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18 comparative aspects between Lean and Six Sigma: complementarity and implications

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1. Introduction

A number of different approaches focused on the continuous improvement of production processes have emerged focusing on the increase of productivity and cost reduction. These approaches, directly or indirectly, are related to waste mitigation and variability reduction, as a way of contributing to enhance the organization's competitiveness. Lean Manufacturing and Six Sigma are two well-known representatives of those approaches.

The raise of approaches for improving production processes accompanied the gradual transition of society from the pre-industrial era to the industrial era. Even after the event that marked the onset of the Industrial Revolution, production of goods in the first decades was quite limited, with a slow and gradual exploration of consumer markets, still characterized by local consumption. In most cases, the points of production and consumption had not yet been decoupled (Bornia, 2002). As of the second decade of the twentieth century, with the advent of Scientific Administration (Taylor, 1947) and the Ford Production Line (Ford, 2003), the logic of artisan production was replaced with mass production as the search for significant improvements in industrial productivity gathered momentum by factors such as: components and parts standardization, interchangeability of components, specialization of work and industrial production capacity lower than the consumer market demand.

The 1973 oil crisis significantly altered the relationship of supply and demand that had existed until then. Prior to 1973 manufacturers had more power over the product features that were made available to the consumer market. Until then manufacturers had made a point of manufacturing standardized goods using manufacturing systems with little flexibility. But from the 1973 oil crisis onwards, the consumer market began to be more demanding in terms of product features and quality, considering an environment of limited resourced (Antunes et al., 2008). As a result of this reality, a conflict arose between the production based on rigid manufacturing systems, with little flexibility and variety and large production lots, and the need for systems that were flexible enough to introduce new models and frequent changes in the production schedules. In order to stay competitive in a market relatively more difficult to please, organizations started to set up more complex production models, such as the production of diversified products based on the preference of segmented markets, and to carefully consider dimensions such as quality, after sales services, and cost.

With those changes in the production and consumption scenario, different approaches have emerged in the industrial literature proposing improvements in the production systems and the elimination of trade-offs. Among them, Lean Manufacturing and Six Sigma have become recognized as viable alternatives for improving processes in such fashion. These two approaches are designed to contribute to increasing the organizational competitiveness by reducing losses in the production environment, improving the overall quality and eliminating defects, failures and errors, among other aspects. Originated from different conceptual bases, Lean Manufacturing proposes the elimination of wastes by means of actions that will enhance the throughput of the production system whereas Six Sigma aims to improve the quality based on premises such as the reduction of variation, measurement, data collection, focus on the processes and customer satisfaction (Mehrjerdi, 2011; Santos and Martins, 2010).

However, some authors like Arnheiter e Maleyeff (2005), Harrison (2006), Narasimhan (2007), Bañuelas and Antony (2004), Sharma (2003), Bendell (2006) and George (2010) advocate that the use of one strategy does not exclude the other and benefits may be reaped by using both strategies in conjunction. Given this context, the purpose of this research paper is to present a theoretical comparative analysis focusing the Lean Manufacturing and Six Sigma approaches, highlighting the main points of divergence between these philosophies. Comparison is based on 18 criteria: 17 are derived from the studies of Arnheiter and Maleyeff (2005), Pitcher (2010), Nave (2002), Bendell (2006), Bañuelas and Antony (2004), Harrison (2006) and George (2010); and the criterion 'Quality Control' is added by the authors of this research. The main intended contribution of such study is to reinforce the basis for the development of better models, able to integrate Lean Manufacturing and Six Sigma approaches, converging to the continuous improvement of processes with focus on customer satisfaction to sustain the organization in the long term.

The research paper is structured in five sections. Section two and three presents a summary of the theoretical framework that was used in the research. Section four presents a brief description of the research paper methodology. Section five presents a critical comparative analysis between Six Sigma and Lean Manufacturing. Lastly, section six presents conclusions and considerations on the research work.

2. Six Sigma

The literature on Six Sigma traces its origin to applications at Motorola, back in the 80's (PEREZ-WILSON, 1999). However, there are diverging opinions about its real mentors. Sharma (2003) states that Six Sigma was developed by Mikel Harry in the middle 1980's to provide a consistent approach whose focus was the solution of problems in manufacturing companies. This data-based approach was employed to solve complex business issues by identifying the root cause, the solution and the statistical control of the solution.

