They can be easily tailored to the skill levels of the training audience and are readily accessible.

In military training, it is acknowledged that serious games, just as with simulator training devices, have limitations, for example they cannot replicate morale, fear, fatigue or physical
adaptations to extremes of climate which are best trained in the live environment. This does not undermine the use of serious games for military training, but acknowledges that serious games are not the media solution for all training needs. (Caird-Daley, A (2009)) The other advantages of serious gaming are as follow:

- Reduction of the requirement for costly sites and equipment
- Lower environmental impact
- The ability to do things that are impossible in the real world
- Acceleration of experience
- Integration of knowledge and skills
- Improved transfer of learning to real-world

3.4 Analysis of Serious Games in the market

According to Straka (Straka 1986) – who is following the constructivist approach – an individual does only learn what he can perform and convert/implement. This implies, that in order to offer vocational training for training employees to face new situations and carry out new collaborations in a dynamical environment, curricula need to be developed, which allow active participation of the employee.

Mediating skills to employees puts different requirements on the learning environment than to students as an employee usually cannot leave his job for longer period. E-learning is a suitable method for vocational training. It provides many of the benefits of classroom training from nearly anywhere and at any time. It is flexible, virtual learning that reduces the cost and time efforts, and it demands active participation. Additionally, the employee can monitor the progress as well as test himself. However, it is difficult to mediate “soft skills” like communication and collaboration skills on a theoretical level; the employee usually need to experience the situation. Educational computer games, like business games, can be seen as an extension of the traditional e-learning concepts. Simulation based business games offer a way to internalise knowledge in a safe environment and is especially useful to train judgement skills and own performance. Employees do have the possibility to experience the consequences of their decision and behaviour and thereby gaining new skills without fearing that they may cause any damage to their company.

Even though it is proven that simulation based business games are an appropriate way for mediating soft skills and organisational aspects (Windhoff 2001), the demand on specific collaboration skills of employees working in a collaborative environment implies additional requirements. Performing collaboration in the “right” way, it is not only question of carrying out the task according to the process instruction, but far more a question of the interaction with the other participants, which is much more difficult to mediate in front of a new situation. Most
simulation games in the field of production networks or product development do mainly focus on the mediation of one certain aspect of product development or distributed production.

3.4.1 Compilation of various Educational Games

The following provides an in-depth analysis of educational games. As these skills to be mediated have to be experienced in authentic situations to be acquired, related simulation games have to simulate the mentioned characteristic working situations:

- collaboration in distributed environments
- exchange and management of knowledge in and between organizations

Another characteristic to reduce the amount of games to analyse is that the game needs to deal with new product development or process development. This approach reduced the large amount of educational games to nine.

In order to identify whether the existing simulation games do address the characteristics of future working scenarios and to find out whether the essential skills are mediated, the simulation games are compared on the basis of the applicable classification of simulation games developed by Blötz (Blötz et al. 2002):

- game medium,
- scope of the game model including simulated working scenario (s)
- social arrangement
- kind of tutorial support
- and learning goals.

3.4.2 Overall Analysis of Educational Games

The Internet based “COSIGA” simulation game simulates product development and distributed work. Within this scenario, the players learn about concurrent engineering, product development and partly acquire communication skills for disperse locations as well as ICT skills. The game scenario does not particularly address the management and exchange of knowledge. Self-directed learning skills and the attitude to share knowledge are not mediated. However, the simple four step product development process appropriately reduces the complexity of product development and does not exceed the learner’s capabilities so that they are still able to cope with the challenging distributed working scenario. Additionally, the Internet based architecture enables the realistic simulation of a distributed work setting.

The “GLOTRAIN” simulation game addresses different organisational forms of product development and production. Within one scenario, it simulates the development and the
production of a product in a distributed work setting. The players improve their communication skills, their collaborative skills as well as the related ICT skills. Again, the game scenario does not particularly address the management and exchange of knowledge. Self-directed learning skills and the motivation to share knowledge are not mediated either.

The “CITY CAR” simulation game addresses product development and project management. The players undergo the board based development of a product. During the game, they improve their communication skills and their capacity for teamwork. The characteristics of distributed work and the exchange and management of knowledge are not considered. Accordingly, the related skills are not mediated either.

The “MINT” simulation game focuses on distributed factory planning. The players undergo the continuous distributed collaboration in order to complete their tasks. This game scenario addresses the work in a distributed setting. The players improve their communication skills, their collaborative skills as well as their ICT skills. Interestingly, the game also addresses intercultural issues. Again, the game scenario does neither address the management and exchange of knowledge nor the development of a product. Self-directed learning skills and the motivation to share knowledge are not mediated either. The conceptual effort to specifically distribute wrong information and the secrecy of important information is well eligible to simulate realistic obstacles of knowledge exchange and to enhance the players’ communication and collaboration. Additionally, the inclusion of a joint content management system increases the degree of realism of the simulation game.

The “BUSINESS NETWORKING GAME” does simulate collaboration in a business network. This game addresses collaboration in a distributed work setting from a strategic perspective. It does neither consider product development nor the management and exchange of knowledge. Because of that, the related skills are not mediated either.

The “CHAIN GAME” simulates collaboration in a distributed supply chain work setting. The players learn about trading, logistics and the use of ICT to improve their communication and collaborative skills through intense negotiation in the supply chain. The value of trust and the impact of intercultural diversity are especially highlighted in this game. Again, the web based architecture enables the realistic simulation of a distributed work setting. The game scenario does neither address product development nor the management and exchange of knowledge. Thus, the related skills are not mediated either.

The “KNOWLEDGE MANAGEMENT SIMULATION GAME” focuses on the management and exchange of knowledge. Thus, the players learn about knowledge management and sharing tactics as well as the development of implementation plans. It is intended that they develop a motivation to share their knowledge by experiencing the benefits of knowledge sharing. This game does neither address product development nor distributed work. Accordingly, the related skills are not mediated either. The conceptual effort to let players
experience the benefits of knowledge sharing in order to start to develop an intrinsic motivation
to share knowledge have proved to be a positive element within simulation gaming. Apart from
that, the inclusion of a joint content management system increases the degree of realism of the
simulation game.

The “TANGO” simulation game focuses on strategic decisions concerning the management of
intangible assets of a company. It does address the management and exchange of knowledge on
a rather abstract level. Thus, it does mediate strategic management competencies about the
management of knowledge, but it does not mediate the immediate interpersonal skills that are
important to facilitate the management and exchange of knowledge. The game does neither
address product development nor distributed work. The related skills are not mediated either.

The “KMQUEST” simulation game focuses on knowledge management related problems and
their resolutions. The scenario addresses the management and exchange of knowledge on a
rather abstract strategic level in order to improve the problem solving capabilities of the players.
As the “Tango” simulation game, it mediates strategic management competency. It does not
mediate the operational skills or attitudes that are important to support the immediate process
of knowledge exchange. Again, this game does neither address product development nor
distributed work. Thus, it does not mediate the related skills.

The product development related simulation games mainly cover production related topics and
distributed work, while the network related simulation games cover collaboration in distributed
work settings but nothing else. Two of three knowledge management related simulation games
cover the management of knowledge and its exchange on a rather strategic level. As a
consequence of that, no simulation game aims at mediating the complete list of skills identified
in the previous chapter. Furthermore, none of the simulation games mediates conflict
management skills, communications strategies for distributed work settings or learning
strategies. These findings are illustrated in Table 10.
<table>
<thead>
<tr>
<th>Game Name</th>
<th>Distributed Work</th>
<th>Knowledge Management and Exchange</th>
<th>New Product Development</th>
<th>Product Manufacturing</th>
<th>Mediation of Skills</th>
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<td>ICT skills</td>
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<td>Communication skills</td>
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<td>Motivation for knowledge sharing</td>
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<td>Conflict management capabilities</td>
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<td>Inter-cultural sensitivities</td>
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<td>COSIGA</td>
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<td>(X)</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
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<tr>
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<td>X</td>
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<tr>
<td>MINT</td>
<td>X</td>
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<td>(X)</td>
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<tr>
<td>Business Networking Game</td>
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<td>Chain Game</td>
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<td>KM Simulation Game</td>
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<tr>
<td>Tango</td>
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<tr>
<td>KMQuest</td>
<td>(X)</td>
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</table>

Table 10 - Comparison of Education Games (Alfamicro, PRIME Version 8.0)
Chapter 4

Research Domain
4 Research domains

In the previous chapters have been exposed many theories about NPD system, lean thinking and serious games. After understand all the previous concepts, it is time to mix all of them to proceed to the LeanPPD game.

The goal of this chapter is to explain all the theory behind the LeanPPD game. It can be said that this chapter try to joint all the previous chapters. All the steps, activities and models of a lean NPD system explained in the chapter 2, will be adapted to the game following the rules needed to get a successful game explained in the chapter 3.

The flow of the game will be: a NPD model of the chapter 1; them a list of lean activities from the chapter 2 will be applied by the player; and finally, a Lean NPD process will be got. All of this taking into account all the points a good serious game must to have.

4.1 Goal of the LeanPPD Game

In order to successfully act within global competition, companies have to differentiate from competitors by e.g. targeting the customer’s needs through extending their physical products with additional services or components. The production of these complex and knowledge intensive products requires the combination of certain key competencies that can often only be accomplished in enterprise networks. As knowledge has evolved to the central factor of production, especially engineers are forced to constantly create, acquire process and share new knowledge to efficiently contribute to the new product development process. Due to the growing significance of enterprise networks, this often happens inter-organisationally. As a consequence of the described developments, engineers have to deal with a new working situation, consisting of three characteristic scenarios. They have to:

- collaborate efficiently in and in between companies,
- manage and share knowledge,
- increase the effectiveness of the new product development process

Consequently, the educational requirements that engineers face have changed as well; interpersonal skills such as communication skills, collaborative skills as well as performance skills that can be applied in multiple situations are becoming vital.

Simulation games are well eligible to mediate the mentioned skills in an authentic context since they allow students to experience the complexity of cause and effect relationships and consequences of decisions in a sufficient practical manner, while significantly reducing costs of time, money, and adverse real-world consequences. Current simulation games do neither simulate inter-organisational collaboration, knowledge exchange and new product development nor mediate the set of skills that is required to efficiently collaborate in and in between companies, manage and share knowledge in order to then contribute to the new product development process. Furthermore, the simulations games are limited to predefined game
scenarios and do not allow the reconfiguration to tailor game scenarios to the particular user needs.

In this context has been developed the LeanPPD Game. As it was told in the previous chapter educational games can be divided into computer based and traditional educational games. Taking into account the coming advances in networks and ITC technologies, the LeanPPD Game has been thought as a computer based educational game. Although the idea is that in the future this game will become a WBT, the prototype that is presented here is CBT that means not use of web resources.

With the main goal of become an important tool in teaching lean philosophy born this game. As has been studied before, one of the best ways to interiorize concepts is by serious games. In other hand, new product and process development nowadays is full of wastes. It is known, that exist a need in the actual market for what companies needs to decrease this wastes and refine the process. This is the main objective of Lean new product and process development, and the main reason of this game.

The original idea is create a game oriented to companies that needs to start implementing Lean tools to improve its performances in new product and process development. This game must help employers to become familiarized with the lean methodologies like standardization, guest supplier, previous knowledge or trade of curves, between others. It’s try to be a start point in understanding the lean concepts and how to apply them to a real case of new product and process development.

The design of this game is focus on achieve the next purpose:

- Responding to an on-going need to teach lean concepts applied to New Product and Process Development in an effective way
- Revitalize and innovate the existing training programs
- Create addiction on the player to keep them focus on what are learning and optimize the learning process

## 4.2 Researches of Process and Product

As a New Product and Process development game, the first step to research is the process model. In the first part of this section is done a deep study of how to transform the actual models in a viable model to be implemented in a game. For that the value stream mapping tool was used to model the actual process, identify the wastes of the process and create a future process.

The second main important issue to solve is to choose a correct product to develop in the game it will be treated in this section too.
4.2.1 Research of the New Product Development model

The first step to define the game is to define the model. The purpose of the game is to improve a NPD model since a traditional NPD system until a LPD system. The idea is that the player introduces some lean tools in the traditional model to adapt it to the lean model.

In addition, the wastes in the traditional model have to been identified in order to put the lean tools and eliminate them. So the two firsts steps are: define the model and identify wastes.

For this, a very common tool used in Lean Manufacturing, the Value Stream Mapping has been used. Most researchers discuss about the use of this tool in Lean Design, but no one do that about Lean Manufacturing. The point is that for this game, this tool has been very useful to define the “current state” of the model and its “future state”.

For the current state, the model chosen was the Decision-stage model (explained in the chapter 1). More precisely it has been chosen a Stage-Gate model, which is an extension of the Decision-stage model. This model was chosen because is one of the simplest and the most intuitive. As it was said in the chapter 3, a game must be clear and simple. The way to play must be intuitive for the player. A general PD process can be seen in the Figure 10, while the current state for the game can be seen in the Figure 20.

In the Stage-Gate models, the process consists of stages (where the activity takes place) which are always followed by Gates (with are review points with specific input, exit criteria and a go/kill/hold/reiterate decision as output). The game is pretended to be sequential, where there are points of decisions where the player has to choice what to do. The stages selected for the game are: marketing & sales, product design, validation, manufacturing and supplier.

The process starts with the definition of a necessity in the market, a new product. The “stage” of sales and marketing studies the market and develop a bill of requirements. This project waits till the “stage” of engineering of design accepts the project and starts working in it. In this stage appears the first gate: there is a review of the design, where it choices if the design is good or not (iteration to improve it). After the acceptance of the design, the project goes to the third stage, the validation (Prototyping & tests). Here the design is tested and if is defined if is good or not (second iteration). Then the stage of manufacturing had to determine if the product can be manufactured or not (third iteration) and finally the acceptable of the supplier.

The most important wastes identified in the previous model were many. A common waste called “wishful thinking” (Allen C. Ward, 2009). This means take decisions precipitated without enough knowledge or data. For example, a wishful thinking occurs when the sales & marketing
department fixes some performances or characteristics of a product that maybe it is impossible to do for the design engineering. Also happens when the design engineering select a product that maybe it is impossible to manufacture. This waste brings another waste, the unnecessary iterations. The iterations are not a waste. They are needed to improve the product and for the continuous improvement, but the excess of iterations are absolutely a waste. With this model, most of the iterations are wastes. Other simple identifiable waste is the waiting time of the project. Normally, the workload is not leveraged. For this reason, there are departments that finish their work before others. In this model could happen than the sales & marketing department selects projects faster than the prototype & test department can do, so the projects are stopped until the most saturated department can take them.

Using many of the activities listed in the chapter 2, the wastes should be eliminated and the current state (Figure 21) transform into the future state (Figure 22).

In the future state most of the previous wastes are eliminated. With the chief engineer, the cross-functional teams and the supplier integration the wishful thinking is eliminated. The Set-Based Concurrent Engineering adds value to the product and eliminates the most of the iterations in the process. With the fast prototyping it is possible to identify if the design is good or not. And with the trade-off curves, quality matrix, decision matrix and standardization is very fast to take data, to add parts or take important choices.

In the figure it can see that just a lean activity it does not do the process lean. To get a lean process it is necessary the integration of all the activities. All of them are related, and one needs the others to develop its functions.

The two previous models are the basis of the game. They explain a general process for a general product, but it is not possible to take into account all the actors described. They must be simpler and clearer, in order to give the player a good lesson about lean.
Figure 21 – Current State of the first model
Figure 22 – Future State of the first model
4.2.2 Research of the product

Select a product for the game it is not an easy task. As it was told before the role of the trainer – the one that develops the content of e-learning – remains critical in e-learning. One of the most important things to teach something is to know deeply about it. For that the main idea was that the product must be very good known for us. An example of not choose correctly the product:

- We select a motorbike, but we don’t know anything about motorbikes. We define a relation between the weight of the motor and the stability of the motorbike. A day, a player, expert in motorbikes, plays the game and this relation confuses him, since this relation doesn’t exist in real motorbikes.

Things that explained previously don’t happen if the product selected in the game is well known. For this reason, was chosen a product well known for the trainers: planes.

The knowledge about planes let us develop a list of restriction, relations, concepts and penalties that any other product shouldn’t do.

4.2.3 Transformation of the process through the product

Once the product and the process were chosen, the next step was transforming the process to the selected product. As was talked in the Chapter 1, new product development consists in bringing a new product or service to market. There are two parallel paths involved in the NPD process: one involves the idea generation, product design, and detail engineering; the other involves market research and marketing analysis.

Sales & Marketing department

The Sales & Marketing department has as main responsibility “Focus on the Customer Value”. But the question is: what is the customer value in the game? To clarify this, our experience was used.

It is known in aeronautical that to sell an airplane to an airline the most important parameter is the number of passenger. If is a low cost company it will want as much passengers as possible, but if is a jet private company they will want the Commodities of the passengers so they will ask for a spacious airplane. For that the number of passenger was fixed as a customer value.

Other two relevant characteristics are the speed and range of travel. When an airline buy an airplane is because of they have the need to transport the passengers for one place to other in the less time possible. If the company use to travel from Europe to United State or Australia where the kilometres of travel are really high, they will need an airplane with a particular characteristics; in the other hand if is an intercontinental company (Europe-Europe) the technical data of the airplane will be really different.
An airplane needs to be parked all days in a hangar. All companies have its own hangars with its own dimensions allocated in airports. As is logical when a company buy an airplane they will try to reuse the hangars that they has. For that is really common that the length and wingspan of the airplane are restrictions for the company.

Finally as in all business, cost and time are really important, so it will be customer value too.

Now that the customer values are clear for the game, it´s needed to explain the role of the Sales and Marketing department. It will focus on understand that customer want, but it isn´t always easy. To show this fact in the game, this department won´t be able to detect exactly the values of these parameters, they will show a range or estimation make by studies of market.

