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Lean Six Sigma: yesterday, today and tomorrow

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QUALITY PAPER

Lean Six Sigma: yesterday, today and tomorrow

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Abstract

Purpose – The purpose of this paper is to share the experiences and perspectives of three practitioners from two continents on the subject of Lean Six Sigma (LSS) from both academic and industrial viewpoints. The authors of the paper have each been working on the topic of LSS over the past 15 years and have contributed over 150 journal and conference papers to the topics of lean and Six Sigma.

Design/methodology/approach – The approach is to synthesize the practical experiences and research conducted by three authorities on the topic of LSS. In addition, relevant secondary data have also been used in the sections where and when appropriate.

Findings – The authors initially present the history of LSS emphasizing the importance of integration of the two most effective process excellence methodologies over the past 30 years. The authors also report the current trends of LSS in organizations as well as the emerging future trends. They argue that LSS will continue to grow and evolve across the globe for several years.

Practical implications – The paper is intended to be equally useful to both academics and practitioners who are interested on the topic of LSS. From a pure practical standpoint, the paper provides an overview of the past, present and future trends of LSS as a powerful business strategy and problem-solving methodology for all industrial sectors, irrespective of their size and nature. The documentation of the history and recent developments in LSS should be useful to researchers in academia.

Originality/value – In authors' best knowledge, there are no recent journal articles which cover all the three of these aspects; the past, the present and the future of LSS. This paper presents the above three aspects in a unique manner and addresses the gap between the current state and future directions of LSS.

Keywords Six Sigma, Lean, Continuous improvement, Lean Six Sigma, Operational excellence, Process excellence

Paper type Research paper

Introduction

Quality improvement (QI) or continuous improvement (CI) has become an important business strategy for many organizations today across the globe, despite of their nature and size. This includes manufacturers, financial service organizations, healthcare services, public sector organizations and most recently third sector organizations. Development of an effective QI or CI strategy is a key factor for long-term success of modern organizations. Over the last decade, Lean Six Sigma (LSS) has become one of the most popular and proven business process improvement methodologies organizations have ever witnessed in the past.

The concept of lean thinking (LT) developed from Toyota Production System (TPS) involves determining the value of any process by distinguishing valued-added activities or steps from non-value-added activities or steps and eliminating waste so that every step adds value to the process. Lean focuses on efficiency, aiming to produce products and services at the lowest cost and as fast as possible (Antony, 2011). The commitment to LT must start at the top management level and should be cascaded down to various levels across the

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organization to improve flow and efficiency of processes. Lean strategy brings a set of proven tools and techniques to reduce lead times, inventories, set up times, equipment downtime, scrap, rework and other wastes of the hidden factory (Sharma, 2003).

Six Sigma was developed at Motorola by an Engineer Bill Smith in the middle of 1980s. Six Sigma is a business improvement approach that seeks to find and eliminate causes of defects or mistakes in business processes by focusing on process outputs which are critical in the eyes of customers. Six Sigma principles can be used to shift the process average, help create robust products and processes and reduce excessive variation in processes which lead to poor quality (Shah *et al.*, 2008). The statistically based problem-solving methodology of Six Sigma delivers data to drive solutions, delivering dramatic bottom line results (Snee and Hoerl, 2007).

The term LSS was first introduced into literature around 2000 and LSS teaching was established in 2003 as part of the evolution of Six Sigma (Timans *et al.*, 2012). Since that time, there has been a noticeable increase in LSS popularity and deployment in the industrial world (Shahin and Alinavaz, 2008), especially in large organizations in the west such as Motorola, Honeywell, General Electric and many others (Timans *et al.*, 2012; Laureani and Antony, 2012) and in some small- and medium-sized enterprises (SMEs) (Timans *et al.*, 2014). LSS has been defined by Snee (2010) as "a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom line results." LSS methodology aims to improve capability in an organization, reduce production costs (Lee and Wei, 2009; Chen and Lyu, 2009) and maximize the value for shareholders by improving quality (Laureani and Antony, 2012).

This paper addresses three aspects of LSS; the yesterday, then the today and finally the tomorrow. The yesterday aspects of LSS will be presenting the background to LSS, history of LSS and also the rationale behind the integration of lean and Six Sigma. The today aspects will be looking into a number of themes including LSS for manufacturing, LSS for services, LSS for public sector, LSS for SMEs, LSS and innovation and standards for LSS certification. The tomorrow aspects will be looking into the future trends of LSS, the importance of developing a holistic approach of process excellence (PE) in organizations, the synergy between Big Data and LSS for problem solving, sustainability of PE initiative such as LSS and the use of LSS for dealing with human variation.

