Chapter 5
Lean Teaching Experiences in Universidade NOVA de Lisboa and the TRIZ-LEAN Model

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5.1 Introduction

The Lean Philosophy and Continuous Improvement continue to be the day's agenda of organizations.

The universities feel a growing and increasingly widespread interest of undertakings in engineers and other staff with good preparation in this area. The students realize up search, and attempt during the courses at the Faculty or immediately after taking courses or disciplines related to Lean.

The Faculty of Science and Technology, *Universidade NOVA de Lisboa*, attempts to offer students a wide and updated education, according to the need of a good generalist academic background and, at the same time, provide students with opportunities for learning new techniques and approaches.

In the Department of Mechanical and Industrial Engineering a Course of Postgraduate Studies in Lean Management was created and, later, the discipline "Lean and Six Sigma Methodologies" was created as an optional discipline for students of the Masters in Industrial Engineering and Management. With this, Lean is no longer the exclusive subject matter of post-graduate courses, becoming accessible to the Master of Science regular students.

In recent years in the Department of Mechanical and Industrial Engineering several studies were developed that aim to investigate the joint deployment opportunities of different methodologies. This study reflects the search of a model for the joint use of the TRIZ methodology with Lean philosophy.

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The publications described in this chapter are related to various practical applications of some techniques and analytical tools of TRIZ together with Lean, Lean Maintenance approach in several industrial companies. These case studies were based on the students work who did a traineeship and their M.Sc. Dissertations in respective companies.

Our experience confirms the usefulness of joint use of methodologies.

5.2 Post-graduate Studies in Lean Management

Lean has entered the everyday life long ago at the Faculty of Science and Technology of *Universidade NOVA de Lisboa*, Portugal.

For several years the Department of Mechanical and Industrial Engineering has ministered a Course of Post-Graduate Studies in Lean Management.

This course is addressed to entrepreneurs, managers, middle and senior managers of companies, consultants, trainers and other professionals with Bachelor's degree. Through the years, the course has passed dozens of graduates from various fields of academic education and professional activity. This type of graduate degree attracts not only industrial engineers, but also engineers from other numerous different branches of engineering, as well as economists, pharmacists, doctors, etc.

This course provides an introduction to the principles, methods and practices underlying the Lean Management and aims to provide knowledge necessary for the implementation of its principles.

The program structure has been evolving over time, however, always contains certain key elements:

- Lean Thinking;
- Strategy Deployment;
- Leadership;
- Lean Production;
- Lean Tools;
- Value Stream Mapping;
- Lean in Services;
- Lean Six Sigma;
- Lean Supply Chain.

At the end of the program the participants should be able to:

- Interpret the concepts inherent to the philosophy of Lean Management,
- Identify obstacles and waste,
- Dominate the knowledge underlying the Lean thinking,
- Know the tools and methodologies of Lean operation,
- Develop methodologies for strategy deployment,
- Understand the methods of analysis and mapping of value streams,
- Develop Lean projects in their organizations.

The specialized training in Lean Management is dedicated to make available technical knowledge of great professional applicability in the field of process management, providing access to a set of practices and knowledge for increasing productivity in industry and services.

5.3 "Lean and Six Sigma Methodologies" Discipline

There has been a great interest amoung regular undergraduate students for more knowledge about Lean. A few years ago a new optional discipline has been established titled "Lean and Six Sigma Methodologies". So the teaching of Lean ceased to be one of the exclusive themes of post-graduate courses, and began to be ministered in the regular courses of the Faculty.

It is an optional discipline of the M.Sc. in Industrial Engineering and Management.

This curricular unit provides an introduction to the principles, methods and practices underlying the Lean Six Sigma Management and aims to provide knowledge necessary for the implementation of its principles and methodologies.

At the end of the program students should be able to:

- Interpret the concepts inherent to the Lean Management philosophy,
- Know the Lean's tools and methodologies,
- Value stream mapping,
- Understand the implementation requirements of Lean projects.
- Know the Six Sigma methodology in the improvement of existing processes
- Know the DFSS methodology (Design for Six Sigma)
- Know the metrics associated with Six Sigma and DFSS methodology
- Know the tools to support the implementation of Six Sigma and DFSS
- Apply the DMAIC cycle for Six Sigma projects
- Apply the DMADV cycle (redefinition) or IDOV cycle (innovation) in DFSS projects.

