The integration of Six Sigma and lean management

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Abstract

Purpose – Lean and Six Sigma are the two most important continuous improvement (CI) methodologies for achieving operational and service excellence in any organization. The purpose of this paper is to explain how lean compares to the Six Sigma and outline the benefits for integrating them. Also, this paper discusses the existing models that describe how Six Sigma and lean fit together. A new detailed description for integrating Six Sigma and lean is developed to provide an improved approach for CI.

Design/methodology/approach – The following research included proposals and discussion, which were mainly based on the authors' own findings and experience, in addition to a literature-based review of some of the most common and traditional lean and Six Sigma models.

Findings – The paper proposes a new lean Six Sigma (LSS) approach and provides a detailed description of its phases. The paper also presents the views on the integration benefits as well as on how Six Sigma compares to lean. Six Sigma and lean are related and share common grounds in terms of striving to achieve customer satisfaction. Their integration is concluded to be possible and beneficial.

Research limitations/implications – The paper discusses the existing models that describe how Six Sigma and lean fit together. Finally, a new detailed description for integrating Six Sigma and lean is developed to provide an improved approach for CI.

Originality/value – The paper extends previous works on LSS and proposes a novel approach to LSS. The proposed structure is built upon the existing define, measure, analyze, improve and control structure which is well renowned in the literature.

Keywords Lean production, Six Sigma, Continuous improvement, Total quality management, Integration

Paper type General review

1. Introduction

Quality improvement is the reduction of variability in process and product. Continuous improvement (CI) is one of the important goals of quality. The effectiveness of how

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an organization implements CI methodologies is one of the key reasons for success. Among various process improvement methodologies, Six Sigma and lean stand as the best methodologies widely used by various industries and are currently referred to as state of the art. There is a drawback in applying only one of the two methodologies alone, as the CI may have the deficiency of being slow.

The Six Sigma methodology is a well disciplined and structured approach used to enhance process performance and achieve high levels of quality and low levels of variability. Six Sigma quality means only two defects exist per billion opportunities. The necessity to operate at such a low level of defect may not always be economical. Motorola's Six Sigma quality program was created by B. Smith in 1987. Details can be found in Smith (2003). Motorola created a number of steps to achieve Six Sigma, which were later replaced by the four phases of measure, analyze, improve and control by General Electric (GE). After that, the define phase was added before the measure phase to form the well-known define, measure, analyze, improve and control process (DMAIC). When the product or service under consideration is under major design change requirements or still at the early stages of development, the five phases that are used become define, measure, analyze, design and verify (DMADV) or design for Six Sigma (DFSS). The goal of DMADV is to strive to achieve a Six Sigma level right from the early design. The Six Sigma approach starts with the identification of the need for an improvement initiative.

The lean methodology is proven to help organizations achieve on time delivery of the right quality and quantity to satisfy customers. Lean is unique as it focuses on enabling people to see the product or service and the whole value stream from the perspective of the customer. Lean is used to eliminate waste, variation and work imbalance. By waste, it means unnecessarily long cycle times, or waiting times between value-added activities. Waste can also include rework or scrap, which are often the result of excess variability, so there is an obvious connection between Six Sigma and lean.

2. Integration of Six Sigma and lean

The claim that lean and Six Sigma have a complementary relationship is widely accepted today and more companies are establishing lean Six Sigma (LSS) programs, especially after the proven capability of lean and Six Sigma in leading companies like GE and Toyota. Recently, some companies have teamed up to coach each other, like Boeing and GE, where Boeing is a leader in lean and GE is a leader in Six Sigma. Since 1986, The George Group were the first to integrate and popularize lean with Six Sigma.

LSS can be described as a methodology that focuses on the elimination of waste and variation, following the DMAIC structure, to achieve customer satisfaction with regards to quality, delivery and cost. It focuses on improving processes, satisfying customers and achieving better financial results for the business.

The evolution of LSS had started in the 2000s (Byrne *et al.*, 2007). Sheridan (2000) had used the term lean sigma to describe a system that combines both lean and Six Sigma. Some companies who had used Six Sigma prior to using lean are still calling it Six Sigma and others use the term Six Sigma lean (Byrne *et al.*, 2007). Also, some companies call it LSS or Six Sigma lean, depending on which methodology they choose as the leading initiative. Furthermore, Honeywell calls it Six Sigma plus (Kovach *et al.*, 2005).

Antony (2004) believes that there will be more tools added to the Six Sigma package in the future as there is a need to improve Six Sigma methodology to cope with market changes. Six Sigma is expected to evolve and be integrated with other improvement methodologies. With regard to lean, Hines *et al.* (2004) have indicated that it is possible to integrate lean to other approaches, without contradicting its objective of providing customers with value.

The tools used in lean and in Six Sigma were not all invented in these methodologies, but they were used in a structured approach to form each methodology. Thus, both can be thought of as tool boxes, where certain tools might be more suitable than others depending on the nature of problem or opportunity faced. A lot of tools are interchanged between Six Sigma and lean (McAdam and Donegan, 2003) and Figure 1 shows an example of this. An LSS approach enables people to choose the right tools to attack different problems, either quickly in the form of Kaizen events or using more in depth analysis for complex projects. Six Sigma and lean should not be used in parallel, but simultaneously, so that their synergy can be leveraged. The attempt to work on both methodologies in parallel is not always successful, as they are still applied separately to solve problems. Companies doing that are facing troubles in prioritizing initiatives, allocating resources, selecting the right methodology and proving financial gains.

In some organizations that have been applying lean for years, Six Sigma is introduced to tackle problems of product variation. Hines *et al.* (2004) considered Six Sigma as a useful addition to lean as it attacks variation in a way compatible with the lean approach. However, their framework uses Six Sigma only as a tool within lean and this undermines the power of the DMAIC approach. Mader (2008) gives an example of a model where a traditional Six Sigma approach can be used in parallel with a lean Six Sigma light approach, which mainly uses a lean Kaizen event approach to decrease the project duration. After a project is selected as a result of value stream mapping (VSM), a decision is made on which method is more suitable and what phase of DMAIC is shortened. However, this does not achieve the integration intended as it still proposes two separate approaches.