**Engineering Design**

The most important parts in the new product development are the idea generation, product design, and detail engineering. The product chosen was an airplane, but an airplane is really difficult and sophisticated to be designed in a game. Maybe the player does not have notions about airplanes, but to design something is needed to know about it. So in this part a big challenge was raised: How to get that a person that don´t know nothing about airplanes design an airplane in a right way? And how make this design enough efficient to apply lean tools in it?

The simplification of the airplane model was needed. An airplane is a 3D object, what means that it needs to be described in 3 main views: top (Figure 23), lateral (Figure 24), and front (Figure 25). Design an object in 3D for a prototype game is difficult and not needed. As the object of this game is not to learn aeronautical concepts, if not lean philosophy, the design phase is used as essential, but not for the grade of difficult, if not for the idea of design. Considering all these arguments, just one view of the airplane was included in the design phase.

For sure the front view don´t show the shape of the airplane that users are used to seeing. The lateral view is intuitive but is not useful to design, because of in it the player can´t identify the main parts of an airplane and this shape can´t be easily divided in raw shapes. The most intuitive and easy shape to design was the top view. The top view can be divided in squares and triangles, in a simple way, so this met all the requirements for the chosen.
Figure 23 – Front view

Figure 24 – Lateral view

Figure 25 – Top view.
**Manufacturing and Supplier**

It is known that it is important to take into account manufacturing during the product development phase. If companies are able to anticipate the manufacturing problems and eliminate it in the design state, they will save money and time. This is one of the principles of the lean philosophy, so manufacturing needs to be included in the game.

The term manufacturing is commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale. Such finished goods may be used for manufacturing other, more complex products, such as aircraft, household appliances, or automobiles, or sold to wholesalers, who in turn sell them to retailers, who then sell them to end users – the "consumers".

As was studied in Chapter 3, a game should be a challenge that the player can achieve. So now the question is: How can it be possible to design the airplane and introduce the manufacturing idea in this phase?

To divide the airplane in basic shapes is the answer to this question. To apply the manufacturing concept to the game it is needed select some raw materials or basic shapes that will form the full airplane. This basic materials and shapes should be easily to understand and apply, because as already was told is not the issue of this game make complicate designs.

For that, three basic shapes were selected: square, isosceles triangle and rectangle triangle. The last one component to add in the manufacturing is the engines. The idea of engines is complicated and need of equations, but this game can’t be a challenge if the engines are not included. They are fundamental to give the airplane the power to fly and it is going to be one of the most important variables in the designing phase of the game and in the application of the lean enablers.

**Review**

While most addiction creates a game, more attention will pay the player and most efficient will be the learning process. In this way, it is necessary to pose a challenge to the player. If a game were any design is good were done, regardless of any restrictions, the player is bored. On the other hand, would not be able to see how "lean tools" can help him meeting these restrictions in a more rapid and efficient way, which is one of the major goals of this game.

Therefore, a phase of review was necessary. This phase will see if the player has designed according to design criteria. It also should include how close the design is to what market demand.

It has been considered that if the design does not meet the requirement to be an airplane and to fly, the player should modify the design until these are fulfilled. These constrains will be in terms on dimensions, and aerodynamic topic, for what will be necessary to include some helps explaining these concepts and how to achieve them.
Once the design is correct, the review phase takes place and the player will have the possibility to back to the design phase if he is not agree with the performances and redesign; or continue if he consider that the performances are good.

Given all the above considerations, it is proceeded to develop the process shown in the figure below. This will be the process where it will be fundament the design of the game, as well as all future improvements, Figure 26.
Figure 26 – Final model
4.3 LeanPPD game Overview

In this section will be introduce the bases of the game. It starts explaining the general flow of the game, detailing the stages of the game and the player will go through it. It continues defining the role of player, what player needs to do to play in a right way and what his challenge is.

Due to the product that was chosen, some prior knowledge is needed in the game. In the most basic principle that the player must know is the parts into which the plane is divided, as its design must hold them all.

This section ends by explaining the "lean tools" that have been selected, the reason why these are chosen and an introduction to the concepts they apply in the game.

4.3.1 Approach to the LeanPPD game

Has been used the existing literature on e-learning has identified evaluation type questions to guide the development of the game. When selecting a multimedia e-learning environment, there are several learning principles that need to be rigorously applied. These are:

- Learning requires doing something – not just clicking through screens. The more active the learner, the greater the retention. Learning should not be confused with simply regurgitating what was on a previous screen. Applying to the game, the player will need to "design", selecting the pieces, the number of then and where they want to allocate it.

- Tasks should be sequenced from simple to complex. The learner should go from recognizing a pattern, to differentiating what fits and what does not fit into that pattern, to how that pattern differs from other patterns already learned, and finally to integrating that pattern with what has already been learned. This has been applied to the game using a sequence of two stages. In the first stage the pattern of the game will be show to the player and then in the second stage the lean tools will be integrated in this pattern.

- Learning requires feedback, not just what answer was wrong and this is the right answer. The feedback of the game is given in terms of points; it is a score, so it will increase while the player better design.

[Freeman, 2002]

4.3.1.1 Learning Environment and flow of the game

Technology-based learning methodologies require a focus on the learners’ environment. The ease with which the leaner can navigate through the learning environment affects the amount of
learning that occurs as well as the learners’ level of satisfaction. Learner-based tools should be selected based on the way that they help players to learn. The key criterion in the evaluation of ICT in this context is how well any given tool supports the learning process (Norton and Wilbur, 1998).

In this context, has been tried to create in the game a correct learning environment. For that the players have been placed in what could be a real situation in a company.

With respect to the flow of the game, that means the way in that the player can go through the game, has been selected two stages. It has been considered that one first stage was necessary to introduce the player in the interface and in the concept of the game. In this stage, the player will found the problems of design an airplane without the correct information and without using lean philosophy. Anyway a basic knowledge need to be teach to the player, as for example the how to play or basic airplane concepts about parts of the airplane, the basic shapes that form the plane and about the constrains of the design.

The idea is that the player found as much problems as possible in the designing face to appreciate in the second stage how value is to have the right information, the lean enablers. It is needed to emphasize that the problems that the player must find must be related to the lack of communication between departments or lack of previous knowledge in similar situations; that are the problems possible to solve with lean tools.

Once the player has been introduced and has seen the problems and difficulties to solve it, he is mentally prepared to go to the second stage of the game. In the second phase of the game it has tried to convey the feeling of relief in the player to use the lean tools. The player will have several tools that will help him in communications between departments, as well as give him necessary knowledge of previous designs, between others.

### 4.3.1.2 Interface design

User interface design is important too. User interface design refers to the overall look and feel of the program that allows the learner to access information (Hall, 1997).

Identifying what navigational tools are most user-friendly and where to place information are concerns associated with the design of the user interface. When it comes to evaluating the user interface, Brandon (1997) has identified the following questions: Is the course intuitive to use, such that the learner needs little or no explanation to proceed through the course? Is the overall screen design consistent, consolidated, clean and clear? Are the graphics appealing and understandable? Answering these questions will help to ensure that the user interface design is effective and user friendly.

In a first design phase of the prototype of the game, the Visual Basic joint to Excel has been used to create the interface of the game. Many others programs could be used, but was found in this code an easy way to program the game and make the needed modifications quickly. Other
codes like C++, Flash are more adequate designing games, but are more sophisticate and require high level of knowledge. Visual basic is intuitive and easy to learn as it contains all the needed tools to develop the game where is joined with excel.

4.3.2 Role of the player

In the most of computer serious games, the player just has the role of manager. The player takes decisions that affect in a good or bad way in the run of the game. The role of managers is ok in production or manufacturing games, but is not the most important figure in design. Of course, the most important figure in the design phase is the designer.

The role of designers can be got with Lego games. With some Lego games, sometimes the player is an authentic designer. The problem with the Lego games is that much information is lost during the process, since it is very difficult to control all the players in a room at the same time. Indeed, design games with Lego can transform into manufacturing game easily. The fact that a product is already designed by the Lego’s people is a temptation. This means, sometimes people try to copy the original design.

In the LeanPPD Game, the player always has the role of designer. He is in charge of design a new product, trying to meet a list of specifications. Indeed, the player has to take the decisions of what lean enabler wants to activate. So sometimes, he actuates also as managers.

Learning can’t be out of context because of it reduces significantly its potential; it is important to remember that context is what converts information into knowledge. In this way the role of the player is defined:

The player is a designer of a very important company of airplanes. The environment where the player is positioned is a market with very high competition and many new countries with a high and turbulence demand of aircrafts. The player is asked to design, in the fastest and most efficient way, the airplane that the customer wants.

During the game, the player also experiments an evolution. While more times the player plays the game, more experimented and faster will do the designs. He will understand better how the game works and he will interact more. This is the experience and the knowledge what Oppenheim (2004) said. This is the raw material in a product development process. While more knowledge and experience, better products will be created. So while more experimented the player is, better designs he will do.

To understand the needs of the market the company has a Sales and Marketing department that will give him an estimation of customer’s requirements. This estimation is a range of values where the real customer’s requirements are include. The player has to design an airplane as closer as possible to the customer’s requirements in the lower time possible. The customer’s needs estimation is in a concrete period of time so the player needs to be faster designing, otherwise he will lose the market opportunity and he will be penalize. When he finishes the
design, this will be tested and he will know the characteristics of its design and if the plane can fly or not. After this he can chose redesign the airplane or put it in the market. Depending on how close the design characteristics are respect the customer requirement he will get more or less money (score) selling the airplanes.

In the first stage of the game the player won’t have any lean tool to design, but in the second stage he will have 7 tools that will help him to decrease the time and cost of design and increase the quality.

4.3.3 Approaching the lean tools

The goal of this thesis is to develop a serious game to give a global vision of the Lean Product Development Process. This task is due to the need of a game that joins the New Product Development Process with the Lean Thinking. As was saw previously, there are few games about New Product Development, and no one about Lean Product Development.

To create this game, one has been the most important problem founded; in a NPD system, the raw material is information, the product is a paper concept, the workers are designers, so, how to put in a game intangible and abstract concepts as an integrated supplier in a clear and playable way? All the references were about manufacturing process or try to extrapolate manufacturing to design. Of course are two very different things. The tools used to improve a workshop are not the same to improve a study room.

However, the methodology used to create this game has been the same than the used in the manufacturing system. As it has been explained before, with the value stream mapping a process has been defined. Then the wastes were identified, and finally some tools were introduced in order to eliminate or reduce these wastes.

4.3.3.1 Identify wastes

During the development of the model the wastes were appearing themselves. So while the model was created, the wastes were created too. The four main wastes in the game are the next:

1. Number of iteration until an acceptable design is achieved or number of test until the plane can fly. This waste is interpreted in terms of bad communication between departments, because of the player is testing a design that doesn’t meet the requirement of other departments.

2. Time in understand what are the main rules in the design of the plane. This waste is interpreted like lack of previous information.
3 Time drawing the plane. This time is related with the before explained. As much information and knowledge has the designer about the product and about constrains, less will be this time.

4 Bad design with respect customer requirements. It is interpreted like a lack of understanding of customer value.

These wastes take almost the 70% of the total time consumed by the player. In order to eliminate the majority of these wastes, a group of lean enablers was included to facilitate the labour to the player.

4.3.3.2 Lean activities/tools selected for the game

In the chapter 2, many activities were explained. For the game, the most representative have been selected.

The basis for select the lean activities has been the Liker’s model, since his model is based in a set of tools. He numerates 13 activities (Table 11) and divides them in three subsystems (as it was explained in the chapter 2). Most of the Liker activities are named for others authors. For example the chief engineer is a lean instrument/tool taking into account for all the authors. The Liker’s model was the first classification of the tools, and with the other models, others activities were added, deleted or modified.

Womack et al. 1990 and Karlsson & Ahlstrom (1996) talked about the Cross-functional teams. For them this activity is one of the most important in a lean NPD process. For them the goal is the integration rather the coordination.

The Lean Enterprise Resource Centre (2000) and Cloke (2000) explain the families of products and the modular designs. The families of products refer to the standardization; this is one of the bases of lean thinking, in lean manufacturing and in lean product development. The modular designs are standard designs, what are modified to develop new designs; this activity seems a little the front-loading activity of Liker.

Others authors talk about the value of the people in the lean NPD process. The skilled people are the highest value in the process. In this sense the formation and experience of the people are very important.
<table>
<thead>
<tr>
<th>Process</th>
<th>People</th>
<th>Tools &amp; Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Customer’s Values</td>
<td>5 Chief Engineer</td>
<td>11 Adapt Technology to Fit your people &amp; process</td>
</tr>
<tr>
<td>2 Front-Load the PD process</td>
<td>6 Cross-functional integration</td>
<td>12 Simple and visual communication</td>
</tr>
<tr>
<td>3 Leverage PD process flow</td>
<td>7 Develop Towering Technical Competence in all engineers</td>
<td>13 Use powerful tools for standardization and organizational learning</td>
</tr>
<tr>
<td>4 Standardization</td>
<td>8 Fully integrate suppliers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9 Learning &amp; continuous improvement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 Build a culture to support excellence</td>
<td></td>
</tr>
</tbody>
</table>

Table 11 - 13 principles of Liker

Taking into account all the models explained in the chapter 2 and seeing the keys of a lean product development process, the next lean enablers/activities were selected:

- Guest supplier
- Chief engineer
- Learning courses
- Standardization
- Front loading
- Cross-functional teams
- Trade-off curves

These activities can be included in all the subsystems of the Liker’s model. They are related with important points of the lean NPD, and the most of authors talk about them or about topics related with them.

Most of these activities include, in an indirect way, others not show here. E.g. the Obeya activity would not be possible without the Front-load nor Cross-functional integration. Furthermore, the Obeya room is presided by the Chief Engineer. To get a successful lean PD process, all the activities must be related, and each one is based in the others.
Now the activities will be explained using Toyota as example of its implementation to get a clearer vision of them.

4.3.3.2.1 Chief Engineer

As it was said in 2.2, the chief engineer (CE) is one of the key elements in the Toyota’s product development system. For this reason, the chief engineer is the figure most publicized and imitated of the Toyota’s PD system. However, it is difficult to get a real chief engineer. The main task of the CE is to represent the voice of the customer. To achieve this, the CE must know the customer wants and must have the technical knowledge to implement this.

A Toyota’s CE moved in with a young target family in southern California to enhance his understanding of the generation X lifestyle associated with RAV Four customers. With his experience Toyota developed the Sienna. The Sienna CE drove his team in the Toyota’s previous minivan model more than 50,000 miles across North America through every part of Canada, the United States and Mexico.

The CE is different from the traditional project manager in several respects:

- The CE does not manage the engineers working on the project, with the exception of a small group of assistants, six or seven engineers. The CE leads through personal influence, technical know-how, and authority over product decisions.
- The CE represents the voice of the customer and is responsible for the success of the project program from concept to sales.
- The CE focuses more attention on decisions about systems integration than on personnel decisions and project administration.

Some responsibilities of the CE are the next:

- Profitability
- System architecture (he signs every drawing)
- Project planning and timing
- Negotiating for resources with the departmental leaders
- Achieving consensus in the design team
- Sometimes, approving the initial marketing campaign

4.3.3.2.2 Guest supplier

Toyota always has a crew of hundreds of engineers from suppliers, residing full time in its product development office called guest or resident engineers. These engineers interact daily with Toyota’s engineers, sharing information and learning how Toyota works. This has two benefits: free engineering resources for Toyota, a good training for the supplier’s engineers, and the most important, integration between them.
This activity gives to the supplier a familiarization with the Toyota’s PD practices and advanced information on new model programs.

4.3.3.2.3 Learning courses

In the learning activity, there aren’t any short-cuts or trick to accelerate the process or minimized the time required. This is a long term activity. Many companies do not invest in the formation of their employees. They think is lost money and time. Most of company are looking for short time inversions, and invest in knowledge is not a short time inversion.

In the lean companies the personnel is key. The selection process is very exhaustive and they are in a formation process continuously. Toyota pays expensive driving courses for its engineer. With this, the engineers can design cars from a pilot point of view.

Learning course is not properly an activity of the LPD system, but it has been selected to include and remark the learning process in the game.

4.3.3.2.4 Standardization

As it was said in the chapter 2, in a LPD system it is needed to standardize products, processes, and competence to create a foundation of flexibility and speed. Standardization is critical to the LPD system because it underpins many of the other LPDS principles by reducing variation, subsequently creating greater flexibility and more predictable outcomes.

To show standardization in the skills or the competences of the staff is complicate, but to show standardization in products or designs is very easy. For this reason this tool has been selected. In an easy way can be explained for the player a very important concept in a lean system, in manufacturing and in design.

4.3.3.2.5 Cross-functional teams

A cross-functional team is a design group composed by engineers of different departments. With these groups, during the design phase different point of views of different departments are considered, so the strengths and the weakness of the design can be identified early. The cross-functional teams should reduce miscommunication. With this the numbers of iterations in the design phase should be reduced, since the evaluation of the design is occurring continuously while the project is going on. This activity implies a good communication in the organization; not a good coordination of communication, but an integrated communication.
4.3.3.2.6 Front-load

Learning requires the transfer not only of explicit and codified knowledge but also of tacit knowledge which is usually associated with experience and practice.

In the beginning of the new programs, is where the most critical aspects of the new product are defined. Each error in the start phase can be translated in millions during the production or manufacturing phase. However, to change these errors in the start phase is very easy and cheap. For this reason, the LPD system is front-loaded at the start of the program, where the company can have the key for the success of the product for the lowest cost. The activity of front-loading is developed by cross-functional teams made up with the most experienced people, looking a broad range of solutions and anticipating and solving problems.