From the statistical standpoint, the Greek letter Sigma (σ) refers to the intrinsic variability measure of a given process defined by the standard deviation. Under normal conditions, the Six Sigma measure of conformance represents a level lower than 2 defective parts per billion. However, considering a fluctuation of 1.5 sigma of the process in a long term perspective, the process tends to operate at a rate of 3.4 defective parts per million (PPM), which, in effect, corresponds to 4.5 sigma in relation to the mean (EHIE; SHEU, 2004). Thus, according to the concept originated in Motorola, although the mean shifts 1.5 sigma from the nominal value, the expectancy is 3.4 defects per million opportunities. Table 1 synthetically illustrates the main values adopted by the Six Sigma approach according to Harry and Schroeder (2000).

Table 1 – Sigma Scale.

Sigma Level	Quality Level	Error Rate	Defects per Million Opportunities (DPMO)	Cost of Non Quality (% of Sales)
1?	30.90%	69.10%	691.462	N/A
2?	69.10%	30.90%	308.538	N/A
3?	93.30%	6.70%	66.807	25 - 40%
4?	99.38%	0.62%	6.21	15 - 25%
5?	99.977%	0.023%	233	5 - 15%
6?	99.99966%	0.00034%	3.4	< 1%

Source: Harry and Schroeder (2000).

Initially, Six Sigma had its focus set on manufacturing plants, however as the approach matured over the years, Six Sigma began to be more widely used in the services industry and on different branches of production, such as in the food industry, the automotive industry and so on. According to Santos and Martins (2010), as the management of organizations increasingly focused on measurement, quantitative methods, specialized teams and clearly defined performance goals, Six Sigma started to be used in a wider context, being recognized as an effective strategy for business performance improvement.

According to Langabeer et al. (2009), Six Sigma's core philosophy focuses mainly on reducing variability to standardize production and business processes so that flow can be leveled and all waste or inefficiencies removed. As explained before waste is everything that increases cost without adding value to the customer. In this way, Hoerl and Gardner (2010) pointed that eliminating waste helps an organization to gain efficiencies in all aspects of their business processes, especially those that impact the customer.

To implement Six Sigma with focus on reducing variability and waste, the literature presents the DMAIC method (Define – Measure – Analyze – Improve – Control), which was developed based on the PDCA cycle (Plan – Do – Check – Action) proposed by William Edward Deming. According to Rotondaro (2002), this method is centered on identifying the base problems in order to prioritize projects (Define) that will be carried out; in the data collection (Measure) honestly to identify the current process performance, in determining the causes of the problems (Check) which leads to the analysis of the causes; the creation of improvement actions that will impact the process improvement (Action); and in the consolidation and the maintenance of the improvements, i.e., maintaining the process under control). In the same sense, variant approaches suitable for services applications of Six Sigma include the Design for Six Sigma (DFSS) method, using the Define – Measure – Analyze – Design – Verify (DMADV) project model (Atwood, 2005).

3. Lean Manufacturing

The term “Lean” was originally coined in the book “The Machine that Changed the World” by Womack, Jones and Roos (1990), as a result of a comprehensive study about the world automobile industry conducted by MIT (Massachusetts Institute of Technology, USA), where the advantages of using the Toyota Production System (STP). The study showed, among other things, that STP brings expressive differences in relation to the productivity, quality, and development of products and explained the success of the Japanese automobile industry at that time.

The fundamental principles of the Toyota Production System according to Antunes et al. (2008) are: (i) the Mechanism of the Production Function; (ii) the non-cost principle; and (iii) the wastes in the production systems. According to Shingo (1989), the Mechanism of the Production Function defines the production system as a functional network of processes and operations. Processes are characterized as the transformation of raw materials into products, whereas operations are actions that perform such transformation. The analysis of the process looks into the flow of material or product while the raw materials are undergoing a transformation in the production system; the analysis of operations looks into the actions that the workers and the machines perform on the products. Both look into the work performed during the process, aiming at separating production (value aggregation while consuming resources) from waste (no-value aggregation while consuming resources). The non-cost principle states that the producers should let the market determine the product prices. Thus, the primary way of increasing the profits in this context would be cutting down on costs (Shingo, 1989). And the reduction of costs is achieved by completely eliminating the wastes in the production system (Shingo, 1989).

