A Lean way to teach Lean Product Development to Graduates

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Abstract

This paper describes the Lean Product Development (LPD) course taught in the Mechatronics Engineering Graduate Program from the Instituto Tecnológico de Aeronáutica – ITA. During the course the sensei-lecturer discusses the theory, proposes frameworks, asks questions, and challenges the students. The course backbone is based on the Value Function Deployment (VFD) technique, which interlaces concepts from LPD, Integrated Product Development, Systems Engineering, and Project Management. The VFD is used in a course long practical exercise, stressing the concepts of “go and see”, Obeya, Set-Based Concurrent Engineering (SBCE), and pulled development. Finally, the students’ theoretical evaluation occurs by applying the “Design for Correction” tests, where multiple choice questions, while having a better alternative, might have more than one possible answer. The lecturer guides the correction process, when the students advocate their choice of alternatives. Therefore, the course promotes a lean way to teach LPD.

Keywords

1. Introduction

Product Development Process (PDP) can be understood as some kind of information based factory [1]. The goal of the PDP is to create a “recipe” for producing a product [2], which reduces risk and uncertainty while gradually developing a new and error-free product, which can then be realized by manufacturing, sold, and delivered to the customer.

PDP is a problem-solving and knowledge-accumulation process, which is based on two pillars: "do the thing right" and "do the right thing”. The former guarantees that progress is made and value is added by creating useful information that reduces uncertainty and/or ambiguity [3, 4]. The latter addresses the challenge to produce information at the right time, when it will be most useful [5, 6]. Developing complex and/or novel products and systems multiples these challenges. The coupling of individual components or modules may turn engineering changes in a component into “snowballs”, in some cases causing long rework cycles and making it virtually impossible to anticipate the final outcome [7]. Not surprisingly, overtime, over budget and low quality are commonplaces in PDP projects.

PDP evolved from artisanal, highly customized product development prior to the Industrial Revolution in the 18th century. This period brought the serial production into scene, and extending its principles to the PDP as well [8]. At that moment, the PDP was characterized by highly specialized personnel, low communication among the company departments, and standardized products. Several authors [9, 10, and 11] refer to this product development process as Serial or Sequential PDP. A number of problems emerged from the lack of integration within the Serial PDP, such as: fragmented views of the same product, and not taking into account production issues until the PDP late stages, when product modifications, if needed, are more difficult and costly to carry out, than those in the PDP early stages.
To overcome these problems, an integrated approach to PDP has emerged in early 1990’s, being known by a myriad of names: Concurrent Engineering, Simultaneous Engineering, Integrated Product Development, New Product Development and so forth [12]. Regardless the name, these approaches aim to rescue the integration aspect that was lost by the Serial PDP: the product and production planning processes are then conducted in an integrated and simultaneous manner. The integration proposal was constantly enlarged to encompass the whole product lifecycle, starting from the customer needs, and including the conceptual and detailed design, production, use, and discard.

A step further from the integrated approach was taken by the Toyota Motor Company, where the company wide Lean Philosophy application allowed the emergence of a PDP that has consistently succeeded in its product development projects, presenting productivity four times better than their rivals [13].

To deliver better products faster and cheaper, some firms are attempting to use the same principles as Toyota’s, and create “lean PD” processes that continuously add customer value (i.e., that sustain a level of “progress” toward their goals) [14, 15]. In order to succeed in this endeavor, duplicating some lean tools and techniques does not suffice, the company has to understand the principles behind them, and how these principles apply to the company’s culture [16].

This paper aims to present how the Lean Product Development (LPD) concepts, tools and techniques are being taught in an integrated way with the concepts from Integrated Product Development. Systems Engineering, Project Management, and Lean Product Development, as part of the Mechatronics Engineering Graduate Program at the Instituto Tecnológico de Aeronáutica – ITA (Brazilian Aeronautics Institute of Technology). The course is conducted as a lean journey, centered on the reflection of how to improve the company’s current PDP into a Lean PDP.

This paper is organized as follows. Section 2 presents how the LPD Course’s value proposition was built. The course’s proposed “lean journey” is presented in Section 3. Section 4 shows how the course evolved through the years. Finally, in Section 5, some conclusions and challenges to future work are presented.