Also exist the activity of develop a new design from an existing one. This activity can be also called front-load or modular designs. Anyway, the goal of this enabler is to show the player an easy way of how to front-load a design.

4.3.3.2.7 Trade-off curves

The trade-off curves are one of the most utilized tools in a lean organization. The trade-off curves represent in a fast and clear way the characteristics of the products using a variable as parameter. E.g. the next Figure 27 represents a graphic with the quantity of fuel in a car and the kilometre of travel that can be done. In the vertical axis have been written the litres and in the horizontal axis the kilometres.
If we want to go from Milan to Como, 70 kilometres approximately, it is needed at least 4.1 litres. If our car has more than this quantity, over the line, we could reach Como without problems. However, if we have less than 4.1 litres, below the line, we could not reach Como. This is a simple example of trade-off curves. Also we can relation kilometres with price or number of passenger with consume, kilometres, etc.

In the chapter 5 more complex trade-off curves will be explained.
Chapter 5

Lean PPD Game
5 LeanPPD Game.

This Chapter presents the LeanPPD game in details. To understand the perfectly the game, it has been divided in the qualitative model were all the concepts are explained and a quantitative model where the equations has been explained. Having explained the complete model of the game, this chapter will continue defining the flow of the game. The last part of the chapter is devoted to calculate the performance of the players.

The qualitative model defines the basic knowledge about the interface of the game, like customer´s requirement, the part of the airplane or the design table, between others.

In the quantitative model all the equations needed for the understanding of the Methodology are explained in detail. The full game is based on a set of general equations: capacity, speed, kilometres of travel, parking requirements, delivery time and cost.

To estimate the customer's needs random functions are used to size the model plane that would be perfect for the customer. After sizing the plane, these variables are introduced in the general equations and the customer´s requirements are got. This methodology was used to be sure that the customer´s requirements meet the general restrictions of the aircraft.

On the other hand, the player designs his own plane introducing the variables of dimension. These variables will be taken and introduced into the general equations to get the characteristics of the design airplane.

The flow of the game is defined as an initial stage which the player will be designed in the traditional way and a second stage in which the player can make use of lean tools to design.

In the last part of this chapter shall be measured the performance of the player. This compares the characteristics of the design done, with the characteristics that the customer wants. Depending on how close are these two variables, the player will obtain a lean score.

5.1 Qualitative model of the LeanPPD Game

5.1.1 Customer’s requirements

The customer’s value is the cornerstone in any lean company. As has been studied in the previous chapters the most important point in a lean product development process is to add value to the product, for this the start point of the game has been focus on customer.

How to translate customer value in the game has been through what has been called "customer's requirements". For the customer, the values in the airplane are its technical data. These technical data are considered the requirements by the customer. The technical data of the airplanes are showed in the Figure 28.
But in the real market, companies don’t know that customers want. Lean theory tells us that it necessary to evaluate field quality data, market research, and competitor’s products to understand the customers. For example Toyota’s philosophy is selects program leaders with the background and experience to establish an emotional connection with the target customer.

To be consistent with the reality, can’t be shown to the player the real needs of the customers, because of they need to understand how important they are, and that they need to dedicate a big effort to understand the market and their needed.

For that has been decided in the first stage of the game give to the player a range of values where real customer need is include. This range in the first stage will be really high, because of their company is not dedicating many recourse to study the market. In the second phase the will have some tools to decrease this range and see the differences.

It is noteworthy to say this usually happens in real life and is one of the major wastes in the development of new products.

Another important fact that has been added to the game is "the market opportunity." It was considered that the sales and marketing department does a market study for a specific time, translated to the game is 30 minutes. If the player is unable to finish in the period of time given means that the estimation is not accurate because the market is constantly changing, it is a turbulent market. Therefore it should be penalized because the product is losing value.

In the chapter before was explained why this variables were chosen and in the second part of this chapter the way of calculate and meaning of each variable will be explained in details.
5.1.2 The airplane

The airplane is the product selected in the game. As it has been said before, the main characteristics of the airplane are its technical data. These technical data are a combination of all the characteristics of the pieces that compose the airplane.

The airplane must be designed using basic figures, triangles and rectangles, but at the same time must have the main parts in an airplane and an aerodynamic shape.

5.1.2.1 Parts of the airplane

The airplane has been divided into five basic parts; body, cockpit, wings, tail and power plant (engines) (Figure 29). This division has been used because is the normal division that the big aeronautical companies use. Each part is composed by squares, isosceles triangles and rectangle triangles (Figure 30).

Figure 29 – Parts of the airplane
It is important this division of the plane, because of each part has its function.

The **body** is the part where the passengers are located. While higher body higher number of passenger can be located. The shape of the body is always a rectangle, which for aerodynamics reason must be slender. The body is the central part of the plane, where are located the cockpit, the wings and the tail. For this reason, the body must be big enough to allocate all these parts.

The **cockpit** is the head of the airplane. Is always an isosceles triangle, and it is the place where are the pilot and the co-pilot. Always has the same width than the body.

The **wings** are the responsible what the plane flies. The parameter most important in the wing is their surface. While more surface more lift the plane has. The wings are also the place where the fuel is storage. That means than higher wings, more quantity of fuel, and so more distance to travel. In a plane, the wings cannot be too much big, since for structural reasons the can broke. There is a structural limit between the width of the wing and its length. Also the width of the wing has limits, since a wing as bigger as the body cannot be installed. So the wings must meet a size relation with the body and a shape relation with their measures.

The main task of the **tail** is to proportionate stability to the plane, although it also proportionate lift to the plane. The tail is always located behind the wings, and his area has to meet a relation with the wing surface. It is not possible a tail bigger than the wings.

Finally the **power plant** or the engines are what give power to the plane. The engines are always located in the wings, but due to the high weight they have, a limited number of them can be in the wing. They never are located in the tips of the wing, since the wing could broke due to the engine weigh. While higher the wing, more engines can be located in it. The engines proportionate speed, and while more number of engines higher consumption of fuel.
5.1.2.2 Components

As it was said before, the entire plane is composed by basic shapes; squares, isosceles triangles and rectangles triangles. Each basic shape has many characteristics depending on the part of the plane where is located. The characteristics of the pieces are:

- Area
- Dimensions (length and width)
- Weight
- Cost
- Time to build it or supply time
- Assembly time
- Capacity (number of passenger can located)
- Power (for engines)

The final technical data of the airplane will be a combination of all the characteristics of the pieces, so he is the big challenge for the player:

“He should find the right combination of all the basic shapes to achieve as closer as possible the customer’s requirements”

Some of the characteristics of the pieces will be shown to the player in a catalogue, the “Supplier Catalogue” (Figure 31). With this catalogue, the player could have an approximation of number of passengers, cost, speed (relating weight and power)…, of the final design of the airplane.

![Figure 31 – Supplier’s catalogue](image)
In the first stage of the game, the previous supplier’s catalogue is shown to the player, but it is not complete. It means that the company is not taking into account all the supplier constrains. It is normal in companies that they don’t ask to supplier for the stock of pieces for the times to arrives this pieces… when they are in the design phase of the product. It is a big mistake because then in the next phases the problems will appears and the due date can’t be met.

In the second stage of the game, a specific tool to solve these problems will be introduced.

5.1.2.3 Constrains

When an airplane is designed many considerations are taking into account. There are many constrains in terms of aerodynamic, structure, engineering, manufacturing that the designer has to consider. In order to do more realistic the design phase, some of these constrains have been include in an easy way. Some of them have been mentioned before, but now they are going to be explained and classified.

Manufacturing

- It is not allow putting two pieces overlapping each other. The pieces have to be put in order to fit between them.
- There cannot be empty spaces inside the airplane.

Engineering

- The maximum size of the airplane cannot exceed the size of the Design table.
- The airplane must be symmetric.
- The airplane must include: cockpit, body, wings, tail and engines.
- The width of the cockpit must be higher or equal than the length of the cockpit
- The length of the body must at least three times higher than the width.

Aerodynamic

Two aerodynamics considerations have been considered: the lift and the stability.

The lift is the force opposite to the gravity, what makes the airplanes flies. This force has to be higher than the weight of the plane in order that the plane can fly. Two are the ways to increase the lift: increase the wing and tail surface or increase the speed. These two variables are related in a direct proportional way with the lift.

The stability is related with the lift of the wing, the lift of the tail and the weight. The way to get a stable airplane is to modify the tail. In this respect, the ratio between tail size/surface and the wing size/surface must be between 0.3 and 0.6.

Structural

The first structural constrain relates the size of the wings with the size of the body. The maximum width of the wing (the part of the wing joined with the body) cannot exceed the 40%
of the length of the body. The width of the tail must be higher than a 60% the length of the wing.

The second structural constrain establishes the position of the engines in the wing. They cannot be put in the tips of the wings or in very narrow zones of it. The zone of the wing must have at least a width of 3 units of length to locate an engine. Also, the wing must be big enough to locate one, two, three or more engines.

The dimensions of the wing must meet a relation of proportionality. The width of the wing must be between 0.3 and 1 the length of the wings. The same relation must be met by the tail dimensions.

5.1.3 The design table

The “Design table” is called the place where the player has to design the airplane (Figure 32). The Design table is a square board of 30x30 cells. Each cell of the design table is considered a unit of area. The goal of the division of the Design table in the 90 cells is to help the player in the design. With this division the Design table is a mesh where in each cells the player put the piece he considers. All the pieces the player put outside the Design table are not considered.

![Figure 32 – Design table](image-url)
As it was explained before, to design the plane the player has to put the pieces inside the design table. The design table is transformed in a matrix (Figure 33) where each piece has a code to identify its characteristics. The code of each piece indicates the part of the plane the piece belongs (cockpit, body, wing, tail or power plant) and the type of piece it is (square, isosceles triangle or rectangle triangle). So the plane can be considered as a matrix of letters, using the next letters:

- \textit{sb} squares in the body
- \textit{tb} small triangles in the body
- \textit{bth} big triangles in the body
- \textit{sw} squares in the wing
- \textit{tw} small triangles in the wing
- \textit{btw} big triangles in the wing
- \textit{st} squares in the tail
- \textit{tt} small triangles in the tail
- \textit{btt} big triangles in the tail
- \textit{sc} squares in the cockpit
- \textit{tc} small triangles in the cockpit
- \textit{btc} big triangles in the cockpit
- \textit{e} engine
Figure 33 – Matrix of design

5.1.4 Test phase

In all the new product development process, there is a test phase. After the product is designed, then is needed to test it in order to check if meets all the requirements, or at least, the main ones. In the game, after the player has the first design, it is needed to check if, at least, the airplane meets with the restrictions; can fly? Is it stable? Is it well dimensioned?

To test the plane, the player has to press the “Can the airplane fly?” button. Clicking this button the game tells the player if the design meets constrains or if it doesn’t. In case the design meets with the restrictions, the technical data of the design will be showed, and the player will have the possibility of redesign the airplane or deliver it to the customer. In case some constraint will not be met, it will be shown an error message informing the player what is the wrong thing in his design.

This button can be pressed whenever the player wants, but of course, test a prototype is not free, it consumes time and cost each time the player send the airplane to test. For this, the player must press the button when he will be sure his design is good.
5.1.5 Design time

The design time is the time the player consumes to design the plane. This time just considers the time required for the player to design the plane (does not include test time, assembly time and others times). This time is measured with a clock situated in the main screen of the game (Figure 34). The player always is going to have thirty minutes to design his airplane. In case the player needs more time, he asks for more when the first 30 minutes runs out. After the first 30 minutes the player will be penalized in term of cost, and the extra minutes he asks will be summed to the final time.

![Figure 34 – Screen of the clock](image)
5.2 Quantitative model of the LeanPPD Game

After giving a general vision of how to play the game, the mathematical model is going to be explained in detail. It is very important to understand the main rules of the previous point, since all the equations explained here have their foundation in the ideas explained in it.

In the schema of the next page is explained the relation between the general equations and the variables of the problem. By one side are the customer’s requirements that are going to be shown to the player. In the other side are the characteristics of the airplane. They are related by the general equations of the game because of both necessary needs to meet these equations to be consistent.

Once this two variables are obtained the performance of the game, which will be calculated in the next section, will be the variance between them.

This section has been divided in three parts. The first part is the general equations. These equations define the technical data of the airplane taking the characteristics of the pieces of the design. To sum up, these equations take all the pieces used in the design and give a list of technical data.

The second part explains how the customer’s requirements are generated. The process since the player presses the Customer’s requirements button until the customer’s requirements appears in the screen. In a simple way, the program generates, by random functions, the dimensions of the body, and using this, the dimensions of the rest of the airplane are calculated. Then all the variables are introduced in the general equations to give the customer’s requirements variables.

Finally, the third part explains all the equations during the design phase. The player designs the airplane, and as was explained before this design is transformed in a matrix. The matrix has the full information to probe is the airplane meet constrains and if is the case, calculate the characteristics of the airplane.

5.2.1 General equations of the model

General equations are called all that equations whose outputs are technical data of the airplane. The technical data were shown in the point 5.1.1, so now just the equations are going to be explained.
Figure 35 – Flow of the equations
5.2.1.1 Capacity of the airplane

The capacity of one airplane is the number of passengers that can be located in the airplane. It’s necessary to take into account that the passengers just can travel on the body. For that the number of passengers has been defined as:

\[ Np = \sum_{i=s,t,bt} cap_{i,b} \times n_{i,b} \]

5.2.1.2 Speed of the airplane

The main parameter that measures the speed of an airplane is the *Ratio of power* [ROP]. This variable shows the percentage of the difference between the total power of the airplane and its weight. The formula is:

\[ ROP = 100 \times \frac{Free \, Power}{W} \% \]

where:

\[ W = \sum_{j=b,w,t,c} \sum_{i=s,t,bt} w_{i,j} \times n_{i,j} + w_e \times n_e \]

\[ Free \, Power = Power - W \]

\[ Power = n_e \times p_e \]

To calculate the weight \( W \), two wings and two tails have been considered. This is going to be considered in all the next equations.

5.2.1.3 Kilometres of travel

As it was explained before, the fuel is storage in the wings. This means while higher wing surface more quantity of fuel. It was explained also, that while more number of engines, more rating of fuel consumption, so the fuel runs out earlier with 6 engines instead of 2.

With the previous paragraph, it can be understood that the maximum range of the airplane increases with the wing surface, and decreases with the number of engines. To take into account these two relations, the kilometres of travel have been defined as:

\[ KmT = Wing \, Surface \times Distance \, per \, block \]
where:

\[
\text{Distance per block} = \begin{cases} 
200 & \text{if } n_e = 2 \\
150 & \text{if } n_e = 4 \\
100 & \text{if } n_e \geq 6 
\end{cases}
\]

\[
\text{Wing Surface} = \sum_{i=s,t,ht} n_{i,w} * a_i
\]

The \text{Distance per block} indicates the kilometres the plane can travel with the fuel storage in one square of the wing. It can be seen that with 6 engines the range per square is much lower than with 2 engines.

5.2.1.4 Parking requirements

In the next figure, it is possible to see the definition of length and wingspan of an airplane. There are no specific equations for the length of the wingspan. The method used to determine these two variables is based on the design matrix as can be seen in the Visual Basic code, Annexes 8.1.

![Figure 36 – Wingspan and length of an airplane](image-url)
5.2.1.5 Delivery time

The delivery time is the time since the player asks for the customer’s requirements until the plane is finished, and it is calculated as:

\[ Dt = time \ of \ supplier + time \ of \ assembly + t_d + time \ of \ test \]

where:

\[ time \ of \ supplier = \sum_{j=b,w,t,c} \sum_{i=s,t,bt} ts_{i,j} \cdot n_{i,j} + ts_e \cdot n_e \]

\[ time \ of \ assembly = \sum_{j=b,w,t,c} \sum_{i=s,t,bt} ta_{i,j} \cdot n_{i,j} + ta_e \cdot n_e \]

\[ Time \ of \ test = 5 \times \# \ tests \]

\[ t_d = time \ of \ design = t_{d,normal} + t_{d,extra} \]

The time of design is measure by the clock installed in the game. Initially the time given to design is 30 minutes, then the player can ask for more time if is needed. This time is the sum of the total time required to design the plane.

The Time of test is the time consumed in doing tests. Each time that the player needs to test the airplane (press the can the airplane fly? button) he will be penalized with 5 minutes of time.

5.2.1.6 Cost

The cost is divided in four parts:

\[ C = Material \ cost + Engineering \ cost + Test \ cost + Opportunity \ cost \]

Material Cost

The material cost is the total cost of all the pieces used in the airplane.

\[ Material \ Cost = \sum_{j=b,w,t,c} \sum_{i=s,t,bt} c_{i,j} \cdot n_{i,j} + c_e \cdot n_e \]
The cost of each piece is given in the supplier catalogue, explained in the chapter 5.1.2.2.