According to Antunes et al. (2008) and Bornia (2002), waste is conceptualized as unnecessary operations or movements that generate costs and do not add value to the system, and therefore must be eliminated from it, such as: waiting, unnecessarily carrying raw materials to intermediate locations, work in process inventories (WIP), among other things. STP identifies seven types of wastes: overproduction; waiting; transportation; inefficient processing; excessive inventory; unnecessary motion; and manufacturing defective products (Pacheco et al., 2014). Liker (2004) presents a type of waste called 'underutilization of employee creativity' which refers to the waste of time, ideas, skills, improvements and learning opportunities for not actively involving or for not listening to the suggestions of employees. In the same manner, previously, Rother and Shook (2003) suggested adding the waste of not using people and their intellectual and technical capabilities to the full. Lastly, Pergher, Rodrigues and Lacerda (2011) present the concept of 'Pergas', i.e., the loss of Global Gain (as defined by the Theory of Constraints), which occurs due to the poor definition of the production mix.

In addition to the concepts presented above, a better understanding of the Lean Manufacturing can be obtained in Dennis (2007) and Liker (2004). To Dennis (2007), the basis of the Lean system is the Stability (which can be achieved by means of activities such as: Standard Work, 5S, Autonomation, TPM, Kanban and Production Levelling) and Standardization (A3 Thinking, Standardized Work, Kanban, Hoshin Planning and 5S). According to Ohno (1988), the supporting pillars of the system are Just-in-time (JIT) and Autonomation, or automation with a human touch. Autonomation is designed to equip machines with devices that are capable of identifying failures; once an issue is identified, the machine stops automatically without the operator's intervention, thus the production of defective parts is eliminated. Also, as the machine stops, all the stakeholders become aware of the fact, search for the cause of the problem and fix it. JIT means that in a flow process, the right parts that the manufacturing process needs arrive at the right time and in the right amount. This cuts down the inventories in the diverse phases of the process function. As inventories are cut down, wastes related to overproduction are reduced or eliminated (SHINGO, 1989).

In order to operationalize the JIT pillar, Kanban (pull, ideally one-piece-flow) systems aim at sending all the information that the production system requires for its operation (Ohno, 1988). According to Kumar and Panneerselvam (2007), Kanban basically consists in a card system management, where the Kanban cards contain all the information required by the production or the assembly of a product in every step of the process. According to Goldratt (2009), the origin of Kanban relates to the characteristics of demand in Japan after the second world war (small amounts and large variety), when companies could not afford to maintain a production line dedicated to each product. In Toyota, Ohno used to conduct trials in non-dedicated assembly lines in order to produce the components required to supply the assembly line. The answer to this issue was found during a visit to the USA where he observed the system of goods replenishment in a supermarket in 1956, originating Kanban.

JIT is not feasible without the support from the concepts of autonomation and zero-defect because without them, the right amount of materials would come in at the right place, at the right time, but with the wrong quality. Ensuring the quality on the different levels of manufacture of components is critical to the JIT synchronized production, according to (Antunes et al., 2008). Lastly, the goal of the Lean system is the customer focus – delivering the highest quality (value) to the customer at the lowest cost, at the shortest lead time.

4. Methodology

This paper is based on bibliographical research, collecting different concepts related to Lean Manufacturing and Six Sigma, followed by reasoning and comparison in order to achieve its proposed objective. The procedures of reading, indexing, relating and referencing papers on a research theme characterize the bibliographical research (Oliveira, 1997). The bibliographical research performed about Lean Manufacturing and Six Sigma made possible to build the framework that summarizes the theoretical foundation of the research, and contributed toward the authors' knowledge about the theme.

Articles indexed in the Scopus and Ebsco databases, published between 2005 and 2013 and containing the keywords 'Lean' and 'Six Sigma' in their titles were searched. The papers were selected and prioritized, focusing on the comparative analysis between the two approaches. Selection of papers was performed in two steps. Initially papers' abstracts were read. The criteria adopted for selection of articles for the research were: (i) preferably articles performing theoretical or conceptual discussion between the two approaches; (ii) qualitative studies that include analysis of strengths and weaknesses and divergence or convergence between the two approaches. Secondly, papers included in the first screening were fully analysed, using the same criteria. At the end of this phase, the criteria for exclusion of references were: case studies not addressing advantages or weaknesses of Lean or Six Sigma; and articles that do not establish conceptual analysis between the two approaches analysis.