LSS yesterday – the history of LSS

The background to LSS

As with most major innovations, LSS did not form out of a vacuum, but was built upon previous approaches and methods to improve quality and business results. In fact, Six Sigma and lean enterprise had unique histories and development cycles until "married" in the early parts of the twenty-first century to create what we call today LSS. Six Sigma was built upon a foundation of such approaches as statistical process control (SPC), the Deming philosophy and total quality management (TQM), to name just a few.

We argue that TQM, as practiced in the 1980s was perhaps the closest thing to Six Sigma that people had seen previously (Feigenbaum, 1983). At its core, TQM attempted to get everyone in the organization actively involved in QI projects, using a variety of methods, including SPC, quality function deployment, experimental design, as well as many others. Sounds a lot like Six Sigma, does not it!

There were some noteworthy limitations of TQM that, in our opinion, led to it not achieving the tangible results that management expected to see (Snee and Hoerl, 2005). Chief among these was the belief that projects should focus primarily on customer satisfaction and culture change, as opposed to bottom line improvements. We are, of course, all in favor of satisfying customers and changing the culture. However, in a western context, at some point management needs to see tangible improvements to the bottom line – either in cost savings or increased business, or they will lose interest and move on to the next fad or bandwagon.

A second limitation was that there was no formal methodology associated with TQM. It incorporated numerous tools, as noted above, but no overall strategy or approach to tackle problems. Therefore, an approach had to be developed for each new project, which significantly limited progress.

A third key limitation was that TQM implementations often lacked supporting infrastructure, such as inclusion in budgets, dedicated resources, formal project selection systems, formal reporting systems and so on. A fourth limitation was that measurements and metrics were often not emphasized, making TQM more of a cultural initiative rather than a business improvement initiative. Unfortunately, without tangible metrics it is hard to demonstrate and track impact. Largely due to these limitations, in our view, TQM was not viewed by western management as successful, resulting in general disillusionment (Snee and Hoerl, 2003).

The launch of Six Sigma

Within this context, Motorola was facing extreme pressures from overseas competition, particularly Japan. While it is impossible to set a definitive date for the beginning of Six Sigma, around 1987 Bill Smith and others began improvement projects that in many ways looked similar to TQM projects (Harry and Schroeder, 2000). Eventually, Mikel Harry and others helped Smith formulate this approach into an overall business initiative aimed at protecting Motorola's pager business (Eckes, 2001; Pande *et al.*, 2000). They named the initiative "Six Sigma" based on the desire to reduce variation to the extent that specification limits for key process metrics were six standard deviations away from target (Harry and Schroeder, 2000).

Importantly, Six Sigma provided an overall "roadmap" within Motorola, or problem-solving process, known as MAIC, which stood for measure, analyze, improve, control. MAIC effectively linked and integrated the individual tools. Therefore, employees could be trained in this one approach that was generic enough to be applied to a wide variety of problems, eliminating the need to reinvent the wheel with each new project. In addition, Six Sigma received clear management support, including supporting infrastructure, such as line items in budgets, resources, project selection systems and so on (Snee and Hoerl, 2005).

Motorola achieved tangible results, and other organizations began to take notice. Honeywell and AlliedSignal, other organizations in similar markets to Motorola, launched Six Sigma initiatives around 1990. These also met with success. However, it was when GE CEO Jack Welch loudly proclaimed that GE was jumping into the Six Sigma game in late 1995 that the initiative moved off the back pages of the business section to the front page of the newspaper.

Welch (2001) told Wall Street analysts that Six Sigma would be the biggest initiative ever launched by GE, and that it would be his personal number one priority for the next five years. Even before results started to pour in, GE stock began to rise sharply, and many other companies started looking more closely at Six Sigma.

GE also played a very significant role in the development of Six Sigma as a methodology. After some projects stalled because there was a lack of clarity on the specific problem being addressed, and on the overall objectives, GE decided to add a "Define" step at the beginning of the MAIC process, created the process we now know as DMAIC (Hoerl, 2001). The define step became critical – a make or break step that often determined long-term success of the project. The need for careful problem definition is well-understood among those researching problem solving in general.