The course program includes the following topics:

- Lean Thinking: lean principles and values in the new paradigms of corporate management; Time based management; Waste identification; Value and the value creation process; Value flows and business processes; The lean diagnosis. (Shingo model).
- Lean Manufacturing: The Toyota Production System; The JIT and Kanban; The cell production and leveling of production; The takt time; The TPM system.
- Lean methods and tools: 5S and visual control; problem solving techniques; poke-yoke; SMED; standard work; POUS; Value stream mapping; A3 methodology.
- Six Sigma: The philosophy of Lean Six Sigma; from simplification to the reduction of process variability; DMAIC method; tools and metrics of Six Sigma; Kaizen events and continuous improvement; DMADV method in redefining of products/processes; IDOV method in innovation of new products/processes.

5.4 Education and Research of the Joint Use of Systematic Innovation with Lean Management

At the Department of Mechanical and Industrial Engineering, Faculty of Science and Technology, Universidade NOVA de Lisboa, there is a group of researchers who in recent years is devoted to teaching and research at the Joint Deployment of Systematic Innovation with Lean Management.

Several theoretical and practical studies on the subject were conducted. In the study several dissertations were developed, some with practical applications in industrial companies.

The Lean implementation environment requires advanced analytical tools and methodologies (ex. VSM and A3), but there is not much work done on tools for generation of solutions (Melton 2005). Theory of Inventive Problem Solving (TRIZ) systematizes solutions that can be used for different technical fields and activities (Terninko et al. 1998). The inconsistencies are eliminated by modification of the entire system or by modification of one or more subsystems (Savransky 2000).

This study intends to propose a conceptual model that explores the relationships between LEAN and TRIZ practices and methodologies. As a potential solution generator, the researchers believe that the use of TRIZ may help to promote improved Lean management environments.

Lean Philosophy is a systematized approach to continuous improvement (Holweg 2007). Its extent is a methodical search of process improvement through reduction of wastes and inefficiencies (Demeter and Matyusz 2011). Lean can be applied to all areas of enterprise and it supposes improvement of efficiency and effectiveness.

Lean has been adopted in a large number of companies from different industrial sectors. It has moved away from being merely a "shop-floor focus" on waste and cost reduction to an approach that consistently drives to increase value for customers by adding product or service features and removing wasteful activities (Cruz Machado and Tavares 2008).

Lean Production is focused on the value stream that originates the product, aiming at maximizing value and eliminating Muda (waste in Japanese), optimizing the whole and not just parts of the process.

The idea is that the value should flow continuously over all the organization, to reach the costumer as quick as possible. A Lean thinking environment requires a "learning to see" approach, in order to find obstacles (waste) to be removed. This means that it is vital to research a problem solving methodology which improves the value stream.

Lean Thinking includes all employees and requires significant changes in their attitudes and professional behavior. Lean has a profound effect on both the organization and the people that make up the organization.

Systematic innovation is crucial for increasing organizational effectiveness, enhancing competitiveness and profitability (Navas 2013a). The Lean management philosophy depends on the creation of systematic innovative solutions to improve processes.

At the start of Lean implementation, the vast majority of improvements can be achieved by simple solutions. While Lean implementation process moves forward, it depends more and more on the really innovative solutions and radical changes.

Traditional engineering and management practices can become insufficient and inefficient for the implementation of new scientific principles or for radical improvements of existing systems (Navas 2013b). Traditional ways of technical and management contradiction solving is through search of possible compromise between contradicting factors, whereas the Theory of Inventive Problem Solving aims to remove contradictions and compromises (Fey and Rivin 1997).

Traditionally Lean tools are Value Stream Mapping, Quick Changeover/Setup Reduction, Single Minute Exchange of Dies (SMED), Kaizen, Flow Manufacturing, Visual Workplace/5S Good Housekeeping, Total Productive Maintenance (TPM) and Pull/Kanban Systems (Ikovenko and Bradley 2004).