2. The LPD Course’s Value Proposition

According to Trabasso et al. [17], Mechatronics is defined as an integrated design process to develop products and systems, which have two main characteristics: mechanical equivalent work and algorithmic integrated control. This definition has been adopted by the Mechatronics Graduate Program at ITA. Therefore, ITA sees Mechatronics as a design process (or PDP) for a particular set of products such as robots, satellites and automation systems. The PDP applied to Mechatronics has also experienced the evolution pattern: from serial PDP to Integrated Product Development (IPD), and finally to lean IPD, or simply LPD, which is detailed herein.

The value proposition was defined according to four stakeholders’ categories, and the value pulled by them:

- the students themselves: learning objectives;
- the lecturers: a lean way of lecturing an engineering content;
- the Mechatronics Graduate Program: LPD course fills the gap between the mechatronics contents such as microprocessors, sensors, actuators and so forth (Fundamentals of Mechatronics Course) and engineering design content such as Morphological Chart, Quality Function Deployment etc. (Integrated Product Development Course).
- the industrial community: a number of projects are carried out by the researchers from the Mechatronics Graduate Program and the industrial partners. Most of these projects benefit directly from the LPD lean content (e.g. the SBCE approach [18]).

3. The “Lean Journey”

One of the first challenges, while first preparing the LPD course structure and classes, was to embed the lean philosophy into the course material, the course dynamics and the students’ evaluation. The lean thinking (or philosophy) is a way to specify value, align the value-added actions, when requested execute these actions without interruption, and improve continuously [19]. In product development, adding customer value can be less a function of doing the right activities (or of not doing the wrong ones) than of getting the right information in the right place at the right time [13]. Hence, the focus of lean must not be restricted to activity “liposuction” (waste reduction), but must address the PDP as a system (value creation) [14].
The “Lean Journey” proposed by the LPD Course is aligned to this value-centric approach, where the lean principles application to the Integrated Product Development let the choice of tools and methods emerge from the observation of each company’s particularities. This approach is supported by several authors [5, 16, 19, 20, 21, and 22], which defend that learning LPD is not about learning tools, but understanding how to apply the lean philosophy.

### 3.1 The Lean Wheel System

In order to deliver the proposed value, the course was structured using the metaphor of a “Lean Wheel System” (Figure 1). The proposed wheel system enables the visual management of the course’s progress, being itself a representation of the links among its topics. The Lean Wheel System shows pictorially that the tools, techniques, and processes are means and not the end; the lean philosophy itself comprising the concepts of delivering value and yet reducing waste, added to the continuous improvement approach are the core of the LPD System.

The Lean Wheel System is composed by the following elements:

- **The Track**: Each wheel has to be designed considering the terrain in which it will be used; in this case, the environment is composed by the Product Development particularities. Therefore, the concepts, tools and techniques presented during the LPD Course might not apply to different “tracks”.
- **The well hub**: The hub guarantees that the Lean Product Development initiatives are not alone, but connects to the whole lean enterprise. This part comprises the “Core Lean” elements: the Continuous Improvement and the concepts of Value and Waste applied to the Product Development.
- **The Wheel**: The wheel itself metaphor include all supporting organizational aspects, enclosing the Lean Product Organization’s culture, organizational structure, and knowledge management aspects.
- **The Tire**: This part, which actually interfaces with the track, includes the Lean PDP, the Lean PD Tools, and the Lean PD Techniques.

![Figure 1: The “Lean Wheel System”](image)

### 3.2 The Lean Journey Path

The classes’ agenda sets the path to be followed by the Lean Wheel System. Through the agenda the wheel’s elements are taught in an interlaced way, where the resulting lean PDP emerges from the application of the core lean elements.