Because GE had a large financial services business – GE capital, the company obviously wanted to expand the tangible benefits obtained in manufacturing to finance, and other non-manufacturing operations. It therefore created a "Commercial Quality" initiative, and pioneered broader application of Six Sigma into finance, healthcare, sales and many other application areas (Hoerl, 2001). The intent, based on direction from CEO Jack Welch, was to get every employee of GE "in the game" of making tangible improvements.

Based in part on GE capital's success, other financial institutions began Six Sigma initiatives. One of the most successful has been by Bank of America, which was publishing savings in the billions of dollars annually. Similarly, Commonwealth Health Corporation launched the first major Six Sigma deployment in healthcare in the late 1990s, and produced millions of dollars of savings in the radiology department alone within a year (Snee and Hoerl, 2005).

In the late 1990s and early 2000s, a large number of organizations, in diverse industries, launched Six Sigma initiatives, including DuPont, Dow Chemical, 3M, Ford and American Express, to name just a few. The US military began major investments in Six Sigma at this time as well. Overseas, companies in Europe and Asia began to implement Six Sigma to varying degrees, particularly Korean companies such as Samsung (Snee and Hoerl, 2003).

By the early 2000s, Honeywell had already made progress into applying Six Sigma to design projects, where there was no existing process to study and improve (Creveling *et al.*, 2003). GE built upon this development, and created the define-measure-analyze-design-verify approach to Design for Six Sigma (DFSS). By this time, Six Sigma was producing massive bottom line impact in manufacturing, design, finance, healthcare and many other areas. However, there were some things missing that would enable it to have even greater impact. We return to this point shortly.

A brief history of lean

Lean has had somewhat of a tangential development history to Six Sigma. Much of what we call Lean enterprise today is based on the TPS (Womack *et al.*, 2007). Of course, the TPS has roots that go back to Henry Ford's development of the assembly line, and Frederick Taylor's work (Womack and Jones, 2003). This approach to manufacturing cars, which emphasized removal of all types of waste, including non-value-added human motion, began taking shape at Toyota in the 1930s, and has progressed ever since. Krafcik (1988) is generally credited with the first use of the term "lean manufacturing."

In our view, there is some confusion between lean and the TPS, in that some authors use the term lean to refer to any business practice utilized by Toyota, while others use lean to refer to a specific set of principles and tools (George, 2002). For clarity, we will refer to lean enterprise as the set of principles and accompanying tools outlined in George (2002), MacInnes (2002), and other sources that see lean as based on TPS, but having a unique identity from Toyota.

While Six Sigma focused on collecting data in order to apply statistical methods to solve baffling problems, lean was generally applied in a more knowledge-based approach, by applying time-tested principles, such as reducing inventories, pull vs push production systems, line of sight, continuous vs batch processing, cell manufacturing and so on, to reduce waste and enhance productivity (Snee and Hoerl, 2007). That is, while knowledge and data were needed by both methodologies, one can be reasonably accurate in generalizing that Six Sigma was more data oriented and lean was more oriented on applying proven principles based on knowledge and experience.

As noted above, lean began with a manufacturing emphasis, and was in fact referred to as lean manufacturing for many years (George, 2002). Gradually, organizations learned that the same principles of push vs pull systems, having line of sight (electronically), and so on, also applied to non-manufacturing processes (George, 2003). All processes have waste, and sound principles can be applied outside of manufacturing to reduce waste, and improve productivity. For example, the principle of line of sight – being able to physically see the production line, can be applied to financial transactions, in that those working in the financial process should have process transparency, in order to be able to "see" the process in operation, at least electronically. Workflow-based IT systems are one example of providing line of sight to financial systems.

An obviously limitation of lean was that when problems were perplexing, and not directly related to any of the lean principles, there was no obvious way to address it using lean thinking. For example, suppose a chemical process was producing a chemical at the wrong molecular weight distribution, for unknown reasons, leading to high levels of waste and rework. Everyone knows that we need to eliminate the waste and rework, but how? By what method should one investigate the chemical engineering involved in order to figure out how to produce the desired molecular weight distribution? For such problems, a problem-solving approach making heavy use of data, statistical methods – including experimental design, would logically be required.

