THE LEAN PRODUCTION MULTIDISCIPLINARY: FROM OPERATIONS TO EDUCATION

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Abstract
Lean Engineering (LE) had its roots in Toyota automobile production where the main objective is to standardize operations, so that wastes in the production processes can be identified and eliminated. Pursuing standardization in a systematically and continuous way, companies enter a continuous improvement mode of operation where input from all affected parties across the value stream is sought; this requires personnel on all levels of the organization to be prepared to be active learners. As LE has exceeded its original focus and application in the automotive industry, it has transformed manufacturing industries as well as service providers, including travel agents, health care, and many others. Yet, although engineers and non-engineers alike rely on LE principles and tools almost daily, LE has not yet transformed Engineering Education. In this paper, the authors review their concept of Lean Engineering Education which they have based on the three-step of ethics, system-thinking and sustainability. The paper concludes with recommendations for curriculum innovations to improve engineering students’ competencies.

Keywords:
Lean Production; Lean Engineering Education; engineering competencies.

1 INTRODUCTION
Lean Production (LP) had its origin in Toyota Production System [1] [2] of Toyota company. After the Second Great World War, Toyota had to change its approach to production to maintain its automobile production, as the resources were scarce. Its key idea was to “doing more with less” where “less” means fewer resources, less inventory, less human effort, less space, less of everything than their American counterparts [3].

Attending to this idea, Lean Production was the term adopted later in the best-seller “The Machine that Changed the World” from Womack and colleagues [3]. Toyota way to achieve a “lean” approach was to eliminate all wastes, i.e., activities that adds no value to the product from customer point of view. This allows reducing cost and increasing productivity. Nevertheless, waste elimination is not enough because this needs a context and a culture, increasing productivity. Nevertheless, waste elimination is customer point of view. This allows reducing cost and sustainability. The paper concludes with recommendations for curriculum innovations to improve engineering students’ competencies.

Additionally, as the authors considered these initiatives are not enough, in this paper, the authors present and review their concept of Lean Engineering Education which they have based on the three-step of ethics, system-thinking and sustainability. The paper concludes with recommendations for curriculum innovations to improve engineering students’ systems thinking competencies.

This paper is organized in five sections. After this introduction, the authors present a brief literature review about Lean Production (LP) and implementations cases of Lean. The section three outlines the theme of this paper, the LP multidisciplinary, based on the disciplines/areas that had been applying Lean concepts and principles. Furthermore, explore the Lean education area as the most fertile area. Based on this, the authors propose their Lean Engineering Education concept in section four. Some conclusions are presented in section five.

2 LITERATURE REVIEW
This section presents a brief literature about Lean Production definition, principles and tools. Additionally, some implementation cases and benefits are presented.

2.1 Lean Production definition, principles and tools
The National Institute of Standards and Technology (NIST) [6] defined Lean Production as “… a series of tools and techniques for managing your organization’s processes. Specifically, Lean focuses on eliminating all non-value-added activities and waste from processes. Although Lean tools differ from application to application, the goal is always incremental and breakthrough improvement. Lean projects might focus on eliminating or reducing anything a final customer would not want to pay for: scrap, rework, inspection, inventory, queuing or wait time, transportation of materials or products, redundant motion and other non-value-added process steps.”

In this definition the wastes are also presented which were defined the first time by Ohno [2]. Additionally, others authors, namely Liker [4] had been defined others wastes...
such as untapped human potential that it is considered the most serious waste as inhibits companies to evolve. In this human potential is the ability of people to learn and continuously improve to achieve perfection. Pursuit perfection is the fifth Lean Thinking principle from Womack and Jones [7]. The other four are: Value – identify what is the value for the client; Value Stream – identify the activities that adds value to the products; Continuous flow – means a smooth and levelled workload without waste and 4) Pull system – this means that it is the client that trigger the services delivery and content. Applying systematically these principles, companies continuously improve in order to aspire perfection.

