Lean Systems Engineering: Concepts and Discussion

1 Introduction

The global scenario, characterized by constant change and the increasing complexity of products and systems, requires that organisations are prepared for dealing with the uncertainties and risks arising from this environment. In addition, the need to adopt a systemic approach to the construction of effective and efficient solution to a problem has made the practice at Systems Engineering (SE) more widely applied.

SE provides perspectives, models, methods and tools that help solving complex problems. Sage and Armstrong Jr (2000) suggested SE as the management of technology which controls all the processes of the life cycle of a system that has high quality, reliability and fitness for purpose with a controlled level of schedule and cost. The purpose of SE is to guide the engineering of complex systems (Kossiakoff et al., 2011). System is: "a collection of different things so related as to produce a result greater than what its parts, separately, could produce" (Retchin, 1992).

The value added by the system as a whole is primarily created by the relationship between the parties, which is more than the independent contribution of each element (the so-called emergent properties) (Rechtin, 1992). The SE approach is an interdisciplinary process to ensure satisfying the customers' needs with high quality, reliability, efficiency throughout the lifecycle of the system. This process usually consists of the following tasks: identify the problem, investigate alternatives, model the system, integrate, implement the system, evaluate performance, and review (Bahill and Gissing, 1998).

Lean Thinking includes tools and forms of systematic elimination of wastes on the conception and design of products and processes. The lean manufacturing initiatives improve activities, interfaces and flows between internal and external processes (Womack and Jones, 1998).

Womack and Jones (2003) suggested that the first lean principle is to understand, define and identify the concept of value, second is to identify the value stream for the product, third is to optimize flow to create value, fourth is to begin the processes to deliver a product based on a real demand, that is known as pull production, and finally the perfection, that is the principle that suggests continuous improvement of the value creation activities.

The Lean SE is an emerging field of research that studies the application of lean principles, practices and techniques in SE. This interest, to integrate two extensively used concepts to improve business performance is motivating some authors to expand this concept. The purpose of this paper is to describe and analyze the academic efforts on Lean Systems Engineering (LSE), exploring the current state of the art, the configuration of the discussion about the theme and opportunities for research.

2 Research Description

In order to identify the academic efforts on LSE we reviewed the publications in the most important journals and conferences about SE between 2002 and 2012.

This study has a qualitative nature, based on a literature review and was conducted through a process that is composed by four steps: (1) first selection of the articles; (2) analyze each article to select it based on the content; (3) identify the variables considered in the various articles; and (4) compare the articles' reviews looking for gaps and opportunities.

The selection of the articles was based on at least one of these criteria: (1) Part of the list that was generated using MetaLib, a service which enables you to cross-search up to ten databases at once, looking for articles with "Lean" and "Systems Engineering" in the subject; (2) Part of the list that was generated using Google Scholar looking for articles with "Lean" and "Systems Engineering" on the subject.

The following section is going to describe the reviews of each of the 23 articles found and in chronological order. This is done to try to discover a sense of evolution in the ideas. The section 4 we present our discussion and conclusions.

3 Articles Reviews

Browning (2003) introduced a discussion about Lean and SE. Firstly, explained the concept of value and Lean, secondly, mentioned how this concept could be applied in product development and, finally pointed out that an SE approach could contribute to these. According to Browning (2003), the concept of Lean, which is commonly related to the elimination of waste, is also to increase benefits when minimizing the risk to satisfy the customers' needs. He argued that a product development process has a particularity that requires different analyses when compared with production processes and emphasized that, as important as the value adding activities, is the way that these are realized and integrated.

Browning (2003) discussed how to increase customer value in product development, however, argued that value to the customer could mean something different from value to other stakeholders. For example, employees receive value from recognition, career development, and challenge; the organisation receives value from organisational learning, developing capabilities and strategic position, and so on. Each process has a value trajectory that represents the relationship between process benefits, associated with the risk to achieve customers' needs, and process costs, time and money expended (Browning, 2003).

Oppenheim (2004) suggested a framework for product development based on the five Lean principles identified as "Lean Product Development Flow – (LPDF)", which is proposed for legacy programmes with mature technologies that could be well managed by SE. The value of LPDF means delivery of a product that meets the requirements and expectations of the stakeholders according with a schedule and lower cost, and in this way shares a common view with SE (Oppenheim, 2004).

It is important to note that, the key to the LPDF method proposed by Oppenheim (2004) is the application of the "takt time" concept to product development. "Takt time" means the rate of production necessary to meet demand (Alvarez and Antunes Jr., 2001). In this way, He suggested that the team has a common and frequent rhythm to realize the activities with short durations and similar deadlines, however with different team composition and efforts. He listed the success factors and metrics for each one of the five Lean principles applied to product development, where the process is ordered as "a value-pulling workflow pulsed by takt-periods".