Table 1 presents the course schedule, which is composed by sixteen three-hour encounters, divided into two blocks. The table’s lines show (1) the main aspects to be stressed in each weekly encounter; (2) the tools and techniques, considering not only those from LPD, but also those from Integrated Product Development (IPD), Systems Engineering (SE), and Project Management (PM); (3) the related wheel’s elements; (4) the pedagogic resources; and (5) the related theoretical foundation. The students are evaluated both by knowing the theory itself, and by knowing how to apply the theory during practical exercises. Table 2 describes the acronyms included on Table 1, and that were not previously explained.
### Table 1: Weekly class summary

<table>
<thead>
<tr>
<th>Week</th>
<th>Topics</th>
<th>Tools &amp; Techniques</th>
<th>Wheel Element</th>
<th>Pedagogic resource</th>
<th>Theoretical foundation</th>
</tr>
</thead>
</table>
| 1    | - Present the LPD Course;  
- Product Development Overview [8, 23];  
- Lean Principles Overview [16, 19];  
| 2    | - The concept of “Value” [25];  
- Value through the Value Chain [25];  
- Product-Service Systems [26, 27]. | Genchi Gembutusu [21], DFD [28] | Value, Tools & Techniques | Lecture, Exercise 1 | LPD, IPD |
| 3    | - How to define and keep track of the value proposition. | VFD [25, 29], Concept Paper [21], WBS [30], and Obeya [31] | Value, Tools & Techniques | Lecture | LPD, PM |
| 4    | - From Value to Requirements [28, 32];  
- Prioritizing the value [25]. | VFD, Objective tree [32], Requirements engineering [28] | Value, Tools & Techniques | Lecture | LPD, IPD, SE |
| 5    | - The concept of “Waste” in the product development context [33];  
- How to identify the wastes in the PDP [34]. | PDVSM [34] | Waste, Tools & Techniques | Lecture, Classroom Exercise 2 | LPD |
| 7    | - Course-long practical exercise – Intermediate Presentation. | All Tools and Techniques presented so far | Value, Tools & Techniques | Students’ presentation | LPD, IPD, SE, PM |
| 8    | - Individual Test  
- Sole and group reflection of the progress so far. | Design for correction, Hansei [21] | All the elements presented so far. | Classroom Test | LPD, IPD, SE, PM |
| 9    | Course Break | | | | |
| 10   | - Knowledge [21] (and risk [25, 30]) Management  
| 11   | - Org Structure and Culture [21] | VFD | Org Structure, Culture | Lecture | LPD |
| 12   | - Knowledge [21] (and risk [25, 30]) Management  
| 13   | - Knowledge [21] (and risk [25, 30]) Management  
| 14   | - Knowledge [21] (and risk [25, 30]) Management  
| 15   | - Continuous improvement | Kaizen [41] | Continuous improvement | Lecture, Exercise 5 | LPD |
| 16   | - Individual Test | Design for correction | The complete Wheel | Classroom Test | LPD, IPD, SE, PM |
| 17   | - Course-long practical exercise – Presentation 2: Final Presentation. | All Tools and Techniques | The complete Wheel | Students’ presentation | LPD, IPD, SE, PM |
Table 2: Acronyms’ description

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>DFD</td>
<td>Data Flow Diagram</td>
</tr>
<tr>
<td>DSM</td>
<td>Design Structure Matrix</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effect Analysis</td>
</tr>
<tr>
<td>PDVSM</td>
<td>Product Development Value Stream Mapping</td>
</tr>
<tr>
<td>SBCE</td>
<td>Set-Based Concurrent Engineering</td>
</tr>
<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
</tr>
</tbody>
</table>

3.3 Rolling through the path

In order to “roll” the Lean Wheel System through the path, a course-long practical exercise, and a series of 5 short classroom exercises where included into the course. The exercises aim to practice the theory and foster discussion (Figure 2), when they can “go and see/perceive” how the theory is applied to practice.

The description of the exercises is as follows

**Exercise 1: Value Concept Practice**

The objective of this practice is to stress the value concept and the process of creating a value proposition. In the first moment, the class is divided into 4 people groups, with the task of eliciting the value to be delivered from a “Lean Product Development Course” according to different points of view: the students themselves, the lecturers, the organization offering the course, and the companies that might send some of its employees to attend the course. In a second moment, the whole group discusses their different perspectives, while the lecturer guides them to define a final value set.