Based on the theoretical framework and the knowledge acquired by reading the papers and abstracts, a critical analysis was written under the light of the following guiding aspects: (i) points of divergence and convergence between the approaches; (ii) articles that blended the Lean and Six Sigma methodologies in industry; (iii) potential possibilities of synergism in using the techniques of both approaches; and (iv) weaknesses of each approach, Lean Manufacturing and Six Sigma. Lastly, as the outcome of the comparative critical analysis of this research, the main points of divergence between these philosophies were highlighted based on 17 criteria obtained from the literature reviewed and one criteria suggested by this research authors.

5. Six Sigma versus Lean Manufacturing

The comparative analysis proposed in this research was supported by criteria obtained from the studies of Arnheiter and Maleyeff (2005), Pitcher (2010), Nave (2002), Bendell (2006), Bañuelas and Antony (2004), Harrison (2006), Snee (2010) and George (2010). The criterion Quality Control was suggested by the authors of this paper, based on their experience on Operations Management and Quality Engineering, and on readings from Montgomery et al. (2009) and Pande, Neuman and Cavanagh (2005). The choice of criteria, by compiling those used in the aforementioned studies is, thus, intentional. It is justified by two aspects: (a) such works have covered most of the comparative elements that can be considered in a qualitative study; and (b) they provide a logic standard for comparing approaches pertaining to the production environment.

To Arnheiter and Maleyeff (2005), Lean Manufacturing and Six Sigma both implement continuous improvement cultures throughout the entire organization. On the one hand, the advantage of using these approaches in conjunction lies in the scientific and quantitative approach to quality provided by Six Sigma complementing the qualitative approach of Lean techniques. On the other hand, Six Sigma projects focus their efforts on the reduction of variation from a standard proposal, which may lead the organization to lose the focus on the customer requirements, restricting itself to a cost reduction exercise. For this reason, this paper suggests that the value-stream vision of Lean (Bendell, 2006) should be used in a complementary fashion. To Harrison (2006), using the approaches in isolation may not be efficacious under risk of creating two sub-cultures in the organization, both competing for the same human and financial resources.

Nevertheless, there are limits to the integration of these two approaches inasmuch as the improvement strategy that should be adopted depends on the characteristics of the problem that must be solved and on other strategic drivers of the organization. Therefore, the two approaches must be aligned so as to achieve efficacious outcomes (Bañuelas and Antony, 2004). To Sharma (2003), Six Sigma should be utilized to leverage the implementation of Lean efforts. According to Bendell

(2006), the balance lies in creating value from the customer standpoint so as to keep focused on the market, reducing variation to acceptable levels and cutting down on costs at the same time. Bendell (2006) argues that both paradigms are catalysts of change and may constitute a powerful tool to align the cultural aspects of Lean and Six Sigma projects. There is an enormous potential for a sustainable approach to organizational change and process improvement by integrating Lean and Six Sigma (BENDELL, 2006).

To Snee (2010), Six Sigma is normally used to fix complex problems to which a solution is unknown. According to this author, it is important to bear in mind that the purpose is to identify the causes of poor performance rather than centering on the symptoms. In this case, the value stream vision of Lean contributes to the use of Six Sigma and the simultaneous use of both approaches is recommended. Snee (2010) cites eight key characteristics that contribute to improved performances by applying Lean and Six Sigma in synergism: (i) focus on creating financial results; (ii) activate the top management involvement; (iii) the use of a disciplined approach (DMAIC); (iv) quickly-completion of projects; (v) bear a clear definition of success; (vi) existence of a created human infrastructure (belts); (vii) focus on the customers and on processes; and (viii) base decision-making on a statistical approach. Also, according to Montgomery (2010), Lean improvement projects can be managed using DMAIC, and the joint use of Six Sigma and Lean is associated to a continuous improvement philosophy and to a profound knowledge of the system, as proposed by Deming.

Higgins (2005) differentiates both systems arguing that Six Sigma is performed by few specific individuals within a company whereas, in the Lean model, the skills building process involves all the levels of the organization on the identification and elimination of activities that do not add value. And Mika (2006) assumes a critical stance that the two approaches are incompatible because Six Sigma cannot be adopted by the average manufacturing worker, while Lean is accessible to those workers because it promotes team work through cross-functional teams and improvement groups.