Other companies apply lean and Six Sigma separately in one stage after another. An LSS model as proposed by Crawford (2004) has presented how Six Sigma can first be applied to improve the processes effectiveness followed by lean to improve the system efficiency. However, it is better to draw on both simultaneously to achieve the idea of integration. Another approach is to deploy lean first to eliminate waste and unnecessary steps, and then to introduce Six Sigma after that, in order to focus on certain process steps. Snee (2005) has suggested that lean tools can be very effective in the first stage of process improvement, where the aim is to eliminate waste and simplify processes, before starting to tackle the more difficult problems through optimization and process control aimed mainly at process steps. However, it is more effective to draw on both simultaneously, as root causes of problems occurring within or between processes may

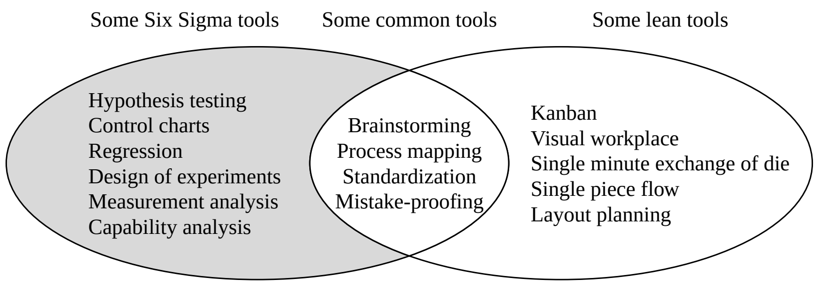

Figure 1.
An example of Six Sigma and lean common tools

be in other locations than where they appeared. Once again, applying one methodology after another does not satisfy the idea of integration where they should be used simultaneously to achieve the most benefit.

With regard to the application of lean and Six Sigma, there are six model types found in organizations. The first and second models are examples of applying one within the other (as a tool within the other). The first model type presents lean as an encompassing methodology that uses Six Sigma as a tool within it, as in the example of a Kaizen idea that appears in a VSM exercise. The second model type presents Six Sigma as an encompassing methodology that forces some lean tools into the DMAIC structure. This is close to the integration model proposed later, but it needs to be explained more and needs to use the two holistically and equivalently. The third model type is where Six Sigma and lean are used separately from each other (to tackle different problems), according to the classification of the project. Figure 2 shows examples of the first three types of models found in different organizations. The fourth model type applies both in parallel (as when applied to the same problem, but separately) and the fifth applies one after another in series (as when applied to the same problem). Finally, the sixth applies both simultaneously, which is the recommended and integrated approach detailed in this work.

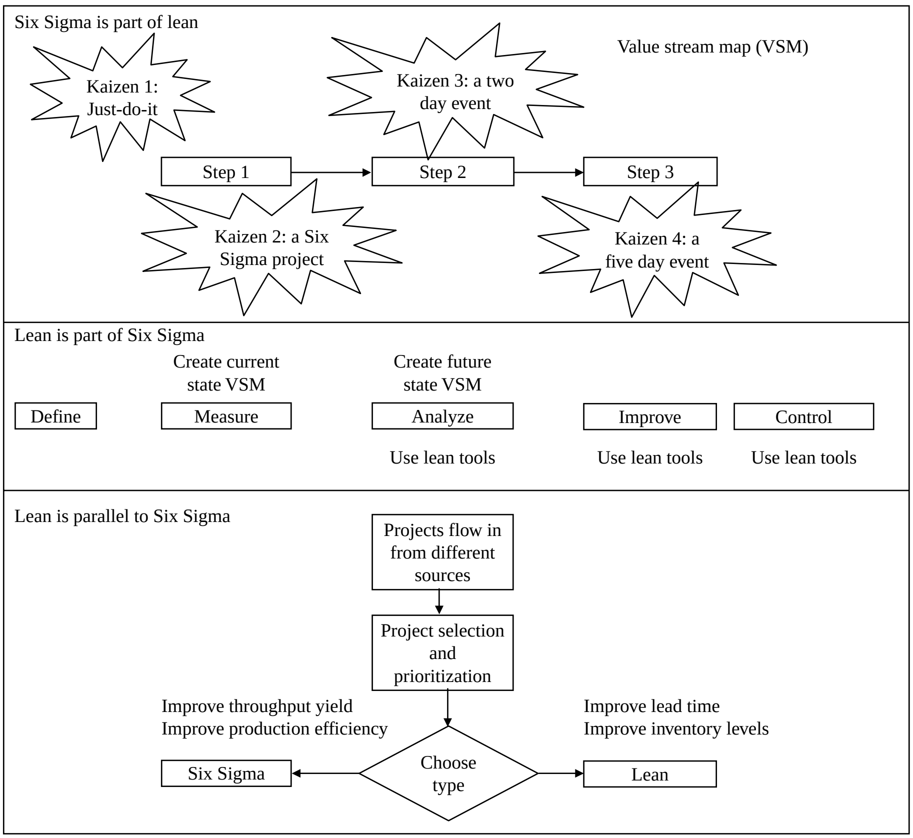

Figure 2.
Some LSS models

Bendell (2006) has concluded that the current literature on the combination of Six Sigma and lean is limited and unsatisfactory when examined for a common model, but that they can be effectively combined into one system. The attempts to combine lean and Six Sigma were merely philosophical or near-religious arguments. These attempts gave examples of incompatibility and conflict leading to sub-optimal process improvement programs. An example of that was the difficulty in the control phase created by not prioritizing waste removal ideas resulting from simple lean walks. Bendell criticized some of these combination attempts for being ineffective, as they take one methodology as the dominant and the other as the subordinate one, ignoring the fact that each has its unique features and benefits.

Mader (2008) has suggested that LSS deployment models, developed in different organizations, vary widely and that the building of a body of knowledge is still required. Many organizations use VSM as a starting point for process improvement, where the resulting projects are lean, Six Sigma, ISO or projects dealing with people issues. There is a need for further definition of the common model proposed by Bendell (2006), which contains strategic features of Six Sigma and lean, integrating people and systems, involvement and participation, deployment change agents, results focus, tool-based approach and integrated training and deployment.