Engineering Cost

The engineering cost is the money the player is going to be paid for design the plane. The player is supposed to have two fares: the price per hour in normal conditions and the price per extra hour of work. The normal scheduled of work is considered the first 30 minutes; after this time all the time consumed will be considered as extra time.

\[ \text{Engineering cost} = \text{cost per min} \times t_{d,\text{normal}} + \text{cost per extra min} \times t_{d,\text{extra}} \]

where:

\[ \text{cost per min} = 18 \text{ unit/min} \]
\[ \text{cost per extra min} = 36 \text{ unit/min} \]

Test Cost

When the player considers the airplane is finished, he will ask for test the prototype. This happens when the player presses the can the airplane fly? button. The cost of the test is 20unit/min (the price per minute of the testers) and each test takes 5 minutes.

\[ \text{Test cost} = 20 \text{ unit/min} \times 5 \text{ min} \times \text{ number of test} \]

Opportunity cost

The customer’s needs estimation is in a concrete period of time so, the player needs to be faster delivering the product. If he is not able to deliver it in the time asked for the customer he will lose the market opportunity and he will be penalized with opportunity cost. While more time needs, bigger will be the penalization, because of the estimation is not so good and the market is continuously changing.

\[ \text{Opportunity cost} = 0.05 \times [\text{Material cost} + \text{Engineering cost} + \text{Test cost}] \times t_{\text{delay}} \]

where:

\[ t_{\text{delay}} = \begin{cases} D_t - D_{tc} & \text{if } D_t > D_{tc} \\ 0 & \text{if } D_t \leq D_{tc} \end{cases} \]
5.2.2 Definition of the customer’s requirements

The generation of the customer’s requirements is a critical point in the game. The game starts with the definition of the customer’s requirements, and the entire process of the player revolves around these values. Indeed, the goal of the player is to get values as close as possible to the customer’s values. For this reason, the requirements of the customer must be coherent values, without any contradiction and reachable values for the customer. For example, the player cannot put as requirements a capacity of 300 passengers and a wing span of 2, because these two numbers will never satisfy the equations of the methodology.

To get these requirements, a mathematical process has been developed. The inputs data are random values of the pieces in the body, and from this point, a list of equations is used in order to get coherent values in a random way.

Now the process is going to be explained in the order the equations are used. The process has been divided in sub-process to a better comprehension.

5.2.2.1 Dimension of the airplane and the number of pieces in each part

The main structure of the airplane, in which all the other dimensions are based, is the body. The first step in the process will be the creation of a body using a random number of pieces.

Body

Length of the body: \[ ly_b = \text{Random}[26; 11] \]
Where 26 is the maximum length and 8 the minimum.

Width of the body: \[ lx_b = \text{Random}[4; 2] \]
Where 4 is the maximum width and 2 the minimum.

Size of the body: \[ \text{BodySurface} = ly_b \times lx_b \]

After obtaining the size of the body (area), it is necessary to divide it in squares, big triangles and small triangles. For this purpose, the process continues using random functions.

First of all, a percentage of squares in the total number of pieces will be defined. Using the same methodology based on the before percentage of squares, the number of small triangles are calculated. Another percentage for the total number of big triangles in the body will be defined. Both percentages cannot overpass the 100% of the body. To get the number of squares and big triangles in the body, both coefficients are applied to the total area of the body, and the results...
are rounded to the lower entire. In the case of the big triangles it is necessary to round down to
the lower pair entire.

\[ a = \text{Random}[0; 1] \]

\[ b = \text{Random}[0; (1 - a)] \]

\[ n_{s,b} = \text{Body Surface} \times a \]

\[ n_{bt,b} = \text{Body Surface} \times b \]

Finally, the number of isosceles triangles will be the rest till complete the total area of the body.
Noted than the area of the little triangles are 0.5 unit of area.

\[ n_{t,b} = (\text{Body Surface} - n_{s,b} - n_{bt,b}) \times 2 \]

**Cockpit**

Using the dimensions of the body the dimensions of the cockpit will be defined. The width of
the cockpit will be the same than the width of the body.
The length of the cockpit will be selected between six standard measures (six standard cockpits).

- Cockpit I

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{s,c} )</td>
<td>4</td>
</tr>
<tr>
<td>( n_{t,c} )</td>
<td>0</td>
</tr>
<tr>
<td>( n_{bt,c} )</td>
<td>4</td>
</tr>
<tr>
<td>( L_c )</td>
<td>4</td>
</tr>
</tbody>
</table>

- Cockpit II

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{s,c} )</td>
<td>4</td>
</tr>
<tr>
<td>( n_{t,c} )</td>
<td>2</td>
</tr>
<tr>
<td>( n_{bt,c} )</td>
<td>2</td>
</tr>
<tr>
<td>( L_c )</td>
<td>3</td>
</tr>
</tbody>
</table>
Cockpit III

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{S,c}$</td>
<td>2</td>
</tr>
<tr>
<td>$n_{T,c}$</td>
<td>4</td>
</tr>
<tr>
<td>$n_{BT,c}$</td>
<td>0</td>
</tr>
<tr>
<td>$L_c$</td>
<td>2</td>
</tr>
</tbody>
</table>

Cockpit IV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{S,c}$</td>
<td>0</td>
</tr>
<tr>
<td>$n_{T,c}$</td>
<td>0</td>
</tr>
<tr>
<td>$n_{BT,c}$</td>
<td>2</td>
</tr>
<tr>
<td>$L_c$</td>
<td>1</td>
</tr>
</tbody>
</table>

Cockpit V

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{S,c}$</td>
<td>0</td>
</tr>
<tr>
<td>$n_{T,c}$</td>
<td>0</td>
</tr>
<tr>
<td>$n_{BT,c}$</td>
<td>2</td>
</tr>
<tr>
<td>$L_c$</td>
<td>2</td>
</tr>
</tbody>
</table>

Cockpit VI

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{S,c}$</td>
<td>0</td>
</tr>
<tr>
<td>$n_{T,c}$</td>
<td>2</td>
</tr>
<tr>
<td>$n_{BT,c}$</td>
<td>0</td>
</tr>
<tr>
<td>$L_c$</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 12 - Different types of cockpits
One of these models will be selected randomly. If the width of the body is 4, the model of the cockpit could be I, II, III or IV. In case the width of the body will be 2, just two models of cockpit will be possible, V or VI. With this the coherence of the value is met.

$$i = \begin{cases} \text{Random}[5; 6] & \text{if } lx_b = 2 \\ \text{Random}[1; 4] & \text{if } lx_b = 4 \end{cases}$$

The coefficient $i$ shows the type of cockpit in the plane.

**Wing**

<table>
<thead>
<tr>
<th>Type I- Rectangle shape</th>
<th>Type II-Triangle shape</th>
<th>Type III- Mix shape</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Type I" /></td>
<td><img src="image2" alt="Type II" /></td>
<td><img src="image3" alt="Type III" /></td>
</tr>
</tbody>
</table>

Table 13 - Different types of wings

The plane can have three different types of wings. Each one of them has different characteristics and different shape. The type of the wing will be calculated randomly and its size will be proportionate to the size of the body in order to meet the constrains explained before (5.1.2.3).

The parameter $p$ indicates the type of wing.

$$p = \text{Random}[1; 3]$$

Once the type is selected, the area (size) and the number of each type of piece are calculated as follow.

In the next equations, all the results will be rounded to the upper entire number.
**Type I: Rectangle shape**

With this model, the width of the wing is going to be a 20% of the length of the body.

\[ ly_w = 0.2 \times ly_b \]

Once the width is calculated, the length of the wing will be defined as 2.5 times its width:

\[ lx_w = 2.5 \times ly_w \]

So the wing surface will be:

\[ \text{WingSurface} = 2 \times ly_w \times lx_w \]

The method to calculate the number of squares, big triangles and triangles in the wing is the same than the method used in the body (see 5.2.2.1 Body).

**Type II: Triangle shape**

The width of this type of wing will be a 30% of the length of the body.

\[ ly_w = 0.3 \times ly_b \]

The length will be 2 times the width:

\[ lx_w = 2 \times ly_w \]

\[ \text{Wing Surface} = ly_w \times lx_w \]

In a triangle shape, the squares can’t be in the hypotenuse of the triangle. To calculate this kind of wing, it has been established that in the hypotenuse just can be big triangles.

The process to calculate the number of pieces is showed below:

\[ c = \text{Random}[0,1] \]

\[ d = \text{Random} \ [0, (1 - c)] \]

\[ n_{bt,w} = \left[ 2 \times ly_w + c \times (\text{Wing Surface} - 2 \times ly_w) \right]_\text{\_} \]

rounded to the lower entire number.
Type III: Mix shape

The width of this type of wing is going to be a 30% of the length of the body.

\[ l_{y_w} = 0.3 \cdot l_{y_b} \]

After obtain the width, the length will be 2 times the width of the wing.

\[ l_{x_w} = 2 \cdot (l_{y_w} - 1) \]

The formula to obtain the area of the wings is:

\[ \text{Wing Surface} = 2 \left[ (l_{y_w} - 1) \cdot l_{x_w} \cdot \frac{1}{2} + (l_{x_w} - 0.5) \right] \]

The way to calculate in a random way the number of each piece what compose the wing is very similar to the method used in the triangle wing. Just it is necessary to add the area of the last raw of the wing. To ease the method the number of isosceles triangles is going to be fixed in two units, one in each tip of each wing. The rest of the wing will be composed by big triangles and squares.

\[ n_{bt,w} = (l_{y_w} - 1) \cdot 2 \]

\[ n_{t,w} = 2 \]

\[ n_{s,w} = \text{Wing surface} - n_{bt,w} - n_{t,w} \]

Tail

The tail must meet all the stability constrains, so its size must be in accordance with the size of the wing. To remember, some constrains are showed.

\[ \text{Condition of stability} \quad 2 < \frac{\text{Wing Surface}}{\text{Tail Surface}} < 6 \]

\[ \text{Shape of the tail} \quad 0.3 < \frac{l_{y_t}}{l_{x_t}} < 1 \]
Equal to the wings, there are three different types of tails. The type of the tail is selected randomly. With the shape and the size of the body, the size of the tail is calculated.

<table>
<thead>
<tr>
<th>Type I- Rectangle shape</th>
<th>Type II- Triangle shape</th>
<th>Type III- Mix shape</th>
</tr>
</thead>
</table>

Table 14 - Different types of tails

The results in the next equations are rounded to the upper entire number.

**Type I: Rectangle shape**

In order to meet the stability constrain, the width of the tail will be the 10% of the length of the body.

\[ l_y_t = 0.1 \times l_y_b \]

Once the width is fixed, the length of the tail will be 2 times the width of the tail.

\[ l_x_t = 2 \times l_y_t \]

Tail Surface = \(2 \times l_y_t \times l_x_t\)

To ease the game, this type of tail is going to be designed only with big triangles. As each big triangle occupies one block, the number of big triangles is the same than the area of the tail.

\[ n_{pt,t} = 2 \times l_y_t \times l_x_t \]

\[ n_{s,t} = 0 \]

\[ n_{t,t} = 0 \]
Type II: Triangle shape

With this model, the width of the tail is going to be a 20% of the length of the body.
\[ l_y_t = 0.15 \times l_y_b \]

The length of the tail will be 2 times the width of the tail.
\[ l_x_t = 2 \times l_y_t \]

Tail Surface = \( l_y_t \times l_x_t \)

In these tails the hypotenuse is made with big triangles and the rest of the tail with squares.
\[ n_{bt,t} = 2 \times l_y_t \]
\[ n_{t,t} = 0 \]
\[ n_{s,t} = \text{Tail Surface} - n_{bt,t} \]

Type III: Mix shape

The widths of these tails are going to be a 20% of the length of the body.
\[ l_y_t = 0.2 \times l_y_b \]

The length of the tail will be 2 times the width of the tail.
\[ l_x_t = 2 \times (l_y_t - 1) \]

Tail Surface = \((l_y_t - 1) \times l_x_t + 2 \times l_x_t - 1\)

The distribution of pieces to compose the tail surface is the next:
\[ n_{bt,t} = 2 \times (l_y_t - 1) \]
\[ n_{t,t} = 2 \]
\[ n_{s,t} = \text{Tail Surface} - n_{bt,t} - n_{t,t} \]
Engines

The number of engines depends on the length of the wing, so:

\[
n_w = \begin{cases} 
2 & \text{if } l_{xw} \leq 6 \\
\text{Random}[2;1] & \text{if } 6 < l_{xw} \leq 9 \\
\text{Random}[3;1] & \text{if } l_{xw} > 9 
\end{cases}
\]

Once the number of engines is determined, it is checked if the plane can fly or cannot. In case the plane cannot fly two more engines are added, and the plane is checked again till the lift will be higher than the weight. When this requirement is met the process stops.

5.2.2.2 Definition of the technical data; Customer’s requirements

After define the pieces of the plane, its shape and its dimensions, it is the turn to determine its technical data.

To get the technical data all the pieces with their characteristics are introduced in the General Equations (see 5.2.1). The meetings of the restrictions are guaranteed since in the dimensioning of the plane all that constrains were taken into account. The technical data are:

- Number of passengers
- Ratio of Power
- Km of Travel
- Length
- Wingspan
- Cost, to calculate it, has been considered that there isn’t opportunity cost, because of is the perfect design, with the higher qualification.
- Delivery Time. For that has been considered that the designer just needs 30 min to design and just need to make one test.

The values obtained with the general equations are exactly the values the customer wants. To be consistent with the reality and to consider the estimation the sales and marketing department does, the exact values are not going to be showed to the player. Instead of this, a range of values will be showed. The exact value of the customer will be inside this range. In the next, the estimation of these ranges of values will be explained.

Number of passengers

The interval of the number of passengers will have a variation of the 20% of the real value. To avoid the exact value will be just in the middle of the interval, the two limits, the lower and the upper, are taken randomly.
\[\alpha = Random [0, 2]\]
\[\beta = 2 - \alpha\]
\[N_{p_{\text{min}}} = N_{p} \times (1 - \frac{\alpha}{10})\]
\[N_{p_{\text{max}}} = N_{p} \times (1 + \frac{\beta}{10})\]
\[N_{p} \in [N_{p_{\text{min}}}; N_{p_{\text{max}}}]\]

Where \(N_{p_{\text{min}}}\) is the lower value of the range and \(N_{p_{\text{max}}}\) is the higher.

The goal of the next example is to clarify the method explained before. If the real value is 300 passengers, \(10f\) can be a value between 0 and 20, for example 15. In this case \(10g\) will be 5, \(N_{1}\) will be 0.85*300=255 and \(N_{2}\) will be 1.05*300=315.

**Ratio of Power**

The Ratio of Power (ROP) will be given to the player in term of speed. There are three ranges of speed: slow, medium or fast. Each range is inside a range of values, so the customer must choice what value takes to meet this specification.

<table>
<thead>
<tr>
<th>Value of ROP</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ROP \leq 40)</td>
<td>Slow</td>
</tr>
<tr>
<td>40 (&lt; ROP &lt; 60)</td>
<td>Medium</td>
</tr>
<tr>
<td>(ROP \geq 60)</td>
<td>Fast</td>
</tr>
</tbody>
</table>

**Kilometres of travel (KmT); maximum range**

The maximum range of the plane is given in the same way than the \(ROP\).

<table>
<thead>
<tr>
<th>Maximum range</th>
<th>Destinies</th>
</tr>
</thead>
<tbody>
<tr>
<td>(KmT \leq 10000)</td>
<td>Continental</td>
</tr>
<tr>
<td>10000 (&lt; KmT &lt; 15000)</td>
<td>Transatlantic</td>
</tr>
<tr>
<td>(KmT \geq 15000)</td>
<td>Very High Range</td>
</tr>
</tbody>
</table>
**Length**

Here, the process is as in the number of passengers:

\[ y = Random [0; 3] \]
\[ \delta = 3 - y \]
\[ L_{\text{min}} = L \ast (1 - \frac{y}{10}) \]
\[ L_{\text{max}} = L \ast (1 + \frac{\delta}{10}) \]
\[ L \in [L_{\text{min}}; L_{\text{max}}] \]

Where \( L_{\text{min}} \) is the low value of the range and \( L_{\text{max}} \) is the higher one.

**Wingspan**

The same as before:

\[ \varepsilon = Random [0; 3] \]
\[ \theta = 3 - \varepsilon \]
\[ ws_{\text{min}} = ws \ast (1 - \frac{\varepsilon}{10}) \]
\[ ws_{\text{max}} = ws \ast (1 + \frac{\theta}{10}) \]
\[ ws \in [ws_{\text{min}}; ws_{\text{max}}] \]

Where \( ws_{\text{min}} \) is the lower value of the range and \( ws_{\text{max}} \) is the higher one.

**Cost**

To calculate the Cost, it has been considered the material cost, the engineering cost for the first 30 minutes of design and the corresponding cost for a test. The opportunity cost has not been considered in this point, since the opportunity cost is not considered by the customer, just for the manufacturer. To get the range of values it is used the same process explained before.

\[ \mu = Random [0; 2] \]
\[ \sigma = 2 - \mu \]
\[ C_{\text{min}} = C \ast (1 - \frac{\mu}{10}) \]
\[ C_{\text{max}} = C \ast (1 + \frac{\sigma}{10}) \]
\[ C \in [C_{\text{min}}; C_{\text{max}}] \]

Where \( C_{\text{min}} \) is the lower value of the range and \( C_{\text{max}} \) is the higher.
\textbf{Delivery time}

\[\tau = \text{Random}[0; 2]\]

\[\varphi = 2 - \tau\]

\[Dt_{\text{min}} = Dt \times \left(1 - \frac{\tau}{10}\right)\]

\[Dt_{\text{max}} = Dt \times \left(1 + \frac{\varphi}{10}\right)\]

\[Dt \in [Dt_{\text{min}}; Dt_{\text{max}}]\]

Where \(Dt_{\text{min}}\) is the lower value of the range and \(Dt_{\text{min}}\) is the higher.

\section*{5.2.3 Design phase}

The design phase starts when the player presses the customer’s requirements button. After this, the clock starts counting and the player starts designing his plane.

As it was explained before, to design the plane the player has to put the pieces inside the design table. As it was explained in the point 5.1.3, the design table is a matrix where each piece has a code to identify its characteristics. The code of each piece indicates the part of the plane the piece belongs (cockpit, body, wing, tail or power plant) and the type of piece it is (square, isosceles triangle or rectangle triangle). So the plane can be considered as a matrix of letters.

The program takes these letters from the design table matrix, and counts all of them, grouping the same pieces and giving the total number of each type with a new variable. These variables are \(n_{i,j}\) and \(n_e\).