The TRIZ method consists of a set of different tools that can be used together or apart for problem solving and failure analysis (Altshuller 1995). There are many techniques and concepts within Lean where TRIZ might be applied (Campbell 2004).

Generally, the TRIZ's problem solving process is to define a specific problem, formalize it, identify the contradictions, find examples of how others have solved the contradiction or utilized the principles, and finally, apply those general solutions to a particular problem (Altshuller 2001).

It is important to identify and to understand the contradiction that is causing the problem as soon as possible (Altshuller 1999). TRIZ can help to identify contradictions and to formalize problems to be solved. The identification and the formalizing of problems is one of the most important and difficult tasks, with numerous impediments. The situation is often obscured.

The problem can be generalized by selecting one of the TRIZ problem solving tools. The generic solutions available within TRIZ can be of great benefit at choosing corrective actions.

The merger of Value Engineering Analysis (VEA), Root-Cause Analysis (RCA), Flow Analysis (FA) and several other engineering analytical methods with TRIZ, originated several integrated methodologies based on TRIZ: ITD, TRIZ Plus, I-TRIZ.

The integrated methods combine the analytical tools with the inventive ability of TRIZ, so they present real advantages, specially integrated on applications with organizational methods like Lean.

There are several key principles for successful application of Lean techniques into a business environment (Womack and Jones 1996):

- Value
- Value Stream
- Flow
- Pull
- Perfection

The approach to value in TRIZ Plus has the same objective as Lean Value Principle: to determine the value of different operations of the process or components of the product.

The traditional Lean seven types of Muda are:

- Overproduction
- Inventory
- Extra Processing Steps
- Motion
- Defects
- Waiting
- Transportation

After the value has been specified, the next step is to identify the value stream.

TRIZ Plus tools can be used in the approach to the value stream and the Lean Value Stream Principle.

Flow is defined as a fabrication process from raw material to final product without interruption or delay.

The key tools for Flow implementation are (Ikovenko and Bradley 2004):

- "Takt Time"
- Standardized Work
- 5S
- Work Balancing
- Leveled Production

The Pull Principle identifies the need to be able to deliver the product to the customer as soon as he needs it.

The TRIZ tools cannot be applied directly to Perfection Principle, however some Inventive Principles and Standard Solutions are appropriate here (Ikovenko and Bradley 2004).

The implementation and deployment of Lean Thinking in organizations will be more sustainable if the Lean approach be supported by a set of TRIZ Plus tools.

TRIZ can support Lean product development by strengthening a team's ability to leverage and reuse knowledge across the enterprise and pull in knowledge from other companies and industries.

Lean Thinking is a highly evolved method of management and organization that aims to improve the productivity, efficiency and quality of products and services. Lean Philosophy focuses on streamlined work process without delays, with maximized production, minimized nomenclature and bureaucratic proceedings.

The current lean approach is to use sensitivity analysis to try to find the best compromise. The TRIZ approach is to find out how to avoid the compromise or trade off (Campbell 2004). While TRIZ tends to focus more often on smaller problems, lean is used more for systems level examination (Bligh 2006).

TRIZ and Lean Thinking are both ways of improving the operation of a system. Both TRIZ and Lean look to optimize the use of available resources. TRIZ focuses on individual elements to optimize, where lean takes in the entire system to find potential efficiencies.

TRIZ could be useful to find solutions that utilize available resources currently seen as waste ("muda" in Lean) (Bligh 2006).

5.5 Students Internships and Dissertations in Lean

Teaching at the Faculty of Lean and a high demand for experts in Lean encourage students to perform academic and professional internships related to the topic of Lean and Continuous Improvement. This phenomenon has led to the significant number of master's degree dissertations developed in Lean and related matters. It was also observed an increased interest of students to perform internships and dissertations on topics related to the joint implementation of Lean with some other methodologies, for example, joint implementation of the Lean Philosophy with Six Sigma Methodology.

In the past, several dissertations (some of them more theoretical, the other more practical) on the joint application of Lean and TRIZ methodologies were developed.