Spector and West (2006) highlight that, when adopting Lean Six Sigma, management professionals may encounter a large number of projects with insufficient results for the amount of time required to complete them. To Bendell (2006), both approaches require adjustments so that they can effectively solve the problems faced by an organization, and, to sum up, the question is: How can you blend the two methodologies? Arnheiter and Maleyeff (2005) point out that Lean companies should adopt the use of quantitative data for the decision making process and a more scientific approach to quality within the system, whereas companies that use Six Sigma should require a wider approach of the systems considering the effects of wastes in the system as a whole. Bendell (2006) says that Lean and Six Sigma have become poorly implemented philosophies, sometimes with reduced efficacy and often the methodologies are placed together without a logical explanation, with no theoretical basis or explanation for the choice of techniques.

According Bentley and Davis (2010), the fusion of Lean and Six Sigma improvement methods is required because: (a) Lean itself cannot bring a process under statistical control; (b) Six Sigma alone cannot dramatically improve process speed or reduce invested capital; and (c) both enable the reduction of the cost of complexity. Pepper and Spedding (2010) and Bendell (2006) also argument that the cause of mistrust about Lean and Six Sigma is the myopic way that these approaches are implemented. For example, the reduction of inventory levels cannot be applied to high variability environments. For this reason, a systematic approach is required to optimize the entire system and concentrate the right strategies in the right places.

According to Jugulum and Samuel (2008), the adoption and blending of the two approaches are not without challenges. The key to Lean Six Sigma integration is to blend the two methodologies into one approach of getting things done faster, better, cheaper, safer, and greener. In their research paper, Andersson et al. (2006) verified that both methodologies, Lean and Six Sigma, possess common objective proposals to achieve operational excellence that, although distinct, are complementary and compatible. In this way, Lean and Six Sigma should be viewed as the platform to launch the cultural and operational change, leading to a complete transformation of the supply chain.

Nevertheless, in spite of the origin of Six Sigma and Lean as defenders of customer satisfaction, many projects are selected for their low implementation cost. As the organization concentrates on the control and reduction of variation and waste, the cost can be cut down and the customer satisfaction increased as well (Bendell, 2006). On the other hand, according to Snee (2010), it is the nature of the problem that defines the selection of methodology and the tools that will be used. To change the process or the variation of the process, Six Sigma is indicated and to improve the process flow, information flow, materials flow or the reduction of complexity, the use of Lean is indicated. However, to Snee (2010), both methodologies can be used to reduce losses, non-value added, and the cycle time. A method of blending the two methodologies consists in subordinating one approach to the other one as the dominant approach. A number of large corporations adopting Six Sigma programs place Lean in a group of additional tools within the Six Sigma program. The other way around, however, is not very common (Bendell, 2006).

On the construction of a new model blending Lean and Six Sigma, according to Pepper and Spedding (2010), the main factors to be analyzed are: (i) the model has to be strategic and focused on processes; (ii) the model should be a balance of the two philosophies and make the most of the recognized advantages of both; (iii) there must be an equilibrium between its complexity and sustainability; and (iv) this model should be structured according to the type of problem for which it is designed. In this proposed model, Lean reinforces the philosophy of the structure and provides the strategic direction for the improvement; it guides the overall dynamics of the system and reports the current status of the operations. Lean identifies the key areas for improvement purposes. Once the critical points are identified, Six Sigma projects are put to use to focus the improvement and lead the system into the desired future state.

The conceptual model proposed by Bendell (2006) hinges on the process mapping or the improvement to be carried out in the system. Depending on the process nature, the company has four ways to go: a Lean project; a Six Sigma project; to invest on human resources; or to invest on quality certifications. In the model proposed by Snee (2010), the first point of analysis is the business itself where the customer requirement is verified: this analysis will reveal whether the current system necessitates improvement projects or a Lean pull system to meet the market requirements. For every flow there is a choice of approach and the last step of the model is the application of Lean and Six Sigma to consolidate the continuous improvement of the business performance.

With regard to the comparison of the two methodologies, Table 2 demonstrates the main points of convergence according to the 17 criteria and evidences depicted from the literature review, and in particular, a new criterion suggested by the authors of this research.