Rebentish et al. (2004) presented the concept of LSE based on the cumulative experience of huge number of research projects in the Lean Aerospace Initiative (LAI) consortium, which showed that SE tends to be allied with Lean principles. They pointed out key differences and similarities between traditional Lean and SE, such as: (1) Both of them are born from the experience of engineering practice; (2) They emphasize different phases of the lifecycle; (3) The concept of value to SE is strongly related with decreasing the risk in the execution of the management plan, and in the production context, which was the traditionally Lean focus, value relates to optimizing product cost, quality, and time; (4) Lean has more emphasis in empowerment, capability of people, flow of information, continuous improvement than SE.

According to Rebentish et al. (2004), SE and Lean have important roles to play to achieve value of a complex system because they share common objectives that are delivering value to stakeholders and suggested LSE is an approach "to deliver the best value to the end customer in terms of system performance, cost and schedule – all with a focus on acceptable risk".

Mathaisel et al. (2005) and Methaisel (2005) suggested the application of SE tools and methods to create a Lean enterprise, where the lean principles and value concepts are the baseline requirements. Lean enterprise architecture - LEA is discussed based on the transformation life cycle to deliver a Lean enterprise, which is composed of three phases, which are: (1) Transformation strategic planning; (2) Transformation; acquisition and integration; (3) Transformation implementation.

Mathaisel (2005) defined Lean enterprise transformation engineering as "a discipline that uses tools of SE and the management practices of Lean to organize all the tasks needed to design, implement, and operate enterprise transformation change". Several benefits of application of enterprise wide Lean transformation are illustrated and according to Mathaisel (2005), that minimize the gap in performance because there is a whole view of the enterprise promoted by the systems approach when SE processes are applied.

Justin (2006) proposed an approach to risk management based on Lean principles that consider the user demand to determine the level of risk on the SE plan, which allocates the resources for mitigating risks.

Hagg et al. (2008) suggested Lean and SE tool applications to redesign clinical processes on a center of health care, and detailed some tools that are related with industrial engineering such as: process flow diagram, process observation worksheet, workflow analysis, and so on.

Nathan (2009) emphasized the importance of the systems engineer in global engineering to contribute in the process in a Lean organisation, because of the needs for integration of projects that are split around the world looking to minimize resources.

Oppenheim (2009) introduced the concepts of LEfSE in the same way that was detailed in the article published by Oppenheim et al. (2011).

Kasser and Hitchins (2010) highlighted that LSE is applied when the SE process does not have non-value activities.

Ramos et al. (2010) cited LSE (Oppenheim et al., 2011) as part of several approaches into contemporary systems, which are more complex and interdisciplinary, and pointed out the LEfSE are such a collection of holistic practices.

Alho (2011) proposed a LSE framework to the development of dependable and fail-safe software architecture. However there was a lack of definition about Lean System Engineering, considering the idea of Lean as cost-efficiency in system development.

Oppenheim et al. (2011) introduced the concept of "Lean enabler for systems engineering" – LEfSE as the practices that support the application of Lean principles in SE. The definition of Lean thinking applied by these authors is: "the dynamic, knowledge-driven, and customer-focused process through which all people in a defined enterprise continuously eliminate waste with the goal of creating value. They reviewed the literature about Lean application in: six sigma, product development and SE. The LEfSE development was based on the tacit knowledge of practitioners with high experience in SE and the 160 enablers were proposed and organized based on the six Lean principles: (1) value, (2) map the value stream, (3) flow, (4) pull, (5) perfection, and (6) respect for people. The result demonstrated that most of the LEfSE are not widespread and some principles have more enablers than others.

Josephe-Malherbe (2011) illustrated that LSE (Oppenheim et al., 2011) promote ways to uncover the tacit knowledge about the end-user expectations creating more opportunities for interactions through the system development process and the customer.

Mckinney (2012) suggested a construct of a technical conception of operations (TechCONOPS) to contribute for a better application of two key pillars of LSE, pull and perfection, and thus promoting access to users and uncovering hidden design flaws at the early stage of the system development. This calls for a better understanding of the client's context and the expected emergent properties of the system in operation.

Turner (2012) and Turner et al. (2012a, 2012b, 2012c, 2012d) worked to create an approach called kanban-based scheduling system (KSS) to optimize the scheduling in SE in large or complex systems environments explaining how to apply this traditional Lean tool, kanban, to SE activities.

Bijan et al. (2012) discussed the concept of Lean System Engineering proposed by Oppenheim et al. (2011) for requirements development and point out that LSE is not a method to write requirements, but it seems to be a new perspective to adding value to unspoken requirements.

Boehm et al. (2012) discussed four key principles for successful SE and compared than with Lean principles. They concluded that the guidance for a successful system is focused on: "team working, efficiently performing value-adding activities at the appropriate point in the development life cycle, and eliminating activities that don't add value". This highlights an important challenge to LSE: SE is tasked with managing the technical risk and when dealing with complex system it is not easy to identify waste.