\subsection*{5.2.3.1 Testing the design}

When the player thinks his design is ok, he presses the \textit{Can the airplane fly?} button. When this button is pressed, the program takes the variables \(n_{i,j}\) and \(n_e\) and checks if all the restrictions are met. In case some of them will not be met, a message will appear showing the problem. The possible problems are listed below.

\textbf{Design problems}

The next errors can happen:

"There is nothing designed" \(\rightarrow\) if the design table is in blank

"The airplane is not symmetric or is not well centred with the axis"

"You need to put a Body" \(\rightarrow\) if the player forgot to design the body of the airplane

“You need to put Cockpit" \(\rightarrow\) if the player forgot to design the cockpit of the airplane
"You need to put a tail" → if the player forgot to put the tail to the airplane
"You need to put a wing" → if the player forgot to put the wings to the airplane
"You need to put power" → if the player forgot to add engines to the airplane

Aerodynamic messages

Two are the aerodynamic errors can happen: not enough lift or not stable.
To check if the airplane has enough power to fly, it is needed to make some aerodynamic considerations.
Condition of fly:

\[
\frac{Lift}{W} \geq 1
\]

Where the weigh was calculated before and the lift is defined as:

\[
Lift = (Wing Surface + Tail Surface) * Coefficient of lift * 3
\]

where:

\[
Wing Surface = \sum_{i=s,t,ht} n_{i,w} * a_i
\]

\[
Tail Surface = \sum_{i=s,t,ht} n_{i,t} * a_i
\]

To obtain the Coefficient of lift it necessary to use the graph showed below. This coefficient has a linear relation with the Ratio of Power. These relations have been simplified of the reality and it can be seen in the Figure 37.
So if the airplane doesn’t meet the condition of fly, the next message will appear:

"Condition of fly: The airplane can’t fly because of Lift/Weight is lower than 1, so your airplane is very heavy"

Condition of stability:

$$3 < \frac{Wing\ Surface}{Tail\ Surface} < 6$$

If the airplane doesn’t meet the condition of stability, the next message will appear:

"Condition of Stability: The airplane can’t fly because of (Wing Surface/ Wing Tail) isn’t between 3 and 6, so your airplane is not stable."

Others errors related with the aerodynamic that can appear are:

“You don’t have enough power to your weight." → It means that the airplane need more power

“The body of the airplane is not aerodynamic” → It means that the length of the body is lower than 3 times the width of the body, so is a bluff body.
Dimensions errors

“The cockpit is not well dimensioned” \(\rightarrow\) it means that the width of the cockpit is lower than the length of the cockpit. This happens when the next relation is not met:

\[
\frac{lx_c}{ly_c} \geq 1
\]

"The wing is not enough big to put so many engines" \(\rightarrow\) This appears when:

\[n_e \geq 6 \quad \cup \quad \text{Wing Surface} \leq 21\]

or

\[n_e = 4 \quad \cup \quad \text{Wing Surface} \leq 9\]

or

\[n_e = 2 \quad \cup \quad \text{Wing Surface} \leq 4\]

"The wing width is not well dimensioned with respect to the body“ \(\rightarrow\) This appears when:

\[ly_w > (0.4 \times ly_b)\]

"The ratio of the wing is not well dimensioned“ \(\rightarrow\) This appears when the next relation is not met:

\[0.3 < \frac{ly_w}{lx_w} < 1\]

"The tail width is not well dimensioned with respect to the wing“ \(\rightarrow\) This appears when:

\[ly_t > 0.6 \times ly_w\]

"The ratio of the tail is not well dimensioned“ \(\rightarrow\) This appears when the next relation is not met:

\[0.3 < \frac{ly_t}{lx_t} < 1\]

If no one of the previous errors occurs, then the airplane met with all the restriction, so it is ready to fly.
5.2.3.2 Technical data of the airplane designed

After passes all the restriction, it is the turn to calculate the technical data of the airplane. To obtain the technical data the variables $n_{ij}$ and $n_e$ are introduced in the General Equations, and the result, will be the technical data.

The technical data are showed to the player, and the player decides if his design has good performances or not compare with the customer’s requirements. In case the player decides redesign the plane, he can ask for this and modify his design. Of course this act will be penalized with the time and cost of the test (5.2.1.5 and 5.2.1.6).

In case the player goes on with his design, he finishes the game and the score will be showed.

5.3 Flow of the game

Once explained each part of the game, it is time to explain what are the steps and the process during the play.

The game is divided in two stages. In the first stage the player doesn’t have any help, and he has to design himself the plane. This stage tries to imitate the new product development process (NPD process) in the most of the traditional companies. The second stage provides some helps for the player. This helps are the lean enablers, and try to show the player how a lean NPD process works.

Finally, the score obtained in the two stages will be compared in order to determine how good the player’s design is in each stage, and the cost and time consumed in each one.

5.3.1 Stage 1

The stage 1 starts when the player presses the button “Customer’s requirements”. In this moment the Sales & Marketing department generates an approximation of the customer’s values, which is the range of values showed to the player. Also, the clock starts counting.

With the instruction of the game, the supplier’s catalogue and his ability, the player must create a plane that meets all the restriction and what has a technical values similar to what customer wants. For this the player will not have any help, just his mind and his calculator to calculate the number of pieces, size of the parts, number of passengers, etc.

Once the player thinks his design is good enough, he will presses the “Can the airplane fly?” button to ask for a test. The player’s design will be checked, and in case the design will be good, the technical data will be showed to the player.
The player now considers if his performance are acceptable or not. In case he considers ok his performance, the final score will be showed. In case he considers not acceptable his performance he can redesign his plane and turn back to the design phase.

The next flow chart shows the steps that can follow the player in the game. This schema is the same for the stage 1 and for the stage 2, because the differences are in the way to design.
Figure 38 – Flow of the Game
5.3.2 Stage 2

The steps in the stage 2 are the same than in the stage 1. The difference is that in the stage 2 the player can use some tools, lean enablers, to obtain better performances and stay closer to what customer wants.

In the next, it is going to be explained how the lean enablers can help the player to get better results.

In the second stage, the methodology to play is the same than in the first stage. The difference is that now the player can use the “Lean enablers”. In the interface of the game (Figure 40) will appear a new button. If the player pushes this button 7 enablers will appears (Figure 39).

The player can activate or deactivate the enablers when he wants using that they needs from it.

These are elements that will help him in the designing process, reducing the time and cost and increasing quality and performances. To understand how these enablers work, a new bottom called “Lean tools instructions” was added (Annexe 8.2.3), where is explained how they need to use it and what makes each one of them.

![Figure 39 – Screen of the Lean Enablers.](image-url)
Figure 40 – Interface of the Stage 1 of the game.
5.3.2.1 Chief engineer

In a lean NPD process, the main task of the chief engineer is to understand what the values are for the customer. The chief engineer has a huge technical knowledge, he has leadership capabilities and he knows the state of the project all the time. He applies the knowledge he has to understand what customers really want.

As has been seen previously, the CE has multiple tasks. Between all of them, represent the customer’s voice is the most critical. Represent the role that the CE has in the LPD system is difficult; however, it is easy to show how it affects in the interpretation of the customer’s values.

The chief engineer is a key part in a lean NPD process. For this it is a lean enabler in the game. The chief engineer enabler gives the player a better estimation of the customer’s requirements. This is got, reducing the range of value showed to the player. Instead a variation of the 20%, the chief engineer gives the player a range of values with the 10% of variation. This led the player his design will be more accurate.

This is the way to show inside the game the figure of the CE and the importance of understand well the idea that “Customer goes first”.

To calculate these variables is needed just to changes the values of the percentage in the equation of the “Estimation of customer requirements” explained before.

It will help the player to get a higher punctuation because of the lean points that the player will get are given for the difference between the characteristic of the design and the characteristics that the customer wants in the airplane.

<table>
<thead>
<tr>
<th>Estimation of customer needs with Chief Engineer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Range of passengers</td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Km of Travel</td>
</tr>
<tr>
<td>Lenght</td>
</tr>
<tr>
<td>Wing Span</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Delivery time to customer</td>
</tr>
</tbody>
</table>

Figure 41 – Screen of chief engineer
5.3.2.2 Previous knowledge

Many companies view paying for employees to learn as an unnecessary cost. Anything that is not tactical or does not produce immediate, measureable results is “fluff”, and those who endorse an opposing view are not considered serious-minded, action-oriented business people. But the absence of deep technical understanding drives a “more is better” philosophy, which leads to more elaborate gauges, more reviews, more audits, more inspections, and more checkpoints (because it is always “safe” to check and check again). You cannot “inspect in quality” – and this applies to product development and manufacturing. Furthermore, constant inspection tends to create a culture of fear.

In a lean company, invest in formation for the people if very important. The success of a lean process is in the people that work in it. The previous knowledge enabler provides the player some extra information in order to design a better plane. This extra information added to the instruction of the game, is all the information the player needs to design a good airplane.

With the previous knowledge, the player will have information about general “aeronautical” knowledge, can be really useful for the player attempt to this tricks. Instead of learn by proof and error, the player can acquire some basic lessons about plane design and applied it.

This enabler requires time, since the player has to read and understand all the points explained. The time consumed by the player to read the information, should be lower than the time saved when the player designs.

As is not the goal of the game know about aeronaunical, the sentences were simplify for that any person can understand. These lessons are related with the most commons mistakes that appear when the player pushes “Can the airplane fly?” , for that it will help to understand and solve this kind of problems.

![Figure 42 – Screen of previous knowledge](image-url)
5.3.2.3 Standardization

The purpose of standardization is to eliminate wastes during the design phase. The wastes are eliminated saving time in develop new designs of some components, and saving errors in new components developed.

With this tool the player can see shapes of wings, tails and cockpits that others engineers have proved before and worked well. With this the player saves time designing new components and he/she will be sure that these designs are going to give good performances.

The standardization is the most intuitive tool. The player takes the model he prefers and adapts the size to his plane. This makes to save time in the design phase and gives good technical data to the airplane designed. Using this shapes the player will eliminate many of the “Dimensions messages” and “Design messages” that don´t allow the airplane fly.

The player will have standards shapes for the cockpit, wing and tail in the Annexe 8.3. These shapes were chosen because of are the most common used in real life. The idea is that the player sees the shapes, the dimensions and the relation between width and length. Ones he selects one shape he will need to scale it to his own model, because of the player can´t forget that all is related with the body of the airplane.

![Figure 43 – Screen of standardization of the cockpit](image)
5.3.2.4 Guest supplier

With the guest supplier the lean company gets a total integration with its supplier. The guest engineer share information daily with their engineers, and learn how the LPD system works.

In the lean companies the relation with its suppliers is very tight. The cooperation between both is very high, what leads both company take advantages each other. A high number of engineers of the supplier company working in the main company. This helps the supplier to understand the necessities of the main company, and helps to the main company to know what the supplier can provide it.

This enabler provides the player a more detailed supplier catalogue. This makes the player to understand what supplier can provide and how much time they need for this. This is a way to show a better cooperation between the company and its suppliers.

In the first stage of the game the player has the Supplier’s catalogue, but it just contains the capacity, power, weight and cost. So the player don’t have any idea of the time that the supplier needs to manufacture the pieces. For that the player can really calculate the delivery time with precision.

With this tool the player can take into account that one big triangle for one passenger will take 43 sec, and 1 square for 3 passengers will take 15 seconds, but the weight of the square is bigger than the triangle so depending on the customer requirements the player best choice will be one big triangle or one square.

<table>
<thead>
<tr>
<th>Pieces</th>
<th>Without passengers</th>
<th>With passengers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Power</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Weight</td>
<td>10</td>
<td>11.5</td>
</tr>
<tr>
<td>Cost</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>Time to arrive</td>
<td>10 sec</td>
<td>12 sec</td>
</tr>
<tr>
<td>Time of assembly</td>
<td>4 sec</td>
<td>4 sec</td>
</tr>
</tbody>
</table>

Figure 44 – Screen of guest supplier
### 5.3.2.5 Cross-functional information

As it was explained before, cross-functional teams are groups composed by engineers of different departments. The Obeya is possible with the cross-functional integration. With the Obeya the state of the project is follow each two days. Cross-functional teams has been selected instead of Obeya cause cross-functional is a concept too much broad than Obeya. The cross-functional integration is one of the key in a LPD system.

Cross-functional information is the same than concurrent engineering. This is the flow of information between different departments at the same time they work. This allows the company to know how the project is developing. All the departments participate in this process, since market & sales till manufacturing.

In the game, it has been tried emulate this process giving the player all the technical data of his design in real time, at the same time he designs. It is as if all the departments work together in the design, and each one of them gives their information about the project while they work. So the player knows exactly its technical data while he is designing, and he can decide if his design is good or not without test it. It’s like if the player is the CE and is communicating all time with the different departments checking the performances of the plane constantly.

This tool does not show if the plane meets all the restriction or not, just helps with the technical data of the plane, so the player must think about the restriction.

The cross-functional team enabler is a dynamic tool in the game. This tool changes the value of the design when the player adds or removes a piece showing the real characteristics of the airplane that is in the design table in the moment.

![Figure 45 – Screen of cross-functional teams](image-url)
5.3.2.6 Front loading

By front-loading, you anticipate and solve problems before tools are even designed and before any capital investment.

Front load means tests the design at the maximum in order to see the weak points, and modify these weakness as soon as possible. This is made in the design phase because is when is cheaper and easier, and the repercussions for the future are higher.

The front-load enabler in the game gives the player some designs of planes with their technical data (Annexe 8.4). With the planes and theirs performances, the player can modify an adapt theirs features to get the characteristics he wants. It is a way to attack and test previous designs to change them into a totally new design with parts of the others.

With this enabler the player is taking into account the knowledge acquired by other engineers that have more experience.

The idea is that the player study each draw and its characteristic, search for the most similar to its customer’s requirements and copy and paste the design to its design table.

Obviously, then the player will need to modify the design to get the characteristic that he needs.

The name of this enabler and the way it helps in the game can confuse the players. The way it helps is not exactly the definition of front-load, but it is an approximation of how the front-load works in a company. For players with high knowledge about lean the way the front-load process is represented in the game is not correct, but for player with no one or less knowledge of lean is a good way to show them how could be the front-load process.

![Figure 46 – Screen of front loading model 1.](image)
5.3.2.7 Trade-off curves

The use of trade-off curves is easy to implement. This tool has been chosen due to its easy use and the quantity of information that they give.

The trade-off curves are curves what represent three variables: one on the vertical axis, one on the horizontal axis and the other represented by different curves. The player can enter in the graph with two variables and gets the other one. These curves show information in a visual and clear way.

The parameters represented in these curves are Weight versus Speed and Wing Surface versus Km of travel.

The Speed and the Km of travel are always a date of the problem, because of is a requirement of the customer. Then can happens two things: that the player has the number of engines that he needs in which case he will get automatically the weight that he can’t overpass; or that the player has an estimation of the weight and he wants to know the minimum number of engines that he needs to put for that the airplane can fly. The same argument can be applied for the second trade-off curve.

With this tool the player will learn how to solve the most of the problems related with the “Aerodynamic messages”.

To represent these two curves have been used the next equations explained in the previous sections.

\[
\text{Ratio of power} = 100 \times \frac{\text{Free Power}}{\text{Weight}}
\]

\[
\text{Km of travel} = \text{Wing surface} \times \text{Distance per Block}
\]

If the player is asked for a determined speed and weight and he needs to know the number of engines, he takes the graph in the Figure 47. Enter with the required speed and weight, and fixes the point. If the point is under the blue line, with 2 engines will be enough. If the point is between the blue and red lines, the options are 4 or 6 engines. And finally if the point is under the green line, the only option is 6 engines.
Figure 47 – Screen of trade-off curves: speed versus weight.

Figure 48 – Screen of trade-off curves: Km of travel versus wing surface.
5.3.3 Evaluation of the game interface

The interface of the game has been designed to be clear and easy to understand by the player. All the ideas behind the game are complex to understand if the interface is not the adequate. User interface design refers to the overall look and feel of the program that allows the learner to access information [Hall, 1997].

As was introduced in the chapter 4, Brandon [1997] identified the following questions: Is the course intuitive to use, such that the learner needs little or no explanation to proceed through the course? Is the overall screen design consistent, consolidated, clean and clear? Are the graphics appealing and understandable? Now these questions must be answer like to ensure that the user interface design is effective and user friendly.

The way the player moves in the window, the design table and the supplier catalogue is very intuitive. He just has to select the piece and put them in the design table. There are just two buttons in the interface of the first stage, so there is no way to the confusion. Actually the difficulty is in design a plane what can fly, but this is the challenge of the game. To meet all the restriction is difficult at the beginning. Before play, the player needs a previous course to introduce him some lean concepts and explain them the instruction of how to play. Even after this, the player will need some tried before understand how to play. When the player really understands the restrictions, the game becomes very easy and intuitive, but it is not easy to get a high score.

As it has been explained before, the interface is very clear and clean. There few elements: the design table, the customer’s requirements screen, a clock, the button for test the plane, and some help buttons. In the second stage appears the “Lean enablers” button. The pieces are separated to avoid mistakes when the player selects one of them. The clock is big enough for not forget it. The customer’s requirements are showed all the time in a clear way, and the design table is very clean and with axis to help the design. So it can be said that the interface meets the characteristics of a good interface.

Ending, the graphs are not the strong point of this game. It has been used easy and basic pieces: squares and triangles. Although they are not very good, its simplicity makes them goods for this game. There are just 3 kind of pieces, perfectly differentiates, so for the player is very easy to decide what piece uses in each moment. The maxima for this game have been: while easier pieces, clearer the game.
5.4 Performances

In games, score refers to an abstract quantity associated with a player or team. Score is usually measured in the abstract unit of points, and events in the game can raise or lower the score of different parties. Most games with score use it as a quantitative indicator of success in the game, and in competitive games, a goal is often made of attaining a better score than one's opponents in order to win.