Another trend that was noted in internships and dissertations is the enlargement of Lean application areas. If at first the Lean was further applied to production systems, over time more and more applications appear in services, consulting practice, etc. Also different functional areas within companies began to be the target of continuous improvement/Lean studies, for example, maintenance management, logistics, etc.

The internships and dissertations in Lean as much appear related to important national and international companies, such as cover small and medium side enterprises of different sectors of economic activities.

In most cases the students in Lean are invited to work in the company when they had finished the traineeship.

Sometimes our former students become responsible for continuous improvement/Lean in companies and provide internships in Lean to current students.

The study carried out under internships and dissertations in Lean has produced a significant number of presentations at national and international congresses and other scientific events by students and faculty advisers. It has also published a significant number of articles in national and international scientific journals based on the results of theoretical studies and practical applications of Lean by our students and their faculty advisers.

Some of the students work was awarded in national and international competitions and events. For example, the project of the team consisting of professors and former students, won the bronze medal at The 5th Global Competition on Systematic Innovation (GCSI) held in July 2015 in Hong Kong. The project "TRIZ and Lean in an Industry of Air Handling and Ventilation" was developed under the collaboration between the Department of Mechanical and Industrial Engineering, Faculty of Science and Technology, Universidade NOVA de Lisboa, Portugal, and Sandometal—Metalworking company and Air Conditioning S. A., based in Alverca and in Castanheira do Ribatejo, Portugal.

The project was based on the work done under the traineeship held in Sandometal and the Master's Thesis of a former student, a recent graduate of the M. Sc. in Industrial Engineering and Management. After the traineeship and the conclusion of the M.Sc., the young engineer was invited to work in the Sandometal company. Thus, this traineeship and the thesis gave one paper in an international conference and an award-winning project, which was also presented and defended in an international scientific event.

Another Master's thesis, a M.Sc. in Mechanical Engineering thesis, was seen by many as revolutionary for its time, since it aimed at applying Lean for improving the production processes and operations in a pharmaceutical company. Back then the pharmaceutical companies did not yet know and did not apply Lean. Nowadays it would be nothing new.

In our faculty, we have had several dissertations related to the implementation of Lean Maintenance. Some of these dissertations were more theoretical, others were of a more practical application. Maintenance Lean has a lot of demand. Students many times begin to do an internship in a company that initially did not give importance to maintenance management, amounted in practice a modern maintenance service, implement correct and modern procedures and after the internship are to head the service.

5.6 Conclusions

Lean and Continuous Improvement have become unavoidable issues in the education of future engineers, especially industrial engineers. The graduate students seeking to enroll in disciplines related to Lean, the demand for postgraduate courses in Lean and similar is very high. The graduate students are looking to get diplomas and certificates in lean, even during the last years of Faculty or soon after, before entry into the labor market.

Students know that entering into the labor market is easier for recent graduates who acheived the dissertation or an internship in Lean. Thus, there remains high demand among the finalists of internships and dissertations related to Lean and continuous improvement.

The Faculty of Science and Technology, Universidade NOVA de Lisboa, accompanies this demand and interest with post-graduate courses, thematic optional courses, offering themes and scientific support in carrying out dissertations related to Lean.

The Department of Mechanical and Industrial Engineering along with organizes conferences, seminars and other events in Lean and other related topics.

In recent years, in the department and in the research center (UNIDEMI), valences were developed under joint deployment of Lean with other methodologies (6 Sigma, Agile, TRIZ, …). These methodologies complement each other.

The Systematic Innovation can be used in Lean environments with success, as illustrated by the case study presented in the chapter. The TRIZ methodology, with its vocation of solutions generating and with its creative and innovative approach to problem solving, can contribute positively to evolution and development of organizations.

Lean maintenance is being increasingly studied and demanded by companies. The TRIZ methodology could significantly contribute to improve and accelerate the processes of Lean Maintenance, to create more innovative solutions.

Several case studies, developed by students, reflect an importance of the application of TRIZ together with the techniques of Lean, Lean Maintenance in various industrial companies and organizations. The results were very positive, so the teaching model was validated.

Some Lean education initiatives have already been implemented, others will be implemented in the short or medium term. Thus, the focus on Lean teaching clearly wins.

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