Kiemele (2005) has recommended critical success factors for the deployment and implementation of LSS, such as leadership alignment, proper selection of people and projects, training, motivation, accountability, information technology, marketing and supply chain management. Antony (2006) has indicated that top leadership commitment at GE was essential to the success of Six Sigma deployment, as effective implementation depends heavily on how passionate leadership is in its support. Here are the ten steps suggested by Martin (2007) to form the LSS solution process: align project with strategic goals, ensure key people buy in, communicate results, prove causal effects, improve the management system, develop an improvement plan, integrate countermeasures to root causes, standardize process, train and audit and apply controls. Martin (2007) has also indicated that some key LSS initiative success factors include management support, choosing the right people for deployment, selection of the right projects, establishing effective communication and owning the characteristics of an effective change program.

George (2002) has indicated that companies who started integrating lean and Six Sigma used three stages: the initiation of goals, the selection of people and projects and the implementation stage (which includes coaching and building an improvement culture). The organizational culture is what determines which methodology is more suitable for an organization. The LSS methodology should be holistic to encompass a wide variety of cultures and enhance them to become a comprehensive CI culture. George (2002) has indicated that in order to leverage the LSS learning in an organization, there needs to be a strong curriculum, a means of interaction, technology exploitation and best practice documentation. The deployment plan of LSS includes process focus, organization structure, measures, rewards and tools. Caterpillar institutionalized LSS through four phases (i.e. comply, commit, embed and encode) (George, 2002):

(1) *Comply:* the executive team is willing to give LSS a try.

(2) *Commit:* a true belief exists across the organization in the value of LSS.

(3) *Embed:* embrace LSS philosophy and drive it beyond the walls of the company.
(4) *Encode:* make LSS philosophy a culture.

George (2002) has also proposed three institutionalization steps to lead an organization through the phases above:

(1) *Start on the right foot:* dedicate resources and select the right people and projects.
(2) *Build confidence that LSS is a way of life:* publicize results and celebrate, educate and involve employees, train on leadership, leverage existing strengths, focus on all processes (manufacturing and transactional), reinforce corporate values, integrate LSS into strategic planning, create accountability through visibility, communicate effectively and share best practices.
(3) *Extend LSS:* use a common language, integrate LSS with business plans, extend it into the supply chain and into the design processes.

To succeed in integrating lean with Six Sigma, organizations need to adopt a holistic improvement method, where lean and Six Sigma mutually reinforce each other. Although DMAIC originated in Six Sigma, it can be generalized as an overall framework for process improvement. Data show that improvements remain slow without the Six Sigma infrastructure (George, 2002). Snee (2004) has indicated that Six Sigma has a unique characteristic of sequencing and linking improvement tools into an overall approach. An integrated approach is expected to include the use of a current state VSM as a platform for applying Six Sigma and lean tools, applying Six Sigma to adjust process parameters, integrating lean techniques into DMAIC and using future state VSM as a way to change the structure of the process.

The model proposed in this paper will follow the DMAIC structure and use VSM, but will also aim at not using Six Sigma or lean as a lead initiative. Many researchers believe it is possible to integrate lean and Six Sigma without contradicting their core principles. However, there is no consensus on how the integration should be done and there is no widely accepted integrated methodology (Proudlove *et al.*, 2008). So, a detailed description of this integration is still needed.

To summarize, here are some important recommendations to remember when considering the integration approach for Six Sigma and lean. It needs to:

- be holistic in its nature and have a strategic link;
- use DMAIC as the framework or core structure;
- be tool-based using the best tool that suits the problem faced;
- use both methodologies simultaneously and not paralleled;
- integrate both in a balanced way without a dominant or subordinate one;
- use VSM as its focused platform;
- take into account the differences between the two methodologies;
- include a detailed body of knowledge;
- avoid sub-optimal process improvement and be result focused;
- focus on all processes, manufacturing and transactional;
- use an infrastructure of well trained people representing all of the organization;

- ensure management, key people commitment and alignment;
- have the criteria for robust project selection;
- have a reward system, motivation, communication system, financial accountability and visibility;
- have a supporting structure of: management systems, standardization system, control application, information technology, sales, marketing and supply chain;
- be extended to suppliers and customers; and
- own the characteristics of an effective change program.

3. Benefit of integration

The integration of lean and Six Sigma is the solution to overcome the shortcomings of both, as they complete each other. The fusion of the two is the way for organizations to increase their potential improvement (Bhuiyan and Baghel, 2005). This is of significant importance as a lot of companies are only applying one of the two methodologies, without realizing that great benefits lie in what the other methodology can bring. Smith (2003) has also mentioned that the combination of both leads to achieving CI. The integration of Six Sigma and lean helps companies achieve zero defects and fast delivery at low cost. A more detailed description of this integration is needed in order for organizations to succeed in exceeding future customer demands. LSS addresses issues that are overlooked by lean and Six Sigma when applied individually, such as the process steps that should be tackled first and the order of what to apply first and to what extent; it identifies the ways to achieve significant simultaneous cost, quality, variability and lead time improvements (Bhuiyan and Baghel, 2005; Lachica, 2007; Lean Sigma Institute, 2008).

Consultants from IBM have analyzed results from several leading companies implementing LSS and they have found that some companies have achieved impressive results in the past five years. Drawing on the principles, tools and philosophies of both methodologies has enabled them to produce breakthrough innovations that resulted in profound business improvements (Byrne *et al.*, 2007). The integration of the industrial engineering tools of lean with the statistical tools of Six Sigma (which complement each other) provides an operational excellence methodology (Basu, 2004).

LSS can help achieve better system-level performance by improving quality and accuracy measures of products and processes. One of the critical requirements to succeed in CI efforts at an organization is the availability of a common set of problem solving tools (Chapman and Hyland, 1997). This can be effectively achieved through the toolkit that Six Sigma and lean can provide when integrated. The integration of Six Sigma and lean can help provide tools suitable for different production environments, whether uniform or highly variable.

The goal of LSS initiatives is to transform the organizations from separate reactive operations, which are functionally oriented, into cross-functional process focused organizations. The result will be a customer focused, employee empowered and flexible organization (Martin, 2007). LSS is a key enabler of the corporate strategy, driven by the customer and business needs, to achieve competitive advantage (George, 2002). It can achieve faster improvements at less cost (Bogart, 2007). An LSS model can be used to achieve measurable business improvement results for a company and its customers.

In addition to the benefits mentioned above, LSS encourages the use of a common vision and language. The integrated approach will result in less confusion on the side of CI leaders that may feel they have to drop certain Six Sigma projects in favor of lean projects that they are required to accomplish, especially when introducing lean to an organization that already applies Six Sigma. Furthermore, each methodology is more suitable for certain levels and types of problems. That is why the integration of the two methodologies is important and saves a lot of effort and repetition.