**Exercise 2: Waste Concept Practice 1**

This exercise stresses the waste concept in the product development context. During the practice the class is divided into groups of 9 people: 1 manager, 2 subsystem designers, 1 cost manager, 2 subsystem assemblers, 1 final system assembler, and 2 observers. The groups compete to develop, build (using Knex™ blocks) and sell the same predefined product, and have to follow strict development roles (Figure 3): (1) Each designer draws the subsystem under his/her responsibility; (2) the cost manager checks the acceptability of the design; (3) each sub-assembler assembles the subsystem under his/her responsibility according to the approved design; (4) the system assembler assembles the whole system; (5) the manager makes the link among the team members and with the client. No team members talk to anybody but the manager. The observers map the value stream, by taking notes about waste occurrence.
Exercise 3: Waste Concept Practice 2
Most of the wastes relate to each other, in the sense that one might trigger another. In this practice the class is divided into groups of 2, each group in charge of analyzing the causal relations between a particular waste and the others. In the end, each group presents their findings, and, through class discussion a DSM [40] representing the final conclusion is filled and grouped.

Exercise 4: SBCE Practice
Through a card game, each 5 people team competes against each other to have an “optimal hand” of 5 cards. They play 2 rounds with different rules, the former following a point-based search of the solution space, and the latter applying the set-based approach. By this simple game, they can understand the pros and cons of each approach.

Exercise 5: Continuous Improvement Case Study
The Kaizen technique is analyzed during a case study from the automotive industry. The students are challenged to raise the issues from the application of this approach into the product development organization.

Course-long practical exercise
The class is divided into groups of 5 to 6 people, and each group has to execute the initial Lean Product Development phases, in order to plan the development of a product. In 2012 the teams worked on a twin stroller project; in 2013 the objective was to design a coffee and tea machine, and in 2014 their scope is a cleaning robot. In 2014, was also introduced the use of the Lego Digital Designer™ for virtual prototype producing.

The exercise is mainly based on the Value Function Deployment Technique [26, 30]. The VFD is inspired by the Quality Function Deployment (QFD) technique, and supports the operationalization of the lean principles into the PDP. Based on value creation and waste reduction, the VFD derives a project activity network that is based on a sequenced set of confirmation events. These events pull only the necessary and sufficient information and materials from the product development team. The VFD is composed of two interconnected matrices, the value identification matrix and the waste reduction matrix (Figure 4). The former captures, prioritizes and shows the correlation between all the value items expected by the project’s stakeholders. The latter deploys the value items to the value delivery teams, calculating their criticality (rework avoidance sub-matrix), and defines the events that pulls this value from the teams (flow definition sub-matrix).

![Figure 4. The Value Function Deployment matrices.](image-url)
During the exercise, the groups are also requested to create an Obeya [31] to control their progress, while they complete the matrices by using and applying several LPD, IPD, SE and PM tools, techniques and concepts. Figure 5 shows how the exercise evolves through the classes, where the VFD matrices’ elements are printed in italic bold, and some of the used tools and techniques are underlined.

![Figure 5. The Value Function Deployment through the LPD Course.]

3.4 Checking the progress during the journey

There are two individual tests; they occur by the end of each course’s block, on the weeks 8 and 16. The questions are prepared in a way that the students have to establish the relationship among a number of concepts, approaches and techniques discussed during the course. The students are free to check their class notes, slides, books and papers. A sample question is shown below.

Mark the correct alternative(s) with regards to Lean Development Product (LPD)

(a) It is more important to understand how the Lean philosophy is applied to the Product Development Process (PDP) than to know the lean techniques and tools.

(b) LPD radically differs from Integrated Product Development (IPD) what makes LPD a very difficult matter to be understood by occidental companies.

(c) As Knowledge Management (KM) is a weak characteristic of LPD, the two subjects are complementary, and create a sustainable and competitive advantage for the companies.

(d) The continuous improvement associated to LPD has little impact over the PDP performance indicators, once the majority of the companies are already ISO 9000 certified.

(e) Based upon the triad Knowledge, Skills and Attitudes (KSA), the teaching of LPD in occidental enterprises has to be focused on Knowledge.

A single, open question such as “Dissert about the impact of LPD over the ISO 9000 certified companies”, is replaced by five alternatives with more strict content. However, in all the alternatives the student has to review several contents and the relationship among them. In the sample question, the concepts of LPD philosophy, LPD tools, IPD, KM, KSA are intentionally mixed.