Knowing these principles, companies must also have competency to apply the correct tools to achieve each principle. There are many tools available such as standard work, visual management, 5S, kaizen, quick changeover (QCO), single minute exchange of die (SMED), poka-yoke mechanisms, levelling, among others [8]. Then it is necessary to know when and how to apply them [9] [10] in order to walk in the right way for Lean implementation well-succeed.

2.2 Lean Production implementation cases and benefits

Lean Production had been implemented in almost all manufacturing industries and services providers. Some examples (case studies, surveys,….) from literature are too many, evidencing the cross-sectional and globalization of Lean application (Table 1).

<table>
<thead>
<tr>
<th>Table 1: Examples of Lean application</th>
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<tbody>
<tr>
<td>Reference</td>
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<tr>
<td>Swank [12]</td>
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<td>Emiliani [13]</td>
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<td>Melton [14]</td>
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<td>Doolen &amp; Hacker [15]</td>
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<td>Bonavia &amp; Marin [16]</td>
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<td>Abdulmalek &amp; Rajgopal [17]</td>
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<td>Ziskovský &amp; Ziskovský [18]</td>
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<td>Flumerfelt [19]</td>
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<td>Wong et al. [21]</td>
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<td>Waldhausen et al. [22]</td>
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<td>Pool et al. [23]</td>
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<td>Romero &amp; Martin [24]</td>
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<td>Hodge et al. [25]</td>
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<td>Vinodh et al. [26]</td>
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<td>Carvalho et al. [27]</td>
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<td>Staats et al. [28][29]</td>
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<td>Veža et al. [30]</td>
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<td>Chowday &amp; George [21]</td>
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<tr>
<td>Martins &amp; Carvalho [31]</td>
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<td>Bortolotti &amp; Romano [32]</td>
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<td>Ribeiro et al. [33]</td>
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<td>Lyons et al. [34]</td>
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<td>Bragança et al. [35]</td>
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<td>Blank [36]</td>
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<td>Kusler [37]</td>
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<td>Alp [38]</td>
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</tbody>
</table>

Additionally, some surveys cross-sectional industries have been published, namely, Panizzolo [39][40]; Shah & Ward, [41]; Liker & Morgan [42]; Page [43]; Taj [44]; Silva et al. [45]; and Mathur [46]. Benefits achieved by these companies are oriented to the reduction of costs and improvement of productivity. This means reducing all wastes such as reduced transports, defects, motions, inventory, over-processing among others [47]. Such benefits allow companies obtain more profits without increase the resources or firing people.

3 LEAN PRODUCTION MULTIDISCIPLINARY

This section presents disciplinary areas that had been applying LP. Moreover, it presents its application in Educational curricula in some universities.

3.1 Disciplines/areas

It was evident from above that LP is cross-sectional and global. Furthermore, Lean Thinking (LT) is being adopted in many disciplines/areas:

- Lean Services – applied to services (offices, hospitals, schools, restaurants,…)  
- Lean Office – applied to administrative processes in office; normally is included in the first category  
- Lean Higher Education – applied to universities processes; normally is included in the first category  
- Lean Construction – applied to construction of houses, roads, bridges, ships and others products of large dimension in a fixed site (or project) type layout  
- Lean Green – applied to achieve the sustainable development (toolkits of U.S. – EPA)  
- Lean Coaching – applied to training and people development  
- Lean Six Sigma – applied to process improvement  
- Lean Supply Chain Management/Lean Logistics – applied to supply chain and warehouse management  
- Lean Accounting – applied to accounting  
- Factory of One/Personal Kanban – applied to individual performance  
- Lean Startup – applied to software development and companies entrepreneurship  
- Lean Education – applied to Education
The success of LP is related with its inherent philosophy, Lean Thinking as this implies a culture change and a new mind-set. Any company that embraces LT will be in a continuous improvement effort where everything is questioned by all people. People is transformed to active thinkers and learners [48] that will continuously provoke more damage than good. Therefore, it is not a surprise than Lean Thinking principles and tools had been adopted and combined in so many disciplines.