4. Similarities and differences of Six Sigma and lean

To understand how to integrate Six Sigma and lean, they first need to be compared. Based on an extensive literature review and the authors' own experience, a comprehensive and appropriate basis for comparison based on 31 dimensions is considered here. Yang (2004) has reviewed a number of studies and put together 12 dimensions that were used in the comparison between total quality management (TQM) and GE-Six Sigma. Tables I and II use 19 additional dimensions (total of 31) for the comparison between lean and Six Sigma. These tables include a review of their similarities and differences, respectively.

As seen in Table I, there are many areas where Six Sigma and lean share common grounds in terms of: the origin or development, principles or concepts, objectives or applications, leadership roles, staff roles and features or project management approach. As seen in Table II, the differences between the two methodologies lie in: definition, complexity, focus, technique, how they are viewed, what they are criticized for, approach (to people (operation), teams, mapping, processes and systems, certification, design and data), scope, identification of gaps, view of inventory and production, practices (DMAIC vs VSM), cost of poor quality (COPQ) vs waste types, COPQ vs waste percentages, execution, analysis vs action, tools, software, rewards, training (cost and material), change leadership and obstacles, project duration, project selection, financial savings, time to see results, link to suppliers, culture, measures, nature of problem level, shortcomings or desirable characteristics and results. The integrated approach has to take into account the differences between the two. Furthermore, even in the dimensions where they are different, there are still lots of similarities such as in the focus on customer satisfaction. Also, there are many compatible areas where one of them may excel forming an opportunity to help the other one. Thus, the integration of the two is possible and beneficial.

5. Proposed integrated model for LSS

The integration needs to achieve a full fusion of the lean philosophy of waste elimination with the Six Sigma mentality of perfection at all times. The five principles of lean production resemble very much the quality improvement process developed by Motorola.

In Figure 3, the relationship between Six Sigma and lean phases is explained. The use of a single-headed arrow is chosen to emphasize that the proposed model will use the holistic DMAIC structure for LSS. The define phase is where the understanding is formed for what is of value to the customer. The lean mapping of current state is a phase of measuring and analyzing, as data are collected to see what the baseline looks like and the improvement ideas start to arise, causing the analysis to start. The lean integration forces measure and analyze phases to be closer to each other. The improve phase is where the process is adjusted to make the value flow in a better way than what existed before using the future state mapping exercise as an example, and to introduce the pulling concept. Finally, the control phase is where the process is perfected,

Table I. Similarities and the relationship between Six Sigma and lean

	Six Sigma	Lean	Notes
1. Development	Motorola, mid-1980s by B. Smith (Devane, 2004) with the participation of W. Smith (Kumar *et al.*, 2008) and Harry (Harry and Schroeder, 2000) Later developed by GE	Toyota in the 1970s by Ohno based on the teachings of Ford, Japanese experts and others (Holweg, 2007)	Both have roots traced back to TQM The evolution of LSS started in the 2000s (Byrne *et al.*, 2007)
2. Leadership	Uses a top-down approach	Top-down approach focusing on trusting people skills and empowerment	Both emphasize commitment and support of top management (Yang, 2004)
3. Principles	The voice of customer (VOC), financial impact and defect elimination (Yang, 2004) Capability and stability DMAIC, CTQ and COPQ (Han and Lee, 2002) Aligning customer needs with goals, obtaining necessary resources to lead change, using standard measurements and appropriate metrics, deploying teams and setting stretch goals (Friday-Stroud and Sutterfield, 2007)	Provide customers with required value, quality and quantity on time Womack and Jones: identify value from the customer view, map current activities, make the value flow, pull from the supplier and perfect continuously (Bhuiyan and Baghel, 2005; Hines *et al.*, 2004) Lean is supported by a base of industrial engineering (Dong, 1995)	Both principles are embedded in TQM (Sheehy *et al.*, 2002) and could be seen as concepts supporting the aims of TQM TQM can be thought of as an umbrella encompassing all business activities with LSS as the pillar that carries the structure
4. Features	Uses a project management approach with an improvement plan from the improve phase	A project management approach with an implementation plan put by team during future VSM	Both have a project management approach (Anderson *et al.*, 2006) based on teams lead by change leaders; both involve planning, brainstorming and executing
5. Staff roles	Black belt, process champion and master black belt	Kaizen leader, value stream owner and Sensei	

Table II.
Differences and the relationship between Six Sigma and lean

	Six Sigma	Lean	Notes
6. Definition	A collection of process improvement tools used systematically in a series of projects to achieve high levels of stability	Liker perceived it as a philosophy aimed at reducing the time from order to delivery by eliminating waste (Devane, 2004) A culture of improvement (Huang and Liu, 2005)	George defines LSS as a methodology that helps companies achieve better cost, quality, speed, customer satisfaction and higher rates of improvement (George, 2002)
7. Complexity	More scientific, data-based and structured approach to process control, quality building and problem solving (Yang, 2004)	Much simpler methodology that is easier to understand and implement	It is claimed that lean is art whereas Six Sigma is science; however, there is an art and science element in both
8. Operation	Lead by Belt with limited involvement of others Majority of applications aimed at engineering or operations	More emphasis on heavier involvement of all people Majority of applications aimed at manufacturing and assembly	It is argued lean is more suitable for blue collar and Six Sigma is for white collar An integrated approach should target all people and address their concerns
9. Teams	Uses individual teams	Grouping of teams More emphasis on cross-functional teamwork	Value stream owners work across departments Belts may or not (scope is usually narrower)
10. Focus	Key processes driven by VOC (Yang, 2004) Process alignment (Anand *et al.*, 2007) Statistical control, stability, accuracy and defects Not always on flow optimization (Ferng and Price, 2005) Becoming rigorous (Proudlove *et al.*, 2008) Process effectiveness	Major end-to-end core business processes using product family matrix Different than Six Sigma in terms of focus Flow and speed of information or products Learning to see (Proudlove *et al.*, 2008) System efficiency	Lean focuses on customer value; Six Sigma focuses on CTQ (Proudlove *et al.*, 2008) Both focus on customer satisfaction and better financial results (Anderson *et al.*, 2006) Both work on speed and variation at different levels which stresses the idea of integration