Table 2 – Points of divergence between Lean Manufacturing and Six Sigma

Criterion	**Lean**	**Six Sigma**	**Possible Benefits resulting from the Synergy**
Origin	Toyota (Toyoda, Ohno and Shingo; 1950's)	Motorola and General Electrics (1980's)	-
Applicability Structure	1. Specify the value; 2.Identify the value stream; 3.Flow; 4. Pull; and 5.Search for perfection	1. Define; 2.Measure; 3.Analize; 4. Improve; and 5.Control	Robust structure focused on the elimination of wastes and problem solving
Focus	On the flow	On the problem	Simultaneous focus on eliminating problems and improving the production flow
Theory	Elimination of wastes and profit increase	Reduce the variation and profit increase	Increased margins, return on investment and value of the company stock in the stock market
Target	Maximize productivity	Maximize the business results	
Assumptions	The reduction of wastes increases the business performance; Several little improvements are better than a one-shot global analysis of the system	There is a problem to be solved; Statistical tools can help solving the problem; The output rate of the system is improved by the reduction of variability in the processes	Simultaneous focus on reducing wastes and on the solution of a specific problem that might be a loss generator
Primary effects	Reduction of the flow time; Increased process efficiency	Reduction of variability; Uniform process output rate	Reliability and fast delivery of products to the consumer market
Secondary effects	Reduced variability; Uniform process outputs; Inventory reduction; New accounting systems; Flow as a measure of management performance; Improved quality; Increased productivity	Waste reduction; Rapid gains; Reduced inventory; Variability as a measure of management performance; Improved quality; Culture of change	Increased competitiveness of the organization due to a fast delivery of finished goods to the consumer market. Reduced cost of the product sold; development of an improvement culture; and better forecasting of operating activities
Deficiencies	Not based on statistical tools or analysis systems; Rescrict focus on losses	Do not consider interdependencies within the system; Process improvements are achieved independently; Creates an employee elite	Lack of a structured methodology to use the Lean and Six sigma approaches in converging and complementary way
Ease of Implementation	May be classified as presenting less difficulty since no statistical techniques are used	Average difficulty due to the structured method and statistical basis	Lean may be used as a way of implementing the focus, whereas Six Sigma drives improvement actions
Managerial Level of applicability	First level	Technician's level and middle management	Faster decision making; Reduction of hierarchy; Human resources empowerment
Effect on variability	Reduced variability	Reduced variability	Better estimate of the length of activities
Major contributions	Pull-flow, takt time, production levelling, single flow of parts, mapping of the	Organizational structure supported by improvement specialists, oriented projects	Development of an approach to improving the value stream in light of

	value stream and respect for people	and quantification of the cost reduction	cost reduction projects and customer satisfaction projects
Aspects of the Process	Management of the workflow through JIT; Optimization of the processes.	Specific statistical tools; Specific terminologies; Specific specialists' structure.	
Lot sizes	Small production lots	N/A	Six Sigma based operations environments can be benefited from Lean concepts
Production Control	Kanban triggers production		
Production Planning	Detailed planning for the final assembly; Other operations are triggered to feed the assembly through Kanban.		
Quality Control	Indirect, by eliminating wastes	Direct, by tools and instruments of quality	Scope of the Six Sigma target beside the elimination of wastes that cause anomalies in the production flow

Based on Table 2, the following observations can be drawn: (i) the two methodologies are essentially complementary inasmuch as Six Sigma is designed to reduce the system variability whereas Lean proposes, among other results, to mitigate wastes from the production environment, which can be influenced by action of the variability that is intrinsic to the production system; (ii) it is possible, although cumbersome, to create a single model blending the two methodologies studied in this research paper in order to align benefits such as: reduction of the variability, quality improvement, reduction of the lead time, reduction of inventory levels, among other things; and (iii) it is perceived that when Lean is implemented individually, it lacks of specific tools to understand and treat the variability that remains somewhere along the process and cannot be eliminated by means of Lean techniques (e.g., standardization). This fact adversely impacts the efficacy of this methodology in terms of elimination of process waste. Likewise, when a Six Sigma Project is applied without Lean's systemic vision, one may lose sight of the global flow with negative consequences to the improvement project.

Finally, one should observe that the 18 criteria selected for comparing the approaches of Lean and Six Sigma are not exhaustive and may depend on differentiation regarding their relative weights when assessing the effective benefits of using a combined Lean Six Sigma approach. These relative weights may vary depending upon the trajectory of the company, its branch, and the knowledge already established regarding Lean Manufacturing or Six Sigma. The intention of this comparative analysis was not to create a multi-criteria decision support procedure for selecting between Lean or Six Sigma, but to identify, based on the selected references, different criteria and the possible benefits derived from a combined approach. The intensity of each benefit, nevertheless, depends on several other factors that require further analysis besides the arguments presented in this paper, being a theme future research. According Belton and Stewart (2002) in outranking methods, weights measure the influence which each criterion should have in building up the case for assertion that one alternative is at least as good as another. Thus, in a future study, weights could be analysed in terms of represent the relative importance of each criterion for Lean and Six Sigma.