(Wikipedia definition)

Joining the definition of score to the information given in the chapter 3, the conclusion that a score was needed was reached. The way to measure the performance of the player or of the design, the real customer’s values is compared with the values of the design. While closer they will be higher score.

The score process is based in the percentage variation as is showed below:

<table>
<thead>
<tr>
<th></th>
<th>Real Customer needs</th>
<th>Design characteristics</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>( N_{pc} )</td>
<td>( N_p )</td>
<td>( \frac{N_p - N_{pc}}{N_{pc}} )</td>
</tr>
<tr>
<td>Speed</td>
<td>( R_{Op} )</td>
<td>( R_{Op} )</td>
<td>( \frac{R_{Op} - R_{Op} _c}{R_{Op} _c} )</td>
</tr>
<tr>
<td>Km of travel (Kmt)</td>
<td>( K_{mt} _c )</td>
<td>( K_{mt} )</td>
<td>( \frac{K_{mt} - K_{mt} _c}{K_{mt} _c} )</td>
</tr>
<tr>
<td>Parking</td>
<td>( L_c )</td>
<td>( L )</td>
<td>( -\frac{L - L_c}{L_c} _c w_{sc} \frac{w_{sc}}{w_{sc}} )</td>
</tr>
<tr>
<td>requirements</td>
<td>( L_{wsc} )</td>
<td>( w_{s} )</td>
<td>( -\frac{C - C_c}{C_c} )</td>
</tr>
<tr>
<td>Cost</td>
<td>( C_c )</td>
<td>( C )</td>
<td>( -\frac{D_t - D_{tc}}{D_{tc}} )</td>
</tr>
<tr>
<td>Delivery time</td>
<td>( D_{tc} )</td>
<td>( D_t )</td>
<td>( -\frac{D_t - D_{tc}}{D_{tc}} )</td>
</tr>
</tbody>
</table>

Table 15 - Study of the variance

The maximum punctuation will be when the player gets the same values than the values of the customer. Then the score will be 100 points. The way the variations affect the score is not the same. This means, if the player designs a plane with 50 passengers more than the customer wants he will
have a higher score than its design has 50 passengers lower. If the player meets at least the customer requirements, the penalization will be lower than if the player doesn’t meet the customer’s requirements. These are the rules get a lower penalization:

- The number of passenger, speed and Km of the design must be higher than the customer wants
- The Parking requirements cannot be higher than the customer demands. If the plane designed is higher than the hangar of the customer the plane cannot be located inside.
- The Cost and Delivery time are lower than the customer wants the score will be higher than if the player overpasses them.

The last sentence does not mean that the lower cost and delivery time is the best solution, since this means the player is not using all the resources he has. He could make a better design using all the money that the customer is will to pay, or he could use all the time to improve the quality, for example.

The next figure shows the score system for the number of passenger. This means that if the player’s plane has more passengers than the customer wants this contributes positively in the graph (right line). If the player’s plane has lower number of passenger than the customer wants this contributes negatively (left line).

- Variation negative which equation is \[100 - abs(Variation \times 0.5) \times 100\]
- Variation positive which equation is \[100 - abs(Variation \times 1) \times 100\]

Figure 49 – Example of the lean score.
This graphic is an example with values for the number of passengers. Now to calculate the lean punctuation it is needed to make the same for all the characteristics as is shown in the next table:

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Lean points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>[100 - \text{abs}\left(\frac{N_p - N_{pc}}{N_{pc}} * 0.5\right) * 100]</td>
</tr>
<tr>
<td></td>
<td>[100 - \text{abs}\left(\frac{N_p - N_{pc}}{N_{pc}} * 1\right) * 100]</td>
</tr>
<tr>
<td>Speed</td>
<td>[100 - \text{abs}\left(\frac{ROP - ROP_{c}}{ROP_{c}} * 0.5\right) * 100]</td>
</tr>
<tr>
<td></td>
<td>[100 - \text{abs}\left(\frac{ROP - ROP_{c}}{ROP_{c}} * 1\right) * 100]</td>
</tr>
<tr>
<td>Km of travel</td>
<td>[100 - \text{abs}\left(\frac{KmT - KmT_{c}}{KmT_{c}} * 0.5\right) * 100]</td>
</tr>
<tr>
<td></td>
<td>[100 - \text{abs}\left(\frac{KmT - KmT_{c}}{KmT_{c}} * 1\right) * 100]</td>
</tr>
<tr>
<td>Parking requirements</td>
<td>[100 - \text{abs}\left(\frac{\text{Max}\left{\frac{L - L_{c}}{L_{c} - \frac{wsc}{ws}}\right} * 0.5\right) * 100]</td>
</tr>
<tr>
<td></td>
<td>[100 - \text{abs}\left(\frac{\text{Max}\left{\frac{L - L_{c}}{L_{c} - \frac{wsc}{ws}}\right} * 1\right) * 100]</td>
</tr>
<tr>
<td>Cost</td>
<td>[100 - \text{abs}\left(-\frac{C - C_{c}}{C_{c}} * 0.5\right) * 100]</td>
</tr>
<tr>
<td></td>
<td>[100 - \text{abs}\left(-\frac{C - C_{c}}{C_{c}} * 1\right) * 100]</td>
</tr>
<tr>
<td>Delivery time</td>
<td>[100 - \text{abs}\left(-\frac{D_{t} - D_{tc}}{D_{tc}} * 0.5\right) * 100]</td>
</tr>
<tr>
<td></td>
<td>[100 - \text{abs}\left(-\frac{D_{t} - D_{tc}}{D_{tc}} * 1\right) * 100]</td>
</tr>
</tbody>
</table>

Table 16 – Lean scores

Once the lean score is calculated in all the technical data, the final score will be the average of all of them.

The score of the game tries to create addition in the players to increase the grade of attention and learning.
Chapter 6

Validation of the LeanPPD Game
6 Validation of the LeanPPD game

The validation of the game is a really important point to treat. This chapter is an attempt to validate the prototype of the game. Although it is difficult due to problems with the interface, some conclusions are obtained.

Players are segmented according to their skills and technical knowledge. In this way has been studied what is the player model for the game and for what profiles the game is exceedingly complex.

Finally it is concluded that although the results have distortion, the model works correctly, since the lean enablers are useful for most players.

6.1 Validation mode

The goal of the validation of the game is to measure the effectiveness. Validation is the process of checking if the game meets specifications and that it fulfils its intended purpose.

The main objective of this game was to teach. Learner achievement may be based on different learning objectives. To measure the effectiveness the next questions were considered:

- What was most useful to the player? What was least useful?
- Did he achieve the learning objectives through this game?
- How did the player change his mind about the application of lean to the new product and process development?
- Do they feel that what they learned in and through this game will have application in real life?
- How well did they understand the game goals?

Through the validation all this question will try to be solved. To proceed with the validation of the game, 22 different players were tested. Each of them have provided a template like the one shown below, in which the data obtained are written (Figure 50).

As a general rule, it is noteworthy that the game takes time to understand. No player has understood it in the first round, and they need time to get skills designing and understand how it works.

Many of the problems that they found will be solved at the time the game is being programmed in a better programming language that allows a simpler interface for the user.

It has been quite difficult to prove in some users because of their required several tests to get finish the design and get a score.

Therefore must be said that this validation gives us a first idea of model performance, but their results are not entirely accurate or significant, because players are faced with many problems not associated with the model, if not with the interface of game.
During the test, skills and technical knowledge of the players were written, in order to make a classification taking into account these two variables (Table 17).

Remarkably, only one case in which the score on stage 1 was higher than in stage 2 was found. It was due to the requirements of stage 2 were very restrictive and difficult to meet, which took a long time for the player.

The results of the 22 tests can be seen also in Figure 51.
### Customer Requirements

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of passengers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Km of Travel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing Span</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delivery time to customer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Design Performances

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of passengers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Km of Travel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing Span</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delivery time to customer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Lean score

---

Figure 50 – Validation template of the LeanPPD game.
<table>
<thead>
<tr>
<th>Lean Score</th>
<th>Skill playing</th>
<th>Technical knowledge</th>
<th>Profession</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>69</strong></td>
<td>89</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Aeronautical Engineer</td>
</tr>
<tr>
<td><strong>55</strong></td>
<td>95</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Aeronautical Engineer</td>
</tr>
<tr>
<td><strong>43</strong></td>
<td>73</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Aeronautical Engineer</td>
</tr>
<tr>
<td><strong>32</strong></td>
<td>84</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Telecommunication Engineer</td>
</tr>
<tr>
<td><strong>53</strong></td>
<td>81</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Telecommunication Engineer</td>
</tr>
<tr>
<td><strong>59</strong></td>
<td>88</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Industrial Engineer</td>
</tr>
<tr>
<td><strong>42</strong></td>
<td>71</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Industrial Engineer</td>
</tr>
<tr>
<td><strong>73</strong></td>
<td>60</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Management Engineer</td>
</tr>
<tr>
<td><strong>-88</strong></td>
<td>82</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Management Engineer</td>
</tr>
<tr>
<td><strong>74</strong></td>
<td>90</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Management Engineer</td>
</tr>
<tr>
<td><strong>34</strong></td>
<td>71</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Management Engineer</td>
</tr>
<tr>
<td><strong>39</strong></td>
<td>65</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bachelor Student</td>
</tr>
<tr>
<td><strong>37</strong></td>
<td>75</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bachelor Student</td>
</tr>
<tr>
<td><strong>44</strong></td>
<td>69</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bachelor Student</td>
</tr>
<tr>
<td><strong>56</strong></td>
<td>87</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bachelor Student</td>
</tr>
<tr>
<td><strong>-24</strong></td>
<td>35</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Teacher</td>
</tr>
<tr>
<td><strong>-13</strong></td>
<td>56</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Administrative</td>
</tr>
<tr>
<td><strong>-56</strong></td>
<td>27</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bachelor level</td>
</tr>
</tbody>
</table>

**Table 17 - Performances of the players**
6.2 Segmentation of the players

The observations made in during the tests have driven the previous classification: skilled players and players with technical knowledge.

The skill to use the cursor of the computer it is very important, since in this process a lot of time is required. Frequently, the people who use the computer frequently have high skill in this point. By other hand it is the general knowledge about planes and the game. People who know something about the game (planes, lean, play before…) develop the designs faster than others whose starts from zero.

6.2.1 Players with Skill and Technical Knowledge

These are people who have basic knowledge about engineering, dimensions, and ease in dealing with equations. Also they have good skills in handling the computer.

Usually, this segment of players understands the game and they are quickly adapted to the interface. They use the equations and found the helps useful to improve the design.

When they start implementing lean enablers, they find no difficulty with the trade-off curves, since they are accustomed to its interpretation. They don’t have with standardization and are able to apply three simple rules to scale models. Having skills, understand quite well the previous knowledge and meaning of their sentences.

These users are ideal for the game because of they are able to get the most out of the game.

6.2.2 Player with skill but without Technical Knowledge

These players do not understand the gaming operation well. They like playing, coping and pasting the pieces to the design table, but without using the engineering logic or the equations to meet the customer requirements.

The aids are not useful and use probe and error method, which causes that they send the model many times to be tested, with its attendant penalties.

It is necessary to emphasized that these players do not understand customer requirements and therefore only try that the airplane fly as soon as possible.

In the second stage of the game, these players really like the front loading tool. As a general rule the first thing they do is find this tool to copy a model. Once they do that, cross functional team is used to modify the model. The other lean tools are not useful for them.
6.2.3 Players without skills and without technical knowledge

For this segment of players, the game is highly complex. They don’t have good skills putting the pieces and using the Excel format and they do not understand the game operation or the equations. They need much time to understand the operation and are not able to appreciate the lean tools. They don’t understand customer requirements, for that the just try to design the plane to fly but in an intuitive way.

6.3 Conclusions of the validation

As a general conclusion must be said that the game meets the requirements for which it has been develop, as most of the players found useful and recognize the lean tools. In addition the results show that scores on the Stage 2 are always greater than in stage 1 with which the tools make easy the design phase.

Still it is needed to say that due to the robustness of the prototype, there is much distortion and noise, thus validating is not giving all the information it could.

For example, many negative scores are due to that players make mistakes copying and pasting the parts which required much time to fix these mistakes and consequently increase the penalization in time.

These measures cannot be considered entirely accurate, since it is not the aim of game measure the skills of the players, but it is instructive to illustrate how works the model develop and if the lean enablers are understood in the way thought.

So as conclusion, this validation needs to be repeated once the interface problems will be solved, in order to make better and more accurate interpretation.
Figure 51 – Results of the validation
Chapter 7

Conclusions and Future Improvements
7 Conclusions and Future improvements

Through this chapter the thesis is terminating. In the future improvements are introduced thinks that born while the game was being develop, but for various reasons, have not been implemented.

To end, take out one final conclusion about the game and what it can become in the future.

7.1 Future Improvements

That was done on that thesis is a prototype of a serious game. Like all prototype, it can be improve in different ways. In the next are show some improvements to implement for future versions of the game

7.1.1 Interface of the game

The game was implemented in excel joint with visual basic. It is an easy way to make the game works but it is not efficient and visual as working in C++ or Flash. For that as future improvement is proposed to program the game on one of these codes.

With that the pictures, the buttons and the most important the movements of the pieces can be improved. Make possible that the player caught a piece with the mouse and move it to the design table, no with the keyboard, would be a big help to play.

7.1.2 New Lean enablers

With respect to the lean enablers, some more tools will be useful to the game.

7.1.2.1 Set based

This tool will allow the player draw many airplanes at the same time, watching the performances of each one and allowing him eliminate one when he decides that is going far from the customer’s requirements. The idea is that the player start with many designs and at the end he needs to have just the good one.
7.1.2.2 Workload leverage

This enabler is really important. To implement this tool is needed to consider that one new project will arrive each certain time. It means that the player can have many projects at the same time. It will put in action a new concept: “The employee saturation”.

In the first stage the player won’t have any enable to help him, so he is not communication with the sales and marketing departments. It means that the sales and marketing department is continuously searching for new project so one new project will arrives each certain time. But sometimes will happen that the player will be saturated so a new project is a bad idea because of it will cost money to the company.

For that in the second stage the player will learn how important is to communicate with the sales and marketing department and search project just when they are nearly to finish that they are working on.

The enabler will consist in 2 buttons, on to add projects and other to stop the projects, so the player needs to be able to measure the time that rest to finish the project and ask or stop the coming project.

7.1.2.3 A3 communication

Other enabler to implement is the A3 communication. As was explained in this thesis, a list of mistakes that can happen when the player pushes the “Can the airplane fly?” button has been recollected.

The idea is that when the player push the button, the game answer with a table where is include the mistake that happened, why it happens and how to solve it.

This tool will be really useful for the player, because of, usually the players don’t know how to solve the problems and this enabler will help to identify and solve it.

7.1.2.4 Check list

Check-lists are qualitative tools that give guidance to design, environmental management, and setting eco-labelling criteria. Check-list considers various different aspects such as recyclability or minimizing harmful substances (Behrendt, Jasch et al. 1997).

Implement the check list in the game is easy. The idea is to add a list of mistakes in the right order that they are programed in the game. With that when a mistake happens the player can solve it and ask if the airplane fly again, if another mistake happens, the player will have the check-list to check if the before mistake was solved (is higher in the list) or not, that means that he make a new mistakes without solving the before.
7.1.3  Create a Database

Really important would be to add a database to the game. Once the player finish to play, the result of the game can be sent to the database. With this all information the game can be improved studying the punctuation in the first and second stage.

Can be added to the database the number of iteration on each stage to see how in the second stage decrease this number.

Other variable to add is the number of lean tools that the player use and the time dedicate to each one. Many clocks can be put in order to measure the time that the player is using a lean tool and then, evaluate how he use the information (the design need to be save too). With this it is possible to see if the lean tools are easy to understand and how useful they are, and in the case some tool is not working, modify it and continue testing with the new improvements.

7.1.4  Put the game on-line.

With this all improvements the game can be upload internet. To put the game online would be needed to add to the database a new variable: the lean punctuation of each player. With that a new screen will be added to the game, showing the player a ranking of the players that played before and were he is.

It will be really useful because of can create addiction in the player, so the player will play again and get information of how the player interiorizes the concept and about the evolution of the learning process.

7.2  Conclusions

In the beginning of this thesis was introduced a challenge: develop the LeanPPD game. Through this thesis this challenge has been achieved.

The LeanPPD game has been developed taking a standard NPD process. The standard process selected had plenty of wastes. These wastes are very common in the current NPD process.

It has been explained how the lean thinking attacks those wastes to eliminate them. Toyota has been taken as example of how to eliminate wastes using activities and tools. Many authors explain the Toyota’s NPD in different ways, and each one of them remarks different activities. But all the authors coincide what the most important activity in the Toyota’s system is the elimination of wastes in order to add value to the product. This is the main goal in the lean thinking, and this differentiates a lean NPD from the others methodologies of product development.
Some of the most important activities described by the researchers have been applied to the standard NPD process in order to transform it into a lean NPD. So the goal to the game is to develop a lean NPD system from a conventional one.

To achieve this task, the player must select what activity uses in each moment. The final goal of the game is to meet that customer wants. So all the changes in the process are oriented to eliminate wastes and create value, getting requirements each time closer to the customer.