(*continued*)

	Six Sigma	Lean	Notes
			Six Sigma focuses on controls to end projects while lean focuses on ongoing future VSM There is more focus on visual workplace (Antony *et al.*, 2003) A lean plant is recognized easier than a Six Sigma plant
11. Gap Ide-notification	Some organizations use balanced score cards that show gaps using key performance indicators	Uses VSM as a way to understand the VOC (Snee, 2005)	Both, however, lack a formal link with strategic planning and policy deployment
12. Inventory	Not necessarily a focus (Raisinghani *et al.*, 2005)	A waste that needs to be minimized	Waste is classified into certain types in lean clarified better than in Six Sigma
13. Practices	Described as a well-structured CI approach following DMAIC phases Often uses flow charts	Uses VSM of current and future phases and Kaizen events	Both apply to production and business processes Both are state-of-the-art proven methodologies
14. Production	Focuses on reducing variation	Focuses on efficiency	Overproduction (often rewarded in Six Sigma) is a waste in lean like inventory Lean is preferable to mass production (producing more often increases waiting times, work imbalance and prevents product flow)
15. Design	Uses DMADV or DFSS for the design of new products or processes	Focused more on production processes not new product design (Reichhart and Holweg, 2007); uses VSM to design a new enterprise	Six Sigma uses DFSS or DMADV for product design whereas lean uses other tools Lean principles apply to new product development

(*continued*)

Table II.

Table II.

	Six Sigma	Lean	Notes
16. Techniques	Tools are analytical, statistical and advanced statistical	Tools are mainly analytical (Anderson *et al.*, 2006); no practice linking quality and mathematics to diagnose problems (Devane, 2004) but uses basic formulas to identify demand and other parameters	A lot of tools and techniques are interchanged between the two (McAdam and Donegan, 2003) Both criticized for focusing on outdated processes and metrics
17. Mapping tools	Uses supplier-input-process-output customer (SIPOC) high-level map (including CTQ) and simulation process flow charts	Uses VSM for high-level maps (which includes a lot of valuable information and data) and process flow charts for low-level mapping	Lean uses VSM which is static in nature unlike simulation in Six Sigma that is more suitable for dynamic environments (Lian and Landeghem, 2007)
18. Analysis vs action	Focuses on extensive data analysis	Effectively promotes CI using Kaizen events More revolutionary thinking	However, Six Sigma has rapid improvement techniques such as workout at GE and Lean has some data analysis tools (Proudlove *et al.*, 2008)
19. Tools examples	Design of experiments (DOE), hypotheses testing and measurement system analysis (MSA)	Kaizen events, visual workplace, Kanbans, 5S, etc.	Both use mistake proofing (Bhuiyan and Baghel, 2005) as one of the common tools
20. Certification	To be certified, a green or black belt needs to achieve the financial goals of the project done during training	To be certified, a lean facilitator needs to lead an end-to-end system change from current to future state using VSM and Kaizen blitz	LSS belts need to enhance their facilitation and change leadership skills as they are expected to expand their teams to involve more people in their projects
21. Training	Structured and focused on belts (Basu, 2004) who create an implementation infrastructure (Snee, 2004) Less focus on wide teams More intensity in the training of full-time improvement individuals (Schroeder *et al.*, 2008)	Costs less money to train somebody and targets almost everyone in the organization Lean drives superior organizational learning (Pil and Fujimoto, 2007)	Antony (2006) has indicated that the start up of a Six Sigma program in an organization might be costly especially for small- and medium-size organizations (which is not the case for VSM in lean)

(*continued*)

	Six Sigma	Lean	Notes
	Some organizations started setting up introductory white and yellow belt levels to target all people Green Belts		Six Sigma draws more from quantitative science whereas lean draws more from behavioral science when looking at the training and certification requirements of some organizations LSS training need to be integrated where one methodology is taught and not two
22. Rewards	Belts are usually explicitly recognized and rewarded with bonuses and promotions based on project results (Yang, 2004); however, they may risk missing the wider view where their projects success may not be of benefit as the most critical problem may lie elsewhere	Bonuses are tied to project results but it is more challenging to quantify project savings as they may take longer times or be soft Proper low-level metric may not be easily found and higher-level metrics may be influenced by other non-controllable factors Group celebrations occur at end of Kaizen events	There is more incentives and career development focus in Six Sigma (Upton and Cox, 2008)
23. Change obstacles	Main change obstacle is the lack of understanding Success depends on skills of belts to create value and diligence with less focus on the team members who meet for few times during projects	Main obstacles is culture Kaizen events create rapid short-term changes Success depends on team's mind-set and to create value Very important to empower, communicate, coach and listen (Devane, 2004) Resistance is less if people feel they are involved	Success of both requires cultural change Lean requires overcoming the paradigm of mass production It is less difficult to reengineer and evaluate breakup of an organization using Six Sigma as the team is more independent of the processes under consideration (Hwang, 2006)

(continued)

Table II.

Table II.

	Six Sigma	Lean	Notes
			Choosing a cross-functional team representing all process steps is a strong asset for successful change in both
24. Financial savings	Results are tangible Less challenging to quantify savings and introduce incentives Tracks savings on a project by project level (Schroeder *et al.*, 2008)	Results can be intangible More challenging to quantify savings More soft part-time savings A different look at cost savings and inventory than in traditional financial systems (Devane, 2004)	Both result in quick initial returns followed by incremental returns (Bhuiyan *et al.*, 2006)
25. Link to suppliers	Targets supplier only if they are CTQ of process under investigation (Schroeder *et al.*, 2008)	Engages suppliers, helps them improve (Basu, 2004), certifies them and cooperates with a few strategic partners	Linking Six Sigma to suppliers was identified as a success factor needed for its implementation; however, there is generally just as much focus on them in lean
26. Culture	Sets up a culture that focuses on improvement of processes to achieve less defects and better financial gains Focuses on variation reduction	Sets up a waste elimination culture engaging all people to focus on activities adding value from the customers view Focuses on a one-piece flow	Lean engages people into CI, focuses on training them to see waste, find its causes and empowers them to implement changes; focuses on teamwork and seeing more than one's task Six Sigma encourages a CI culture using an approach of a project after another
27. Measures	Measures are primarily financial and cost-oriented, but are often driven by other management strategies	Primarily simple, non-financial and operational Time-based measures are essential	There is more focus on bottom line results in Six Sigma (Snee, 2004)