3.2 Lean Education

Many authors have been integrating Lean Production in students education through some courses included in the program. They have this concern as they felt to train the workforce and to educate students in LP is an imperative to face the new industrial challenge. At the same time, they are providing industrial companies with better prepared students capable to work in Lean environments and avoid companies to spend money in employees training.

For these reasons, Lean Education has been a concern of some important initiatives and networks. Lean Aerospace Initiative (LAI) Educational Network (EdNet) is one of this networks. This was established in 2002 and comprised 32 universities (from US and UK) who share a common interest to collaborate on developing and deploying curriculum for teaching lean six sigma fundamentals [49]. In a faculty collaboration effort, supported by a small staff centered at MIT, a LAI Lean Academy® a week-long course was developed. This course was delivered to multiple audiences on-campus and in industry and government. They based this in CDIO approach (Comprehend/Conceive, Design, Implement and Operate) [50].

Murman et al. [49] discusses Body of Knowledge (BoK) for Lean Thinking arguing that this BoK is not based upon laws of physics and chemistry and is not represented by sophisticated mathematics. This is due to its roots that are based on processes and people/organizational dynamics for which there are no laws. According to them, it relies on understanding “best practices” which are observed through field research of actual enterprises. These best practices are not invariant with time, which means the BoK is subject to change. They also add that much like many engineering science disciplines, information technology is big factor in the current evolution of the BoK.

Another network is Lean Education Academic Network (LEAN) [51]. LEAN is a group of university educators seeking to promote Lean education in United States higher academia. LEAN also helps improve Lean education through sharing of knowledge and teaching materials, collaboration, and networking among colleagues.

These networks, together with Lean Enterprise Institute (LEI) that has been also concerned with Lean Education [52] are sponsoring a conference – Lean Educator Conference (LEC) with the objective of sharing best practices in Lean curriculum and pedagogy.

Table 2 presents some publications about programs, courses or modules that had been adopted to teach Lean Production concepts, principles and tools. Additionally, in this table are presented the learning methodologies used to teach these concepts. It is important to notice that LP demands active learning methodologies [56] to engage actively students in their own learning and in collaborative learning.

Moreover, it is also evident that project work in a company (industrial environment) is frequent as a learning methodology. This is not a surprise because as already explained in the first section (Introduction), Toyota Education Model is a “learning by doing” system. According to some authors, namely Huntzinger [57], this system was adopted from the model Training With Industry (TWI) for training people in industry developed to support U.S. industry during World War II and Lean roots and kaizen were grounded on this model.

According to Suzuki [58] people in companies are simultaneously assuming the role of a trainer and trainee, teaching and learning with each other. This is necessary to empower people and continuous improvement. The concern with people learning is continuous as companies only grow with this. “Making people before making products” can be read in Figure 1 that shows a picture from the book of this author.

![Figure 1. The new shop-floor management vision (aspect from [58])](http://www.leaneducatorconference.org/news/99-2014-lean-educator-conference-call-for-papers.html)

Moreover, a project joined Dutch, Swedish, Polish, Portuguese and Romanian universities and companies in a project in the framework of an Erasmus–Lifelong Learning Program (LLP). Martens [53] presents the report of this project considering this an innovative training program on Lean Manufacturing. The objectives of Lean Learning Academy [54] [55] with this project are to satisfy the need for training lean manufacturing principles in companies and to improve engineering students’ employability in professional life.