The test lasts 60 minutes, and the students keep their test sheets for correction. The lecturer starts the oral correction by stating the correct answer for each question (alternative “a” on the sample question). A student might argue that another alternative is also correct; having to explain what sustains his/her choice. Other students might join the discussion what turns the correction process into a “Greek Agora Square”. Naturally the lecturer has to keep the discussion under control, avoiding the corporatism syndrome. Eventually the argumentation of the student might be taken into account, and the lecturer would consider the student’s choice correct. It is not the case, though, for the presented sample question.
This correction process is named Design for Correction (DFC), by following the same principles of the DFX (Design for Excellence) tools (Huang, 1996): the elaboration of the questions with multiple alternatives (similar to the IPD’s conceptual design phase) takes longer than open questions elaboration (similar to the Sequential PDP’s conceptual design phase). However, the correction process of the DFC approach is far shorter than that for the traditional, open questions tests. This is because the test is elaborated (designed) with the correction process in mind. In the last two courses (average of 20 students), the correction process took 2 hours (average) for completion. At the end of the correction process, the students sum up their correct answers, and register their own grade.

4. Lessons from the past Mileage

The LPD Course was first offered in 2011, since then it continuously evolved to proportionate an improved value delivery. Table 3 highlights some of the major aspects of the course through the years, and the results from the reflections (Hansei [22]) performed during the course execution.

<table>
<thead>
<tr>
<th>Year</th>
<th>Highlights</th>
<th>Hansei Results</th>
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<tbody>
<tr>
<td>2011</td>
<td>“Pilot course”: from the pool of initial candidates to attend the course, was selected only a small group of people with previous experience in the Toyota Production System; the pedagogic resources where lectures and group discussions, aiming to cover the most of Morgan and Liker’s book [22].</td>
<td>In the final reflection, the group concluded that the course would benefit from including some practical exercises, especially in the case of having people with less/no previous experience on Lean.</td>
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<tr>
<td>2012</td>
<td>A long practical exercise and the Knex™ (waste) exercise were included; the group of attendees was bigger and more diverse, in terms of previous knowledge of lean; the focus on presenting most of the content from the Morgan and Liker’s book [22] was maintained.</td>
<td>The group complained that they were overwhelmed by theory, and that some of the aspects presented where secondary or very particular to the body stamping process; they also felt the need of more time for the long practical exercise, since it started only during the course’s second block (week 9).</td>
</tr>
<tr>
<td>2013</td>
<td>The long course practical exercise was turned into course-long: being started in the middle of the first block; A SBCE game was included; the theory presentation changed its focus into the lean principles themselves, and particularities from Toyota were summarized (given as examples to illustrate some of the concepts) or skipped; this time, most of the students had few or no experience with Lean.</td>
<td>The group felt the need of more class exercises to support the application of the course-long practical exercise concepts, tools and techniques.</td>
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</table>

5. Final Remarks

This work presented the Lean Product Development Course taught in the Mechatronics Engineering Graduate Program, at the Instituto Tecnológico de Aeronáutica – ITA, where the lean philosophy is embedded into the course material, the course dynamics, and the students’ evaluation.

The Lean Wheel System was proposed in order to enable the visual management of the course’s progress. It pictorially shows that the LPD tools, the LPD techniques, and the Lean PDP emerge from the lean philosophy itself; while the lean philosophy is composed by the concepts of value creation, waste reduction, and continuous improvement.

By using the Value Function Deployment technique during a course-long practical exercise, useful insight is gained about the implications of interlacing LPD concepts, tools and techniques together with the concepts from Integrated Product Development, Systems Engineering, and Project Management.
The challenges faced so far were: (1) prioritize the theory to be presented in a 50 hour course; (2) define the pedagogic resources to fit different mixes of attendees, considering their previous experience with lean; (3) to not deviate from the philosophy, and give more importance to the tools (maintain the sensei attitude).

After three years offering the course, the main lessons learned were keeping the focus on the core lean (value, waste, and continuous improvement), and foster discussions comparing each student’s particular professional scenario and culture with the Toyota scenario and culture. While the former guarantees stressing what concepts are important to be kept no matter where the LPD is going to be applied, the latter molds a critical mindset needed for adapting the LPD to one’s reality. A challenge for the next years is to explore alternatives to introduce more reality into the course-long practical exercise.

References