(*continued*)

	Six Sigma	Lean	Notes
28. Criticism	Not focusing on people and culture (Proudlove *et al.*, 2008) may be challenging to find data needed for analysis and solutions found may be expensive (Antony, 2006) Over detailed, aiming at an absolute goal that is not always appropriate, difficult to stick with the rigor of the approach and focusing on tools more than problems (Proudlove *et al.*, 2008) Long-term shift of (1.5 σ) in process mean found in Motorola; not all processes behave such a way	Putting lots of pressure on people (Yusuf and Adeleye, 2002); however, does a better job in engaging people Provides more principles than tools or methods (Hoerl, 2004)	In the house of competitiveness proposed by Kovach *et al.* (2005), it is claimed that both are not enough as they fail to deal with innovation and flexibility and thus they need DFSS and agile manufacturing, respectively
29. COPQ vs waste categories	The ASQ recognized four categories for COPQ: appraisal, prevention, internal and external failure (Sower *et al.*, 2007)	Seven types of waste: over-production, waiting, transportation, inappropriate processing, inventory, unnecessary motions and defects (Devane, 2004)	Some consultants add waste of reprioritization and people's skills to the list of wastes in lean Sustainability
30. Project selection	The rights reside with management to ensure financial and strategic implications are considered (Schroeder *et al.*, 2008)	VSM including numerous product families is selected; VSM results in projects such as Kaizen events, Six Sigma projects, just do it, etc.	In LSS, project selection starts with the proper selection of VSM with biggest rate of return on invested resources (George, 2002) A LSS model presented in (Kiemele, 2005) uses VSM as a trigger for project selection
31. Results	Examples: reduction of defects, higher efficiency and higher recovery Uses sigma-level metric to evaluate process capability Has a better effectiveness record (Cheng, 2008)	Some examples are: quality improvement, reduction of inventory, lead time, cycle time and waste, and improvement of people morale	Both share same objective of solving problems, improving current, and reducing waste and cycle times (Snee and Hoerl, 2007)

(*continued*)

Table II.

Table II.

	Six Sigma	Lean	Notes
	Helped reduce defects and operation costs and increase shareholder and customer value (Antony, 2008) GE claimed Six Sigma savings of hundreds of millions of dollars and this success helped spread it (Raisinghani *et al.*, 2005)		Similar to lean, Six Sigma projects can improve process cycle time but lean also improves total lead time Three most important lean indicators are: inventory turns, lead time and percentage of documented production procedures (Bhasin and Burcher, 2006) Experience showed that combining lean with Six Sigma can help companies achieve up to 80 per cent reduction in lead time, 20 per cent reduction in quality and overhead costs, and over 99 per cent on-time delivery (George, 2002)

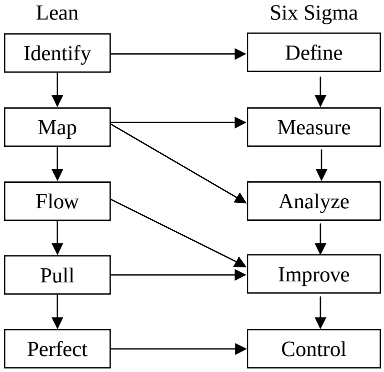

Figure 3.
Lean and Six Sigma phases relationship

by introducing controls and procedures to ensure improvements not only stay, but are also continuously revised for additional ones to be built upon in the future.

6. Detailed description of the integration of PDCA, Six Sigma and lean

Plan-do-check-act (PDCA) cycle was recommended by Deming and has been successfully used in many organizations. There are opportunities to integrate lean and Six Sigma methodologies where businesses have already adapted PDCA. There are many benefits to using the defined Six Sigma methodology over PDCA. In recent years, PDCA seems to be favored by lean in many organizations.

As recommended in the previous section, the integration of Six Sigma and lean into a common model requires the use of DMAIC as its core structure. DMAIC is widely accepted as a comprehensive and robust structure, which is believed to be fitting for the integrated LSS model. Byrne *et al.* (2007) proposed a model that is very similar to DMAIC but is called define, measure, explore, develop and implement. Upton and Cox (2008) proposed an LSS model that uses the charter, explore, imagineer, execute and close phases as a new, helpful and superior structure than DMAIC claiming that it keeps a bias toward quick action from lean without risking the loss of powerful analysis in Six Sigma. However, the DMAIC structure is believed to be robust and flexible to contain the proper lean tools in a way, where all tools are subject to be chosen at a certain phase based on suitability to the problem tackled. The use of DMAIC is believed to simplify matters as it is already known and understood by many process improvement practitioners.

The integration of lean and Six Sigma can follow the DMAIC road map and it is not necessary that each of these phases be a major milestone in the project. Some projects may focus mainly at fixing a measurement system, which means there is no need to pass through the Analyze phase in depth. Other projects may merely be solving a problem of lack of standard operating procedures, where the project does not require lots of data analysis. Also, based on the nature of the problem faced and the situation of the organization, the VSM of the current state can be done within the measure phase as a part of understanding and measuring the baseline performance. The future state VSM can be done within the analyze phase to introduce a faster lead time and better quality process. So, in some projects it is expected that there will be more usage of lean tools and it is not necessary to pass slowly through each of the DMAIC phases.

Depending on the project, DMAIC may take different forms as there may be different levels of detail in each of the phases. For example, it may take the form of DMaIc, which means that problems were mainly identified in the measure phase and there is no need to do extensive analysis. This will enable the Belt to start implementing improvements if this project is mainly of the straight forward type that might be using more lean tools. There is a need to revise the DMAIC content and generalize it to include lean tools in a balanced way with Six Sigma tools. Thus, any project can be approached holistically using DMAIC and the scope will lead to the proper tools.

Antony (2004) stresses that to succeed in a Six Sigma project, there needs to be a proper answer to when, where, why and how the Six Sigma tools should be applied, as each plays a certain role that is specific to the problem at hand. So, including the lean toolkit is not simply about adding it to DMAIC, but it is about where the different tools properly fit to achieve a successful LSS project. This is a step in the right direction to clarify some of the confusion about lean tools and their application as described in (Pavnaskar *et al.*, 2003). Most lean tools fall under the improve and control phases of DMAIC (Snee, 2005). However, there is no reason why these tools or other process improvement tools cannot be used earlier in the measure or analyze phase, once a quick-hit type of opportunity is identified.