Being this a serious game, can’t be forgotten to talk about serious games in this thesis. A background research on serious games in the context of e-Learning is explained in this thesis. This research has addressed the learning models, the processes, the methodologies and the tools available as well as the profile of the knowledge worker and the impact of games in his/her human capital. As conclusion a Serious Games can take full advantage of the effectiveness of Game Play without incurring in cutting edge graphic technologies costs which makes most of budget in an entertainment game. What is necessary to develop a serious game is a believable and attractive concept that may attract the learner to the multiplayer addiction factor and the self-satisfaction of competitive winning. The balance between the complex real model and the believable simplified model are at the core of a serious game success. Absolutely important was define the role of the trainer and the role of the learner and explain what the challenges of a serious game are.

In the previous context, the LeanPPD game born. This was the direct application of the concept studied, founding a way to transform it in a serious game. The research of the process and the product was a basic point to joint all to create the basic flow of the game. All the theory of the lean product and process development was translate to tangible tools, giving the first ideas of the game.

After introduce the basic ideas of the game, it reaches the completion. It was studied in every detail, conceptually and mathematically, giving for closed the game model. Two stages were the most convenient, because of in the first the player could find the difficulties and then in the second he really understands and appreciates the lean enablers. Select the lean enablers and apply it to the product wasn´t an easy way. A work of abstraction transforming intangibles concepts as cross-functional teams, trade-off curves or chief engineer into enablers that shows these concepts were done.

But a game needs to be tested, so a validation of the game was done. The solutions of the tests were very satisfactory because of it demonstrates that the game met its goals, even having a lot of distortions. The players without any previous knowledge about lean learnt what a chief engineer is, how it works the standardization and what a trade-off curve is. The player with some knowledge of lean, understood other deeper questions, as for example the order to be implemented the tools, or discuss about others method of front-load the project. Anyway, all the players enjoyed playing the game and learnt lean concepts.
Finally some improvements for future versions of the game were given and explained in order to improve the game based on the results obtained.

This thesis is the first time that the lean principles are applied in this way for a product and process development game. With it raise a form to transmit and teach the LeanPPD concept through a game. The future of this game is very promising, as it has opened the mind to the creation of an effective serious game that could be used to teach employees and can be a start point to introduce the lean product and process development concepts in a company in a funny way.
Annexes
8 Annexes

8.1 Annexe I: Visual Basic code.

This code needs to be joint to the correspondent excel file. The way to work is programming the instruction and calling continually the excel sheets. The code that is shown in the next pages need of the calculations that are include in each excel sheet to be complete.

The screen explained in the thesis needs to be jointed to this code to, calling when the flow of the game requires.

'SALES & MARKETING REQUIREMENTS'

Private Sub CommandButton1_Click()
If Hoja13.Cells(2, 35) = 1 Then
MsgBox "You already have the Customer's requirements"
GoTo Lastline:
Else
End If
Hoja13.Cells(2, 35) = 1

'REINICIATE Iterations''

Hoja13.Cells(18, 15) = 0
Hoja13.Cells(18, 16) = 0
Hoja24.Cells(18, 15) = 0
Hoja24.Cells(18, 16) = 0

'CUSTOMER NEEDS'

FirstLine:
Dim Npb
Dim NpbL
Dim NpbW
Dim a
Dim b
'BODY: estimation of the dimensions of the body'

In the Hoja14 the dimensions estimated are going to be save.'

'Number of blocks in the body'

'Length'

\[ \text{NpbL} = \text{Int}((30 - 8 + 1) \times \text{Rnd()} + 8) \]

\[ \text{Hoja14.Cells}(2, 2) = \text{NpbL} \]

'Weight'

\[ \text{NpbW} = \text{Int}((4 - 2 + 1) \times \text{Rnd()} + 2) \]

\[ \text{Hoja14.Cells}(3, 3) = \text{NpbW} \]

\[ \text{NpbW} = \text{Hoja14.Cells}(3, 2) \]

\[ \text{Npb} = \text{NpbL} \times \text{NpbW} \]

\[ \text{Hoja14.Cells}(4, 2) = \text{Npb} \]

'nsb=number of squares in the body='

\[ \text{a} = \text{Int}((10 - 0 + 1) \times \text{Rnd()} + 0) \]

\[ \text{nsb} = \text{Round}(\text{a} \times \text{Npb} / 10, [0]) \]

\[ \text{a} = \text{nsb} / \text{Npb} \times 10 \]

\[ \text{Hoja14.Cells}(5, 2) = \text{nsb} \]

\[ \text{Hoja14.Cells}(5, 4) = \text{a} \]

'ntb=number of triangle in the body='

\[ \text{If a} \geq 10 \text{ Then b} = 0 \text{ Else } d = 10 - a \]
Hoja14.Cells(5, 5) = d

\[ b = \text{Int}((d - 0 + 1) \times \text{Rnd()} + 0) \]

Hoja14.Cells(6, 4) = b

ntb = \text{Round}(b \times \text{Npb} \times 2 / 10, [0])

Hoja14.Cells(6, 2) = ntb

\[ b = (ntb / (\text{Npb} \times 2)) \times 10 \]

'nbtb= number of big triangle in the body='

\[ c = 10 - a - b \]

ntb = \text{Round}(c \times \text{Npb} / 10, [0])

Hoja14.Cells(7, 2) = ntb

'COCKPIT: estimation of the dimensions of the cockpit, related with the body'

'In the Hoja12 are the characteristics of the different types of cockpit'

Dim i

Dim j

If \text{NpbW} = 2 Then i = \text{Int}((6 - 5 + 1) \times \text{Rnd()} + 5) Else i = \text{Int}((4 - 1 + 1) \times \text{Rnd()} + 1)

j = i + 11

Hoja14.Cells(9, 2) = j

nsc = Hoja12.Cells(7, j)  \hspace{1cm} 'number of squares in the cockpit'

ntc = Hoja12.Cells(8, j)  \hspace{1cm} 'number of triangle in the cockpit'

nbtc = Hoja12.Cells(9, j)  \hspace{1cm} 'number of big triangle in the cockpit'

Lc = Hoja12.Cells(10, j)  \hspace{1cm} 'length cockpit'

Hoja14.Cells(10, 2) = nsc

Hoja14.Cells(11, 2) = ntc

Hoja14.Cells(12, 2) = nbtc

Hoja14.Cells(13, 2) = Lc

'TAIL: estimation of the dimensions of the tail, related with the body'
'In the Hoja11 are the characteristics of the different types of tails'

Dim l
Dim n
Dim nst
Dim ntt
Dim nbtt
Dim NptL

l = Int((3 - 1 + 1) * Rnd() + 1)
Hoja14.Cells(22, 3) = l

n = l + 1

nst = Hoja11.Cells(71, n)  'number of squares in the tail=
ntt = Hoja11.Cells(72, n)  'number of triangle in the tail=
nbtt = Hoja11.Cells(73, n)  '= number of big triangle in the tail=
NptL = Hoja11.Cells(74, n)  '=number of pieces in the lenght'

Hoja14.Cells(22, 2) = nst
Hoja14.Cells(23, 2) = ntt
Hoja14.Cells(24, 2) = nbtt
Hoja14.Cells(25, 2) = NptL

'WING: estimation of the dimensions of the wings, related with the body''

'In the Hoja15 are the characteristics of the different types of wings'

Dim p
Dim t

Dim nsw
Dim ntw
Dim nbtw

Dim NpwL

p = Int((3 - 1 + 1) * Rnd() + 1)
Hoja14.Cells(16, 3) = p
Hoja15.Cells(68, 1) = p

\[ t = p + 1 \]

Hoja15.Cells(68, 2) = t

nsw = Hoja15.Cells(72, t)  
\[ \text{'=number of squares in the wing='} \]

ntw = Hoja15.Cells(73, t)  
\[ \text{'=number of triangle in the wing='} \]

nbtw = Hoja15.Cells(74, t)  
\[ \text{'= number of big triangle in the wing='} \]

NpwL = Hoja15.Cells(75, t)  
\[ \text{'=number of pieces in the wing'} \]

Hoja14.Cells([16], [2]) = nsw

Hoja14.Cells(17, 2) = ntw

Hoja14.Cells(18, 2) = nbtw

Hoja14.Cells([19], [2]) = NpwL

'ENGINE: estimation of the number of engines''

If 3 \leq NpwL < 6 Then ne = 2 Else If 6 \leq NpwL < 9 Then ne = \text{Int}(2 - 1 + 1) \times \text{Rnd}() + 1) Else ne = \text{Int}(3 - 1 + 1) \times \text{Rnd}() + 1)

Hoja14.Cells([28], [2]) = ne

'CALCULATE THE CUSTOMER’S REQUIREMENTS'

'Capacity (Number pass), just in the body'

Dim Np

Np = nsb * 3 + ntb + nbtb

Hoja14.Cells([33], [2]) = Np

'Fast/Slow'

Dim Weight

Dim Wb

Dim Wt

Dim Ww

Dim We
Dim Wc
    Wb = nsb * 11.5 + ntb * 6 + nbtb * 8
    Wt = nst * 10 + ntt * 5 + nbtt * 7
    Ww = nsw * 10 + ntw * 5 + nbtw * 7
    We = ne * 50
    Wc = nsc * 11.5 + ntc * 6 + nbtc * 8
    Weight = Wb + 2 * Wt + 2 * Ww + We + Wc

Dim TotalPower
Dim FreePower
Dim RatioofPower
Dim WingSurface
Dim WingTail
Dim CoeficientofLift

    TotalPower = ne * 500
    While Weight > TotalPower
        Weight = Wb + 2 * Wt + 2 * Ww + We + 100 + Wc
        TotalPower = (ne + 2) * 500
        ne = ne + 2
    Wend

    While TotalPower > 2 * Weight
        Weight = Wb + 2 * Wt + 2 * Ww + We - 100 + Wc
        TotalPower = (ne - 2) * 500
        ne = ne - 2
    Wend

    If ne = 0 Then GoTo FirstLine
    Hoja14.Cells(28, 2) = ne
    FreePower = TotalPower - Weight
RatioofPower = Round(100 * (FreePower / Weight), [0])

' In the Hoja7 is the Ratio of power graphic related with the coefficient of lift'
Hoja7.Cells(1, 4) = RatioofPower
Hoja14.Cells([34], [2]) = RatioofPower
CoeficientofLift = Hoja7.Cells(Hoja7.Cells(2, 4) + 1, 2)
WingSurface = 2 * (1 * nsw + 0.5 * ntw + 1 * nbtw)
TailSurface = 2 * (1 * nst + 0.5 * ntt + 1 * nbtt)
Lift = (WingSurface + TailSurface) * CoeficientofLift * 3

'Km of travel'
Dim DistanceBlock
Dim KmofTravel

If ne = 2 Then DistanceBlock = 200 Else If ne = 4 Then DistanceBlock = 150 Else DistanceBlock = 100
KmofTravel = WingSurface * DistanceBlock
Hoja14.Cells([35], [2]) = KmofTravel

'Parking requirements'
Dim Lenght
Dim Ws
Lenght = NpbL + Lc
Hoja14.Cells([36], [2]) = Lenght
Ws = NpbW + 2 * NpwL
Hoja14.Cells([37], [2]) = Ws

'Cost'
Dim Cb
Dim Cw
Dim Ct
Dim Cc
Dim Ce

\[ C_b = n_{sb} * 130 + n_{tb} * 70 + n_{ntb} * 170 \]
\[ C_w = 2 * (n_{sw} * 100 + n_{tw} * 60 + n_{ntw} * 160) \]
\[ C_t = 2 * (n_{st} * 100 + n_{tt} * 60 + n_{ntt} * 160) \]
\[ C_c = n_{sc} * 100 + n_{tc} * 60 + n_{ntc} * 160 \]
\[ C_{ce} = n_{e} * 500 \]
\[ \text{CostC} = C_b + C_w + C_t + C_c + C_e \]
\[ \text{Hoja14.Cells([38], [2])} = \text{CostC} \]

'Delivery Time'
Dim Dtc
Dim TotaltimeOfSupplier
Dim TotaltimeOfAssembly
Dim tss2
Dim tss1
Dim tst2
Dim tst1
Dim tbts2
Dim tbts1
Dim tsa2
Dim tsa1
Dim tat2
Dim tat1
Dim tbta2
Dim tbta1
Dim tse
Dim tae

tss2 = 12
tss1 = 10
tst2 = 17
tst1 = 15
tbts2 = 30
tbts1 = 40
tsa2 = 4
tsa1 = 4
tat2 = 6
tat1 = 6
tbta2 = 3
tbta1 = 3
tse = 300
tae = 20

TotaltimeOfSupplier = (nsb + nsc) * tss2 + (2 * nst + 2 * nsw) * tss1 + (ntb + ntc) *
tst2 + (2 * ntt + 2 * ntw) * tst1 + (nbttb + nbttc) * tbts2 + (nbt + nbttw) * tbts1 + ne * tse

TotaltimeOfAssembly = (nsb + nsc) * tsa2 + (2 * nst + 2 * nsw) * tsa1 + (ntb + ntc) *
tat2 + (ntt + ntw) * tat1 + (nbttb + nbttc) * tbta2 + (2 * nbt + 2 * nbttw) * tbta1 + ne * tae

TimeOfDesign = 30 * 60

TotaltimeofTest = 5 * 60

Dtc = TotaltimeOfSupplier + TotaltimeOfAssembly + TimeofDesig + TotaltimeofTest

' + Time of design'

Hoja14.Cells([39], [2]) = Dtc

'CALCULATE THE RANGES OF VALUES TO SHOW TO THE PLAYER'

'Range of Np'

'The Hoja1 is the main screen of the game, where the player is working'

Dim NPE1
Dim NPE2
Dim f
Dim g
f = Int((2 - 0 + 1) * Rnd() + 0)
g = 2 - f
NPE1 = Round(Np * (1 - (f / 10)), 0)
NPE2 = Round(Np * (1 + (g / 10)), 0)
Hoja14.Cells(33, 11) = NPE1
Hoja1.Cells(10, 58) = NPE1
Hoja14.Cells(33, 12) = NPE2
Hoja1.Cells(10, 59) = NPE2

'RatioofPower'

'KmofTravel'

'Range of Lenght'
Dim LC1
Dim LC2
Dim h
Dim o
h = Int((3 - 0 + 1) * Rnd() + 0)
o = 3 - h
LC1 = Round(Lenght * (1 - (h / 10)), 0)
LC2 = Round(Lenght * (1 + (o / 10)), 0)
Hoja14.Cells(36, 11) = LC1
Hoja1.Cells(13, 58) = LC1
Hoja14.Cells(36, 12) = LC2
Hoja1.Cells(13, 59) = LC2

'Range of Ws'
Dim Ws1
Dim WS2
Dim R
Dim s
R = Int((3 - 0 + 1) * Rnd() + 0)
s = 3 - R
Ws1 = Round(Ws * (1 - (R / 10)), 0)
WS2 = Round(Ws * (1 + (s / 10)), 0)
Hoja14.Cells(37, 11) = Ws1
Hoja1.Cells(14, 58) = Ws1
Hoja14.Cells(37, 12) = WS2
Hoja1.Cells(14, 59) = WS2

'Range of CostC'
Dim CostC1
Dim CostC2
Dim z
Dim u
z = Int((2 - 0 + 1) * Rnd() + 0)
u = 2 - z
CostC1 = Round(CostC * (1 - (z / 10)), 0)
CostC2 = Round(CostC * (1 + (u / 10)), 0)
Hoja14.Cells(38, 11) = CostC1
Hoja1.Cells(15, 58) = CostC1
Hoja1.Cells(15, 59) = CostC2

'Range of Dtc'
Dim Dtc1
Dim Dtc2
Dim v
Dim w
v = Int((2 - 0 + 1) * Rnd() + 0)
w = 2 - v
Dtc1 = Round(Dtc * (1 - (v / 10)), 0)
Dtc2 = Round(Dtc * (1 + (w / 10)), 0)
Hoja14.Cells(39, 11) = Dtc1
Hoja1.Cells(16, 58) = Dtc1
Hoja14.Cells(39, 12) = Dtc2
Hoja1.Cells(16, 59) = Dtc2

'ESTIMATION OF CUSTOMER NEEDS WITH CHIEF ENGINEER'

'Np'
Dim NPE1ch
Dim NPE2ch
Dim fch
Dim gch
fch = Int((1 - 0 + 1) * Rnd() + 0)
gch = 1 - fch
NPE1ch = Round(Np * (1 - (fch / 10)), 0)
NPE2ch = Round(Np * (1 + (gch / 10)), 0)
Hoja14.Cells(44, 11) = NPE1ch
Hoja14.Cells(44, 12) = NPE2ch
'RatioofPower'


'KmofTravel'


'Lenght'

Dim LC1ch
Dim LC2ch
Dim hch
Dim och
hch = Int((1 - 0 + 1) * Rnd() + 0)
och = 1 - hch
LC1ch = Round(Lenght * (1 - (hch / 10)), 0)
LC2ch = Round(Lenght * (1 + (och / 10)), 0)
Hoja14.Cells(47, 11) = LC1ch
Hoja14.Cells(47, 12) = LC2ch

'Ws'

Dim Ws1ch
Dim WS2ch
Dim rch
Dim sch
rch = Int((1 - 0 + 1) * Rnd() + 0)
sch = 1 - rch
Ws1ch = Round(Ws * (1 - (rch / 10)), 0)
WS2ch = Round(Ws * (1 + (sch / 10)), 0)
Hoja14.Cells(48, 11) = Ws1ch
Hoja14.Cells(48, 12) = WS2ch

'CostC'
Dim CostC1ch
Dim CostC2ch
Dim zch
Dim uch
zch = Int((1 - 0 + 1) * Rnd() + 0)
uch = 1 - zch
CostC1ch = Round(CostC * (1 - (zch / 10)), 0)
CostC2ch = Round(CostC * (1 + (uch / 10)), 0)
Hoja14.Cells(49, 11) = CostC1ch
Hoja14.Cells(49, 12) = CostC2ch

'Dtc'
Dim Dtc1ch
Dim Dtc2ch
Dim vch
Dim wch
vch = Int((1 - 0 + 1) * Rnd() + 0)
wch = 1 - vch
Dtc1ch = Round(Dtc * (1 - (vch / 10)), 0)
Dtc2ch = Round(Dtc * (1 + (wch / 10)), 0)
Hoja14.Cells(50, 11) = Dtc1ch
Hoja14.Cells(50, 12) = Dtc2ch

'CLOCK: it was programed in Spanish'
ClockLine:
Dim TiempoPausa, Inicio, Final, TiempoTotal

TiempoPausaseg = 60
TiempoPausamin = 30
TiempoPausa = TiempoPausamin * TiempoPausaseg

TextBox2.Text = 0
TextBox1.Text = TiempoPausamin

Inicio = Timer
i = 0

j = 1

Tiempoafter = Inicio + 1

Do While Timer < Inicio + TiempoPausa

DoEvents

If Timer > Tiempoafter Then

i = i + 1

If i = 1 And j = 1 Then

TextBox1.Text = TiempoPausamin - 1

Else

End If

Remindseg = TiempoPausaseg - i

TextBox2.Text = Remindseg

Tiempoafter = Tiempoafter + 1

Else

End If

If i = 60 Then

i = 0

j = j + 1

Remindmin = TiempoPausamin - j

TextBox1.Text = Remindmin

TextBox2.Text = 0

Else
End If

Loop

Final = Time

TiempoTotal = Final - Inicio

MsgBox "You finish your time to design. Do you need another 30 minutes? It will penalize you."