Karvonen et al. (2012) analysed the concurrent engineering process in Lean System Engineering approach proposed by Oppenheim (2004) and stated that the type of information towards SE process that is transferred among the partners depends of the task, capabilities, knowledge and collaboration experience, pointing to the importance at maturity of human resources and processes.

From a review of the 23 articles we extracted what we believe are the variables of interest to researchers between 2002 and 2012 about Lean and SE. In table 1 we present these variables and the articles that are considering them, by chronological order. We can observe differences and similarities among them.

Table 1: Variables and articles published by chronological order

Variables	The 23 articles in chronological order																					
	1	2	3	4	5	6	7	8	9	…												
Agile systems										X			X									
Concept of operations														X								
Concurrent engineering																						X
Cost	X		X																			
Customers' needs	X											X		X								
Dependability											X											
Enterprise engineering				X	X																	
Global engineering								X														
Health systems							X															
Industrial engineering							X															
Lean	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Performance	X																					
Practices/ enablers									X		X		X									
Product development	X	X											X									X
Requirements																				X		
Risk management						X																
Schedule	X		X												X	X	X	X	X			
Six sigma												X										
Stakeholders	X	X									X											
Success factors		X																			X	
Systems engineering	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Takt time		X																				
TQM												X										
Value/ value stream	X	X								X		X										

Source: The authors

4 Discussion and Conclusion

During the review it was observed that the first article (Browning, 2003) widens the discussion about value associated with Lean and could serve as the basis to understand the contribution of SE on the product/ system development. The following year Oppenheim (2004) published the article detailing practices that contribute to apply Lean principles in product development and utilized an SE approach to define the applicability of LPDF.

There is a strong relationship between these two articles to build LSE concepts. Understanding that the actions and the processes for the development of the value activities are important to achieve value, it drives to identify the essential contribution of the success factors proposed for LPDF.

In 2005, the articles amplified the discussion about Lean to the whole organisation. Also, they suggested the application of the life cycle model and SE tools. It is a good contribution to improve the discussion of SE and Lean, which initially were developed for a specific level of the enterprise. A successful introduction of Lean and SE in the culture of the organisation creates good conditions to address LSE application.

Based on the SE approaches, it is possible the development of a different framework to transform the organisation which depends on the principles, methods and change-drive that is important to promote in the organisation. However, it is essential to integrate all different methods and concepts such as, Lean, six sigma, Lean six sigma and others, on the same framework, because all trade offs could be considered. The SE approach allows the view of the whole organisation as a system and minimizes the gaps between several parts of the organisation increasing benefits and improving the probabilities of stakeholder's satisfaction.

There were two papers (Nathan, 2005 and Hagg et al., 2008) with a soft connection with LSE. They discuss some concepts of Lean, as autonomation, and SE applied in other domain as health system, which helps reveal the vast field of Lean and SE.

We found an important relationship between the works of Browning (2003) and Oppenheim et al. (2011), owing to the similarities between the variables investigated. They both seem to want to stress the importance of value in the context of the application of Lean and to extend it from a context of production to a context of full product development. Nevertheless, we think that to accomplish the objective of creating value, it is important to extend the discussion on the concept of value through the suppliers' lens and understand the necessary practices to promote this considering more stakeholders.

In reviewing this body of publications, further research needs to recognize the contribution of this emerging field of LSE and to popularize it. Our recommendation for future research includes using more case studies to understand the constraints of applying LSE and how to integrate LSE in the whole organization satisfying the stakeholders' needs.

Thus, our review suggests that the debate about LSE could be improved if we considered the integration of several of the main subjects of the previous studies described on table 1.

Although Lean follows the important stated 5 principles that are centered on value of the product and eliminating waste, we believe a supplier organization would benefit from framing any application of Lean and SE in programmes attaching a wider- ranging idea of value. We refer to a longer lasting vision of the value to a supplier organization, which would mean, for example, considering: a) the sustainability at its own organization (learning, maturity processes, technology roadmaps, and so on; b) the context and the sustainability of a typical client's supersystem (market trends, optimizing, the SS's emergent properties, business intelligence and so on); c) the technological system being developed with its own horizontal links in the organization like product lines and programmes.

This view changes the place where value is defined, rising it to a level where not only the system of interest is observed, but also includes a supersystem view considering both, the client and the supplier. In doing this, we believe we are covering all the variables detected in the reviewed articles and perhaps more. But above all we are suggesting rethinking a framework that would incorporate a new definition of value that would make it more sustainable in terms of client and supplier. All this with a focus on effectiveness first, developing a system that is fit for purpose first time, every time. This focus will help us define waste much better, to gradually grow the efficiency and maturity of a supplier organization.

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