A GE-proposed model includes the use of current and future VSM within the analyze and improve phases of DMAIC where lean is integrated within Six Sigma using DM"Lean"C (Moscone, 2007). However, there is a lot of measuring happening in the current state VSM, and thus it is recommended to include it in the measure phase instead. Xerox Consulting (2008) proposed an LSS model that used VSM in the measure phase of DMAIC. According to George (2002), the current state VSM happens in define and the future state VSM in Improve. However, it is preferred from the authors' point of view to introduce the theoretical exercise of future state VSM in analyze, as no improvements have generally been implemented yet. Then, the improvement plan, including the physical transformation from the current to the future state, can be prepared in the improve phase.

Delphi is also another example of a company using the DMAIC structure for LSS, where VSM is initially done in the define phase. It is interesting to note that Delphi proposes using Kaizen events earlier within DMAIC, to deal with quick basic fixing and identify major opportunities, and later to speed up the implementation of the improvement plan (Mendoza, 2007). Similarly, it is proposed in this work to use Kaizen events in three phases: measure, improve and control. In fact, the use of Kaizen events in the measure phase is a step that can save a lot of time when there are lots of improvements that do not require further analysis, and thus do not have to wait for the improve phase. Another use for it is when the project team gets together for a concentrated period of time to conduct brainstorming and discussions, as opposed to wasting a lot of time in conducting multiple shorter sessions intermittently. Also, the use of Kaizen events in the improve phase can get improvements implemented much faster. The use of Kaizen events in the control phase helps in the quick implementation of visual controls as another example.

The Lean Sigma Institute (2008) has proposed a model for LSS that follows DMAIC and attempts to fit the lean toolkit into it. It identifies the use of VSM as part of the measure phase and it only lists a few tools. Another attempt has been proposed by Mader (2008), which links the lean (and Six Sigma) tools or skill sets to the DMAIC phases (specified by the level of Belt training). For example, it identifies VSM as being part of the measure phase. In 2008, The American Society for Quality (ASQ) has included the lean methodology understanding as part of the Six Sigma black belt body of knowledge. This is shown in Table III as another example of an attempt to fit the lean tools into DMAIC. To expand on these attempts, Table IV presents a more detailed proposal of how lean tools can fit into DMAIC. This is more detailed than the ones discussed above and is believed to be more balanced, as it attempts to introduce a full package of lean tools, in such a way as to be used simultaneously with Six Sigma tools.

Six Sigma project phase	Applicable lean tool or training topic
Define	Lean; LSS; lean applications; business processes and systems
Measure	Map the current state value stream to identify waste
Analyze	Creating a lean future state value stream map and analyze waste
Improve	Eliminate waste; reduce cycle time; use Kaizen and Kaizen Blitz
Control	Visual controls; total productive maintenance (TPM)

Source: Adapted from The ASQ (2008)

Table III. Lean methodology understanding as part of the Six Sigma black belt body of knowledge

Six Sigma project phase	Applicable lean tool or training topic
Define	Introduce: lean; VSM; and LSS Introduce financial analysis: identify waste; and quantify waste financially Use SIPOC to understand the VOC and prepare for VSM Introduce process baseline performance including VSM metrics; inventory; lead time; cycle time; value-added versus non-value-added activities; and downtime Identify the LSS suitable tools and approach to the selected project: determine if the focus is on product flow or variability
Measure	Measure the baseline performance of the current process Use the lean metrics to measure the baseline Map the current state value stream Identify waste and quantify it financially Use a Kaizen event approach and identify any quick improvement actions
Analyze	Implement the quick hits as they do not require further analysis Analyze the current state VSM. For example: analyze unnecessary steps and ways to minimize waste within and between steps; analyze flow of products and information; analyze lead time, cycle times and rework; and analyze downtime and changeover time Create a lean future state VSM to implement in the next phase
Improve	Optimize and standardize the process; eliminate unnecessary steps or at least minimize waste within it; develop standard operating procedures and best practices; build an improvement implementation action plan Use a Kaizen event to implement improvements. For example: improve time and motion; improve cell design, consider human factors and work balance; implement single piece flow (reduce batching); standardize processes; use Kanban; use 5S approach; use TPM and quick changeover approach; use mistake-proofing techniques; and use visual workplace approach
Control	Design a control plan using the mistake-proofing approach; design and implement corrective actions; design an audit plan; and design visual work place controls Train process owner on using the control plan and monitor continuously

Table IV. Six Sigma project phase and the applicable lean tool or training topic for each phase

The proper selection of lean tools in each phase of DMAIC is critical to success. There have been different attempts by different experts and companies to do this. This work extends the previous works, regarding the integration of these methodologies. It includes new thoughts, which are incorporated in a new manner. The following is a proposed attempt for integrating lean and Six Sigma with a fair amount of detail. The DMAIC phases provide a very effective structure for a process improvement project. After starting the project, it may evolve to use more Six Sigma tools or lean tools or a mix of both. For any of these cases, it can follow the DMAIC phases and the details of each phase of this integrated LSS approach are as follows:

Define

(1) Introduce TQM, Six Sigma, lean, LSS methodologies and tools.

(2) Identify opportunities, evaluate and select the proper project and team.

(3) Draft the project; develop the charter, time-line plan, change management plan, financial case (COPQ and waste) and scope (the charter gets updated as the project progresses).

(4) Understand the customer requirements or the VOC:

- Use the SIPOC diagram to document the high-level process and the critical to quality (CTQ) characteristics; it also helps in preparing for the VSM exercise by understanding the basic flow and who the suppliers and customers are.
- Use the quality function deployment (QFD), matrix lists CTQ, QFD and baseline as part of measure phase).

(5) Identify the LSS suitable tools and approach to the selected project; identify whether the focus is on product flow or variability.

Measure

(6) Start process characterization and assemble the project metrics to establish the baseline performance:

- Build the measure phase data collection plan (especially for baseline data).
- Understand the data and present it graphically using: control charts, run charts, bar charts, pie charts, histograms, box plots, scatter diagrams and Pareto charts, which can also be used in other phases.
- Use descriptive statistics to measure the central location and variability of data.

(7) Measure process capability (use process capability indices, defects per million opportunities or DPMO and process sigma level).