<table>
<thead>
<tr>
<th>Authors/year</th>
<th>Program/course/modules taught to:</th>
<th>Learning methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torres &amp; Stephens, 2005; 2006 [59]</td>
<td>Industrial Technology students; Business process managers - graduate</td>
<td>Lecturing, analysis of cases and the study of real business situations; basic cognitive skills (concepts and theories); project selection and execution</td>
</tr>
<tr>
<td>Lobaugh 2005;</td>
<td>Technical elective for all undergraduate</td>
<td>Lectures and simulations; group participation and investigation of actual industrial applications</td>
</tr>
</tbody>
</table>
Van Til et al. 2005 [63] engineering major; elective for the masters level of lean practices

Fang et al. 2006, 2007 [64][65] Colleges of Engineering and Business

Mehta & Monroe 2006 [66]; 2009 [67] Distance education students and nonmanufacturing employees

Miles & Hawks 2006 [68] Undergraduate students

Candido et al. 2007 [69]; McManus et al. [70]; Murman et al. [49] Audience with little or no experience in LP: undergraduate & graduate engineering students; MBA students; coops and interns new employees; long term employees; military personnel

Chen & Cox 2008 [71] College of Engineering

Hall & Holloway 2008 [72] Undergraduate and graduate engineering; non-engineering students (from business or medicine)

Peters et al. 2008 [73] Industrial engineering students

Thomas 2008 [74] graduate-level Engineering students

Martens [53] Engineering students

Johnson 2010 [75] Industrial engineering

Leduc et al. 2010 [76] Manufacturing Engineering Technology (MfgET) capstone

Peter 2010 [77] Graduate students with different undergraduate educational backgrounds including individuals with no prior industrial experience


Mozammel et al. 2011 [80] Industrial engineering technology

Allam et al. 2012 [81] First-year Engineering

Vila-Parrish & Raubenheimer 2012 [82] Industrial and Systems Engineering (ISE)

Wan et al. 2012 [83] College students and industry personnel

These publications evidences that incorporating Lean Thinking in Engineering Education is utmost a value proposition for engineering students to develop competences needed by industry and society, now and in the future. This is discussed in the next section.

4 LEAN ENGINEERING EDUCATION

Leam Education presented previously showed many examples of the concern in including Lean in engineering and other curricula. This offer benefits for the academy that include the improvement of course design/delivery based on problem/project-based learning and of the overall quality of the learning experience based on student-centeredness competences.

Beyond this, authors of this paper proposed the Lean Engineering Education (LEE) concept. LEE is the term labeled by the authors of this paper to Lean applied to Engineering Education curriculum design. Lean Engineering Education is defined in book "authors in progress [85] as:

"A systematic, student-centered and value-enhanced approach to educational service delivery that enables students to holistically meet, lead and shape industrial, individual and societal needs by integrating comprehension, appreciation and application of tools and concepts of engineering fundamentals and professional practice through principles based on respect for people and the environment and continuous improvement."

When students are taught in LEE, they are enabled to develop problem solving skills [86], to think systemically, ethically [87; 88] and in a sustainable manner [89]. It is advanced that Lean Engineering Education will provide students with three essential competencies: 1) ethics, 2) systems thinking and 3) sustainability. These competencies mastery must be interrelated with the content mastery in a way that resembles a double helix DNA (Figure 2).
According Rychen & Salganik [84] competence refers to the ability to meet demands of a high degree of complexity, and implies complex action systems. The notion of competencies encompasses cognitive but also motivational, ethical, social, and behavioral components. It combines stable traits, learning outcomes (e.g., knowledge and skills), belief-value systems, habits, and other psychological features. In this view, basic reading, writing and calculating are skills that are critical components of numerous competencies. So, acquiring competences means students learn to respect others (humans beings or other lives), they learn to solve problems and they learn to think in a waste-free manner in everything they do, whatever they do. They learn to think globally forwarding the accomplishment of the 3P (People, Planet, Profit).

5 CONCLUSIONS
This paper presented the multidisciplinary of Lean Production. Today, Lean Thinking is viewed as a philosophy, as a mind-set. LP is in the companies not as a new mode but a new paradigm implying changes to behavior and attitudes of all stakeholders. When this change didn’t happen in this way the old habits come again. Engineering students are the future professionals of the companies and their learning must be aligned with industry and society needs. Being taught in Lean Engineering education, concept proposed by the authors of this paper, students will develop competences and will have the ability to meet demands of a high degree of complexity.

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7 REFERENCES
American Society for Engineering Education Annual Conference & Exposition.