6. Conclusion

The purpose of this research was to identify points of convergence between Lean and Six Sigma, and those points have been highlighted based on 18 criteria. Authors such as Arnheiter and Maleyeff (2005), Bendell (2006), George (2010) and Bentley and Davis (2010) reiterate the vision of complementariness between these two approaches. One can infer that the first one translates the focus on eliminating wastes maintaining the perspective of production system, whereas the second one presents the actions required to eliminate those wastes in a more methodological and formal way. Complementarily, both methodologies aim to contribute to increasing the organization's competitiveness.

Among the 18 criteria featured in the present research, it can be noted that the main benefits of using Lean and Six Sigma in synergism are the improved performance of the organization due to improvement actions designed to eliminate losses, reduce the variability (which provides a better forecast of how long the activities will last) and the generation of financial results. Lastly, based on the analysis carried out as part of this research paper, it is possible to infer that: (i) the two methodologies are predominantly complementary; (ii) it is possible to create a single model blending both methodologies studied in this research; and (iii) it was perceived that, when Lean is implemented on its own, it fall short of specific tools to leverage its full potential according to the complexity of the problem under analysis.

Likewise, when a Six Sigma project is applied without Lean's systemic vision, one may lose sight of its impact on the global flow of the production system, incurring on negative consequences to the improvement project. Although the Lean and Six Sigma may not be new methodologies, from the results of our research, was possible verify that there are still gaps that need to be better supported. In this sense, one of those gaps addresses, for instance, weighting the effective benefits associated to combined Lean Six Sigma approaches, considering the trajectory and established knowledge of different organizations and different sectors, in order to better support decision-making and assessment of the outcomes of such type of projects. Another research opportunity is to evaluate the differences and similarities by combining Lean Six Sigma with others continuous improvement approaches, such as the Theory of Constraints and the Quick Response Manufacturing. To that end, further research extending the scope of this work by analyzing other aspects in addition to the ones investigated here is recommended.

References

Andersson, R., Eriksson, H., Torstensson, H. (2006). Similarities and differences between TQM, six sigma and lean. The TQM Magazine, v. 18, n. 3, p. 282-296.

Antunes, J. A. V. A. et al. (2008). Production Sistems: Concepts and pratics to Project and managemente of lean production. 1. ed. Porto Alegre: Bookman.

Arnheiter, E. D. and Maleyeff, J. (2005). The integration of lean management and six sigma. The TQM Magazine, v.17, n. 1, 5-18, 2005.

Atwood, J. (2005), Using design for Six Sigma, iSixSigma Magazine, v. 1, n. 4, pp. 51-8.

Bañuelas and Antony, J. (2004). Six sigma or design for six sigma? The TQM Magazine, v. 16, n. 4, p. 250-263.

Belton V., Stewart, T. J. (2002) Multiple Criteria Decision Analysis. Kluwer academic Publishers.

Bendell, T. (2006). A review and comparison of six sigma and the lean organization. The TQM Magazine, v. 18, n. 3, p. 255-62.

Bentley, W., Davis, P. T. (2010). Lean Six Sigma secrets for the cio. New York, Taylor and Francis Group.

Bornia, A. C. (2002). Managerial cost analysis: application in modern enterprises. Porto Alegre: Bookman.

Dennis, P. (2007). Lean Production Simplified: a Plain-Language Guide to the World´s most Powerful Production System. 2nd edition productivity press.

Ehie, I. , Sheu, J. (2005). Integrating six sigma and theory of constraints for continuous improvement: a case study. Journal of Manufacturing Technology Management, v. 16, n. 5, p. 542-553.

Ford, H., in collaboration with Crowther, S., (2003). Today and Tomorrow. Productivity Press, Portland Oregon, Updated 1988 reprint of the 1926 original.

George, M. O. (2010). The Lean Six Sigma guide to doing more with less cut costs, reduce waste and lower your overhead. New Jersey: John Wiley & Sons, Inc.

Goldratt, E. M. (2009). Standing on the shoulders of giants: production concepts versus production applications. The Hitachi Tool Engineering example. Management & Production, v.16, n.3, p. 333-343.