(8) View the current process:

- Map the current state VSM to understand it, identify waste and improve it (use value stream metrics which include inventory, lead time, cycle time, value-added vs non-value-added activities and downtime).
- Draw a process flow chart and document the current process.

(9) Use a Kaizen event approach to implement quick-hits and to conduct brainstorming of potential causes.

(10) Revise and detail the financial analysis including COPQ:
   - Identify and financially quantify cost of variation and defects.
   - Consider the eight wastes (the hidden factory, where unnecessary work of repeated motion, measurements and rework is happening. It is part of COPQ, which is part of the measure phase. So, it makes sense to introduce lean thinking and the concept of waste as part of this phase).

(11) Identify and financially quantify waste (this will not be complete until the VSM exercise is done and it may include soft savings as well).

(12) Use an MSA to validate the reliability of the data (study the variable gage repeatability and reproducibility).

(13) Use a cause and effect diagram to brainstorm potential variables or inputs that affect the process output.

(14) Identify potential process or design failures using failure mode and effect analysis (FMEA).

(15) Select the vital few potential inputs and identify the quick hits that do not require further analysis (also called just-do-it items).

Analyze

(16) Implement the quick hits or quick improvement actions.

(17) Build a data collection plan to analyze which of the potential inputs are critical.

(18) Use graphical tools to investigate the reasons for variation and differences in processes by different factors (e.g. use interval effects plots, multi-vari charts, box plots and other tools).

(19) Develop hypotheses on the sources of variation and strength of relationships (using hypothesis tests, confidence intervals and other statistical tools).

(20) Use correlation, regression and analysis of variance to study how inputs relate to and impact outputs.

(21) Identify a list of the few critical inputs or key process input variables (KPIVs) to pass to the next phase for improvements.

(22) Analyze the current state VSM:
   - Analyze unnecessary steps and ways to minimize waste within and between steps.
   - Analyze flow of products and information.
   - Analyze lead time, cycle times, downtime, changeover time and rework.

(23) Create a future state VSM to implement in next phase: maximize value-added content and eliminate waste.

Improve

(24) Optimize the settings of the critical inputs and improve processes using benchmarking, regression analysis, process simulation, DOE and other graphical tools such as box plots and control charts.

(25) Document the standard operating procedures and best practices including the revised process map and MSA requirements.

(26) Build an improvement implementation action plan to start the implementation of the recognized improvements.

(27) Use a Kaizen event to implement improvements such as:
- Improve time and motion.
- Improve cell design, consider human factors and work balance. Production smoothing by flow distribution and mixing can be used as a lean tool in this phase (Snee, 2005).
- Implement single piece flow and reduce batching.
- Standardize processes and use Kanban.
- Use TPM and quick changeover approach, i.e. single minute exchange of dies.
- Use the 5S approach.
- Use mistake-proofing techniques.
- Use the visual workplace approach.

Control

(28) Validate and update the FMEA, MSA, process capability, sigma level and control charts.

(29) Design a control plan using mistake-proofing approach and re-assign responsibility to process owner:
- Monitor the performance metrics (KPIVs and key process output variables or KPOVs) to ensure they are in control and design visual work place controls.
- Design an audit plan and corrective actions (a good practice in auditing the project after it is done is that the belt should conduct reviews of results with the process owner after three, six and 12 months of the date when the project is handed over to the process owner. Market demands and CTQ are dynamic (Antony, 2004). A review of CTQ can be done as part of the audit, which may trigger new opportunities).

(30) Reconfirm the financial analysis:
- Conduct a cost-benefit analysis.
- Review and approve the analysis by finance.

(31) Hand over responsibilities, train process owner on using the control plan and monitor continuously.

It is recommended to always follow the DMAIC framework when doing any LSS project at any level. It is expected that the VSM will frequently result to be a suitable tool at the start of LSS implementation. However, the nature of the project should be what determines whether a VSM, or any other tool, is the suitable tool to use or not. Generally, it makes sense to have the VSM applied to all areas in the business, as it helps identify other projects and opportunities. Nevertheless, the priority should be given to other tools, if they are more suitable to the project that has been selected.

For example, if the main issue under investigation is product quality related and not delivery related, other tools than the VSM can be more suitable.

7. Conclusion

Six Sigma and lean are very powerful CI methodologies that share common goals and grounds in terms of striving to achieve customer satisfaction. They complement each other and can be integrated to form a superior methodology, i.e. LSS, which overcomes the shortcomings of the individual methodologies. This work extended the previous works regarding these methodologies. It included new thoughts and incorporated them in a new manner.

In this work, a review of the available literature on lean and Six Sigma was presented, followed by a discussion of the benefits of this integration. More specifically, a thorough comparison of lean with Six Sigma was performed. Six Sigma and lean share common grounds in terms of: the origin or development, principles or concepts, objectives or applications, leadership roles, staff roles and features or project management approach. On the other hand, the differences between the two methodologies lie in: the focus, technique, how they are viewed, what they are criticized for, approach (to people/operation, teams, mapping, processes and systems, certification, design and data), scope, identification of gaps, view of inventory and production, practices (DMAIC vs VSM), COPQ vs waste types, COPQ vs waste percentages, definition, execution, analysis vs action, tools, software, rewards, training (cost and material), change leadership and obstacles, project duration, project selection, financial savings, time to see results, link to suppliers, culture, measures, nature of problem level, complexity, shortcomings or desirable characteristics and results. However, even in the dimensions where they are different, there are still lots of similarities, such as in the focus on customer satisfaction.

It was shown that despite the differences, there are many areas where Six Sigma and lean share common grounds and there are many compatible areas where one of them may excel forming an opportunity to complete the other one. Thus, the integration of the two is concluded to be possible and beneficial. In this paper, a list of recommendations was presented, which was later used as part of a guideline for developing the detailed model. This list can also be taken into account when developing further details on how this model should function in relation to other systems in an organization. For example, it is believed that LSS can fit under the umbrella of TQM to form a better methodology.

In sum, a description of the LSS model following the DMAIC structure was presented in an attempt to explain the model in a more detailed and balanced way. It is recommended that all projects follow DMAIC and use the proper LSS tools (such as VSM) in accordance with the problem and circumstances faced. This integration leads to greater quality improvement results. The next stage for research in this area is to conduct practical studies using data and analysis to further verify the effectiveness of this integration.

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