Iteration = Hoja13.Cells(18, 15)

If Respuesta = vbYes Then

Iteration = Iteration + 1

Hoja13.Cells(18, 15) = Iteration

GoTo ClockLine

Else

End If

Lastline:

End Sub

'BUTTOM Can Fly?'

'In the Hoja13 is going to be calculate the performances and the number of iterations'

Private Sub CommandButton2_Click()

Iteration2 = Hoja13.Cells(18, 16)

Iteration2 = Iteration + 1

Hoja13.Cells(18, 16) = Iteration

'There is Nothing'

Dim Noth

Noth = Hoja31.Cells(3, 40)

If Noth = 0 Then

MsgBox ("There is nothing design")

GoTo Lastline

End If
'SIMETRY'
'In the Hoja31 is a copy of the design matrix and the verification of symmetry is done'

Dim Sim
Sim = Hoja31.Cells(65, 7)
If Sim < 450 Then
    MsgBox ("The airplane is not symmetric or is not well centred with the axis")
    GoTo Lastline
End If

'BODY'
'In the Hoja9 all the variables of the design like number of squares in the body…. are save'
Dim Npb
Dim NpbL
Dim NpbW
Dim nsb
Dim ntb
Dim ntb
Dim ntb
nsb = Hoja9.Cells(5, 64)
ntb = Hoja9.Cells(9, 64)
ntb = Hoja9.Cells(7, 64)
Npb = Hoja9.Cells(11, 64)
NpbL = Hoja9.Cells(13, 64)
NpbW = Hoja9.Cells(15, 64)
If Npb = 0 Then
    MsgBox ("You need to put a Body")
    GoTo Lastline
End If

'COCKPIT'
Dim nsc
Dim ntc
Dim nbtc
Dim Lc

nsc = Hoja9.Cells(21, 64) 'number of squares in the cockpit'
ntc = Hoja9.Cells(25, 64) 'number of triangle in the cockpit'
b btc = Hoja9.Cells(23, 64) 'number of big triangle in the cockpit'
Lc = Hoja9.Cells(27, 64) 'length cockpit'

Dim CockpitSurf
CockpitSurf = nsc + ntc + nbtc

If CockpitSurf = 0 Then
    MsgBox ("You need to put Cockpit")
    GoTo Lastline
End If

'TAIL'
Dim nst
Dim ntt
Dim nbtt
Dim NptL
Dim NptW
Dim NpT

nst = Hoja9.Cells(33, 64) '=number of squares in the tail=
ntt = Hoja9.Cells(37, 64) '=number of triangle in the tail=
nbtt = Hoja9.Cells(35, 64) '= number of big triangle in the tail=
NptW = Hoja9.Cells(39, 64) '=number of pieces in the length'
N ptL = Hoja9.Cells(40, 64)
NpT = Hoja9.Cells(41, 64)

If NptL = 0 Then
    MsgBox ("You need to put a tail")
GoTo Lastline
End If

'WING'
Dim nsw
Dim ntw
Dim nbtw
Dim NpwL
Dim NpwW
Dim NpW
nsw = Hoja9.Cells(45, 64)  'number of squares in the wing=
ntw = Hoja9.Cells(49, 64)  'number of triangle in the wing= '
nbtw = Hoja9.Cells(47, 64)  '= number of big triangle in the wing=
NpwL = Hoja9.Cells(51, 64)  '=number of pieces in the wing'
NpwW = Hoja9.Cells(52, 64)
NpW = Hoja9.Cells(53, 64)
If NpwL = 0 Then
    MsgBox ("You need to put a wing")
    GoTo Lastline
End If

'ENGINE'
Dim ne
ne = Hoja9.Cells(55, 64)
If ne = 0 Then
    MsgBox ("You need to put power")
    GoTo Lastline
End If

'CALCULATE THE CHARACTERISTICS OF THE DESIGN'
'Capacity (Number pass), just in the body'

'In the Hoja17 all the characteristics of the design are going to be saved'

Dim Np

Np = nsb * 3 + ntb + nbtb

Hoja17.Cells(11, 18) = Np

'Fast/Slow'

Dim Weight

Dim Wb

Dim Wt

Dim Ww

Dim We

Dim Wc

Wb = nsb * 11.5 + ntb * 6 + nbtb * 8

Wt = nst * 10 + ntt * 5 + nbtt * 7

Ww = nsw * 10 + ntw * 5 + nbtw * 7

We = ne * 50

Wc = nsc * 11.5 + ntc * 6 + nbtc * 8

Weight = Wb + 2 * Wt + 2 * Ww + We + Wc

Dim TotalPower

Dim FreePower

Dim RatioofPower

Dim WingSurface

Dim WingTail

Dim CoeficientofLift

TotalPower = ne * 500

FreePower = TotalPower - Weight

If FreePower <= 0 Then

    MsgBox ("You don´t have enough power to your weight.")

    GoTo Lastline
End If

RatioofPower = Round(100 * (FreePower / Weight), [0])

Hoja7.Cells(1, 4) = RatioofPower

Hoja17.Cells(12, 18) = RatioofPower

CoeficienteofLift = Hoja7.Cells(Hoja7.Cells(2, 4) + 1, 2)

WingSurface = 2 * (1 * nsw + 0.5 * ntw + 1 * nbtw)

TailSurface = 2 * (1 * nst + 0.5 * ntt + 1 * nbtt)

Lift = (WingSurface + TailSurface) * CoeficienteofLift * 3

If Lift / Weight <= 1 Then

    MsgBox ("Condition of fly: The airplane can’t fly because of Lift/Weight is lower than 1, so your airplane is very heavy")

    GoTo Lastline

End If

If TailSurface = 0 Then

    MsgBox ("You need to put Tail")

    GoTo Lastline

End If

If WingSurface = 0 Then

    MsgBox ("You need to put Wings")

    GoTo Lastline

End If

If 3 > (WingSurface / TailSurface) > 6 Then

    MsgBox ("Condition of Stability: The airplane can’t fly because of (Wing Surface/ Wing Tail) isn’t between 3 and 6, so your airplane is not stable")

    GoTo Lastline

End If

'Km of travel'

Dim DistanceBlock

Dim KmofTravel
If ne = 2 Then DistanceBlock = 200 Else If ne = 4 Then DistanceBlock = 150 Else DistanceBlock = 100
KmOfTravel = WingSurface * DistanceBlock
Hoja17.Cells(13, 18) = KmOfTravel

'Parking requirements'
Dim Length
Dim Ws
Length = NpbL + Lc
Hoja17.Cells(14, 18) = Length
Ws = Hoja9.Cells(9, 57)
Hoja17.Cells(15, 18) = Ws

'Cost'
Dim Cb
Dim Cw
Dim Ct
Dim Cc
Dim Cce
Cb = nsb * 130 + ntb * 70 + nbtb * 170
Cw = 2 * (nsw * 100 + ntw * 60 + nbtw * 160)
Ct = 2 * (nst * 100 + ntt * 60 + nbtt * 160)
Cc = nsc * 100 + ntc * 60 + nbtc * 160
Cce = ne * 500
CostC = Cb + Cw + Ct + Cc + Cce
Hoja17.Cells(16, 18) = CostC

'Delivery Time '
Dim Dtc
Dim TotaltimeOfSupplier
Dim TotaltimeOfAssembly
Dim tss2
Dim tss1
Dim tst2
Dim tst1
Dim tbts2
Dim tbts1
Dim tsa2
Dim tsa1
Dim tat2
Dim tat1
Dim tbta2
Dim tbta1
Dim tse
Dim tae
tss2 = 12
tss1 = 10
tst2 = 17
tst1 = 15
tbts2 = 30
tbts1 = 40
tsa2 = 4
tsa1 = 4	at2 = 6
tat1 = 6
.tbta2 = 3
.tbta1 = 3
tse = 300	.tae = 20
TotaltimeOfSupplier = (nsb + nsc) * tss2 + (2 * nst + 2 * nsw) * tss1 + (ntb + ntc) * tst2 + (2 * ntt + 2 * ntw) * tst1 + (nbtt + nbtc) * tbs2 + (nbttt + nbttw) * tbs1 + ne * tse

TotaltimeOfAssembly = (nsb + nsc) * tsa2 + (2 * nst + 2 * nsw) * tsa1 + (ntb + ntc) * tat2 + (ntt + ntw) * tat1 + (nbtt + nbtc) * tba2 + (2 * nbttt + 2 * nbttw) * tba1 + ne * tae

'TimeOfDesign= we need to put a clock to measure this time. We need to scale this time to have relevance with respect to the others, when we study the duration of the design player.'

Dtc = TotaltimeOfSupplier + TotaltimeOfAssembly

'The time of design is joint at the end in the performance sheet, when the clock finish'

Hoja17.Cells(17, 18) = Dtc

'DESING CONSTRAINS'

'Cockpit'

If NpbW / Lc > 1 Then

    MsgBox ("The cockpit is not well dimensioned")

    GoTo Lastline

End If

'Body'

If (NpbL / NpbW) < 3 Then

    MsgBox ("The body of the airplane is not aerodinamic")

    GoTo Lastline

End If

'Engines'

If ne >= 6 And (2 * NpW) < 21 Then

    MsgBox ("The wing is not enough big to put so many engines")

    GoTo Lastline

End If

If ne = 4 And (2 * NpW) < 8 Then
MsgBox("The wing is not enough big to put so many engines")
GoTo Lastline
End If
If ne = 2 And (2 * NpW) < 3 Then
    MsgBox("The wing is not enough big to put so many engines")
    GoTo Lastline
End If

'Wings'
If NpwL > (0.4 * NpbL) Then
    MsgBox("The width wing is not well dimensioned with respect to the body")
    GoTo Lastline
End If

'Ratio of the wing'
If 0.3 > (NpwL / (Ws - NpbW) / 2) > 1 Then
    MsgBox("The ratio of the wing is not well dimensioned")
    GoTo Lastline
End If

'Tails'
If NptL > (0.6 * NpwL) Then
    MsgBox("The width tail is not well dimensioned with respect to the wing")
    GoTo Lastline
End If

'Ratio of the tail'
If 0.3 > (NptL / NptW) > 1 Then
    MsgBox("The ratio of the tail is not well dimensioned")
    GoTo Lastline

End If
MsgBox ("Your airplane can Fly!!")

Respuesta = MsgBox("Would you like to finish designing and watch your performances?", vbYesNo + vbQuestion, "Review?")
If Respuesta = vbYes Then
    Hoja17.Activate
    Respuesta2 = MsgBox("Do you wanna see your Lean Points (Yes) or redesign(No)?", vbYesNo + vbQuestion, "Review?")
    If Respuesta2 = vbYes Then
        Dim LeanPoints
        LeanPoints = Round(Hoja13.Cells(23, 13), 0)
        MsgBox "Your Lean score is " & LeanPoints
        MsgBox "You are going to start the second round with the Lean Tools"
        Hoja19.Activate
        GoTo Last2Line:
    Else
        Hoja1.Activate
        Iteration = Hoja13.Cells(18, 15)
        Iteration = Iteration + 1
        Hoja13.Cells(18, 15) = Iteration
    End If
End If

'REINICIATE THE RELOJ'
ClockLine1:
    TiempoPausaseg = 60
    TiempoPausamin = 30
    TiempoPausa = TiempoPausamin * TiempoPausaseg
    TextBox2.Text = 0
    TextBox1.Text = TiempoPausamin
    Inicio = Timer
i = 0  j = 1
Tiempoafter = Inicio + 1
Do While Timer < Inicio + TiempoPausa
    DoEvents
    If Timer > Tiempoafter Then
        i = i + 1
        If i = 1 And j = 1 Then
            TextBox1.Text = TiempoPausamin - 1
        Else
            End If
        Remindseg = TiempoPausaseg - i
        TextBox2.Text = Remindseg
        Tiempoafter = Tiempoafter + 1
    Else
        End If
    If i = 60 Then
        i = 0
        j = j + 1
        Remindmin = TiempoPausamin - j
        TextBox1.Text = Remindmin
    Else
        End If
    Loop
Final = Time
TiempoTotal = Final - Inicio
MsgBox "You finish your time to design. Do you need another 30 minutes? It will penalize you."
Iteration = Hoja13.Cells(18, 15)
If Respuesta = vbYes Then
Iteration = Iteration + 1
Hoja13.Cells(18, 15) = Iteration
GoTo ClockLine1
Else
End If

Else
Iteration = Hoja13.Cells(18, 15)
Iteration = Iteration + 1
Hoja13.Cells(18, 15) = Iteration

'REINICIATE RELOJ'

ClockLine2:

    TiempoPausaseg = 60
    TiempoPausamin = 30
    TiempoPausa = TiempoPausamin * TiempoPausaseg
    TextBox2.Text = 0
    TextBox1.Text = TiempoPausamin
    Inicio = Timer
    i = 0
    j = 1
    Tiempoafter = Inicio + 1
    Do While Timer < Inicio + TiempoPausa
        DoEvents
        If Timer > Tiempoafter Then
            i = i + 1
            If i = 1 And j = 1 Then
                TextBox1.Text = TiempoPausamin - 1
            Else
                End If
        Remindseg = TiempoPausaseg - i


TextBox2.Text = Remindseg
Tiempoafter = Tiempoafter + 1
Else
End If
If i = 60 Then
i = 0
j = j + 1
Remindmin = TiempoPausamin - j
TextBox1.Text = Remindmin
TextBox2.Text = 0
Else
End If
Loop
MsgBox "You finish your time to design. Do you need another 30 minutes? It will penalize you."
Iteration = Hoja13.Cells(18, 15)
If Respuesta = vbYes Then
Iteration = Iteration + 1
Hoja13.Cells(18, 15) = Iteration
GoTo ClockLine2
Else
End If
End If
Lastline:
Hoja1.Activate
Last2Line:
End Sub
8.2 Annexe II: Helps of the game.

8.2.1 General Instructions

Figure 52 – Screen of general instructions
8.2.1.1 Goal of the game

Figure 53 – Screen of goal of the game
8.2.1.2 How to play?

Figure 54 – Screen of how to play?
8.2.1.3 General airplane´s knowledge.

Figure 55 – Screen of general airplane´s knowledge
8.2.2 Customer’s requirements instructions

Figure 56 – Screen of customer requirement instructions
8.2.3 Lean Instructions

![Lean Instructions Screen](image)

Figure 57 – Screen of lean instructions
8.2.3.1 Detailed Lean instructions

Now you will have some tools to improve your design, reducing you Time and Cost and increasing Quality and Performances.

Be careful using the tools because if don’t get in right way it will be worse for you design.

Let’s go! Try to improve!

**Figure 58 – Screen of chief engineer help**

**Figure 59 – Screen of guest supplier help**
LeanPPD Game

Now you will have some tools to improve your design, reducing you Time and Cost and increasing Quality and Performances.

Be careful using the tools because if don't get in right way it will be worse for you design.

Let's go! Try to improve!

**Previous Knowledge**

In the previous learning course, you will have information about general "aeronautical" knowledge, can be really useful for you attempt to this tricks.

**Front Loading**

Front loading, will show you a screen with information about airplane's designs that other engineer have design before and worked well.

Figure 60 – Screen of previous knowledge help

Figure 61 – Screen of front loading help
Figure 62 – Screen of cross-functional teams help

Figure 63 – Screen of standardization help
Now you will have some tools to improve your design, reducing you Time and Cost and increasing Quality and Performances.

Be careful using the tools because if don’t get in right way it will be worse for you design.

Let’s go! Try to improve!

**Trade-off Curves**

Trade-off Curves will show you experience’s curves. It will help you designing in a better way, optimizing the variables.

Figure 64 – Screen of trade-off curves help
8.3 Annexe III: Standardization enable.

Figure 65 – Screen of standardization of the cockpit

Figure 66 – Screen of standardization of the tail
Figure 67 – Screen of standardization of the wing
8.4 Annexe IV: Front loading models

![Diagram of front loading model 1](image1)

**Figure 68 – Screen of front loading model 1.**

![Diagram of front loading model 2](image2)

**Figure 69 – Screen of front loading model 2**
Figure 70 – Screen of front loading model 3.

Figure 71 – Screen of front loading model 4.
Figure 72 – Screen of front loading model 5.
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