Harry, M. and Schroeder, R. (2000). Six sigma: the breakthrough management strategy revolutionizing the world's top corporations. New York: Doubleday.

Harrison, J. (2006). Six Sigma vs. lean manufacturing: Which is right for your company? Foundry Management & Technology, 13(7), 31-32.

Higgins, K. T. (2005). Lean builds steam, Food Engineering: The Magazine for Operations and Manufacturing Management. Retrieved from http://www.foodengineeringmag.com/articles/Lean-builds-steam

Hoerl, R. W., Gardner, M. M. (2010). Lean Six Sigma, creativity, and innovation. International Journal of Lean Six Sigma, v. 1, n. 1, pp. 30-38.

Jugulum, R. and Samuel, P. (2008). Design for Lean Six Sigma: A Holistic Approach to Design and Innovation. New Jersey, John Wiley & Sons.

Kumar, C. S. , Panneerselvam, R. (2007). Literature review of Jit-Kanban system. The International Journal of Advanced Manufacturing Technology, v. 32, n. 3-4, p. 393-408.

Langabeer, J. R. et al. (2009). Implementation of Lean and Six Sigma quality initiatives in hospitals: A goal theoretic perspective. Operation Management Research, v.2, p. 13–27.

Liker J. K. (2004) The Toyota Way: 14 principles from the world's greatest manufacturer. New York: McGraw Hill.

Mika, G. (2006). Six Sigma isn't lean. Manufacturing Engineering, v. 137, n.1.

Mehrjerdi, Y. Z. (2011). Six-Sigma: methodology, tools and its future. Assembly Automation, v. 31, n. 1, p. 79-88.

Montgomery, D.C. (2010). A modern framework for achieving enterprise excellence. International Journal of Lean Six Sigma, v. 1, n. 1, p. 56-65.

Narasimhan, K. (2007). Lean Six Sigma Statistics: Calculating Process Efficiencies in Transactional Projects, The TQM Magazine, v. 19, n. 6, p.626 – 637.

Nave, D. How to compare Six Sigma, Lean and the Theory of Constraints. Quality Progress, pp. 73-79, 2002.

Ohno, T. (1988). Toyota production system: Beyond large-scale production. New York: Productivity Press.

Oliveira, S. L. (1997). Treaty of Scientific Methodology. São Paulo: Pioneira.

Pacheco, D. A. J. P. et al. (2014). Balancing or flow balancing capacity? systemic analysis and propositions. Management & Production, v. 21, n. 2, pp. 355-368.

Pergher, I., Rodrigues, L. H., Lacerda, D. P. (2011). Discussão teórica sobre o conceito de perdas do Sistema Toyota de Produção: inserindo a lógica do ganho da Teoria das Restrições. Management & Production, v.18, n. 4, p. 673-686.

Pepper, M.P.J., Speddinn, T.A. (2010). The evolution of lean Six Sigma. International Journal of Quality e Reliability Management, v. 27, n. 2, p. 138-155.

Perez-Wilson, M. (1999). Six Sigma: Understanding the Concept, Implications and Challenges. Advanced Systems Consultants.

Pitcher, M. (2010). The Challenge of Overcoming Success March. ASQ Magazine, p. 1-4.

Rother, M. Learning to See: Value Stream Mapping to Add Value and Eliminate Muda. Lean Enterprise Institute; 2003.

Rotondaro, R. G. (2002). Six Sigma: management strategy to improve processes, products and services. São Paulo: Altas.

Santos, A. B., Martins, M. F. (2010). Contributions of Six Sigma: case studies in multinational. Production, v. 20, n. 1, p. 42-53.

Sharma, U. (2003). Implementing Lean principles with the six sigma advantage: how a battery company realized significant improvements. Journal of Organizational Excellence. Summer, 2003.

Shingo, S. (1989). A study of the Toyota production system. Cambridge, MA: Productivity Press.

Snee, R. D. (2010). "Lean Six Sigma: getting better all the time." International Journal of Lean Six Sigma, v. 1, n. 1, p. 9-29.

Spector, R. and West, M. (2006). The art of lean program management. Supply Chain Management Review, vol. 10, no. 6.

Taylor, F.W. (1947), Scientific Management, Harper & Row, London (a volume of two papers originally published in 1903 and 1911 and a written testimony for a Special House Committee in the US in 1912)

Womack, J.P., Jones, D.T. , Roos, D. (1990). The Machine that Changed the World, Rawson Associates, New York, NY.

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