The marriage of Six Sigma and lean

Because both Six Sigma and lean had produced tremendous results, but had limitations, some type of integration of the two was appealing, and made intuitive sense. Books and seminars on the topic of LSS began to appear in the early 2000s, such as George (2002). As noted previously, lean is not well suited to resolving complex problems that require intensive data analysis, and advanced statistical methods.

Conversely, those implementing Six Sigma found that not every problem needed several months of data collection to resolve. Do we really need to collect data for three months in order to repave a parking lot that has potholes? Quality professionals found that lean principles could be broadly and effectively applied with minimal data collection, and achieve immediate benefits. Then, for more complex problems requiring intense data analysis, Six Sigma could be utilized.

There have been many opinions as to how to best integrate Six Sigma and lean (Snee and Hoerl, 2007), and we feel this is still a work in progress. However, contrary to some opinions, we feel that the nature of the response variable (quality vs waste or time) is not the jugular issue. Neither are the specific tools to be applied, since both Six Sigma and lean have essentially integrated existing tools in novel ways to achieve breakthrough results. That is, neither Six Sigma nor lean has invented tools *per se*, and hence neither has a copyright on any specific tool.

In our view, the key questions to ask when considering a Six Sigma vs lean approach are:

(1) Is the solution known or unknown?

(2) Is the root cause of the problem believed to be in a value-adding step in the process, or in the linkages between value-adding steps?

The first question attempts to probe whether known principles can be immediately applied with extensive data collection, or if a longer-term project involving cycles of data collection and analysis will be required. For example, if the problem is that our inventory levels are too high, the solution is known – reduce the inventories! Exactly how to do so may be complicated, but what must be done is known (Snee and Hoerl, 2007).

We have found that in many lean applications, what must be done is known; we just need a method and tools to implement the known solution. This is because lean is primarily a set of known principles, as opposed to data analysis techniques.

Conversely, in the molecular weight issue noted previously, the solution is completely unknown. We do not know how to obtain the desired distribution. Therefore, it is likely that extensive data collection, analysis and designed experiments will be required to resolve the issue. The need for careful diagnosis of the problem emphasizes the importance of the define stage in problem solving.

The second question points to the fact that the principles of lean are focused on the flow of information and material through the process. Therefore, if the root cause of the problem is a flow issue – in the linkages between value-adding steps, lean is likely to work well.

Conversely, if the root cause of the problem is in a value-adding step, such as a chemical reactor, then understanding of the cause and effect relationships is critical to improvement. Developing such understanding usually requires extensive data collection and analysis, including design experiments. Six Sigma is more likely to succeed for such problems. Figure 1, from Snee and Hoerl (2007), illustrates this point.

The key point is that organizations need to avoid having "favorite" methods that they apply to all problems, even if the method is not suited for that particular problem. Integrating Six Sigma and lean into a broader approach called LSS has enabled many organizations, including GE and many of those mentioned previously, to solve more problems quicker, and enhance the bottom line faster. It can be considered state of the art in improvement at the time of this writing.

Many problems are best addressed with a blend of Six Sigma tools and approaches, as opposed to simply picking one or the other (George, 2002; Snee and Hoer, 2007). Taking this concept one step further, we consider a more holistic approach that integrates an array of potential problem-solving approaches, carefully matching the strategy of attack to the unique aspects of the specific problem at hand. We discuss this approach, which we refer to as holistic improvement, in more detail shortly.

LSS today – the current state of LSS

This section presents the today aspects of LSS which includes LSS for manufacturing, LSS for services in particular financial services, the link between LSS and innovation, LSS and its role in SMEs, standards for LSS certification and the current burning issues around the certification process.

LSS for manufacturing

A systematic literature review (Okoli and Schabram, 2010) carried out between 2000 and 2014 has shown that no research articles related to LSS to be found before 2003 (Albliwi *et al.*, 2014). This result was supported by many researchers such as Wang *et al.* (2012) who have reported that there were no LSS publications to be found before the year 2003. There has been a significant growth in the number of publications since 2003 with the highest number of publications observed in 2012. Nearly 50 percent of the total publications in leading academic journals were from the USA, followed by the UK, Australia, the Netherlands, India, Taiwan, Sweden, China and so on. The authors would like to report the top five benefits, motivation factors for the implementation of LSS and the top five limitations of LSS relevant to manufacturing companies based on the current literature.

A total of over 40 case studies have been analyzed and more than 15 benefits have been identified. The following are the top five benefits which have been derived from the

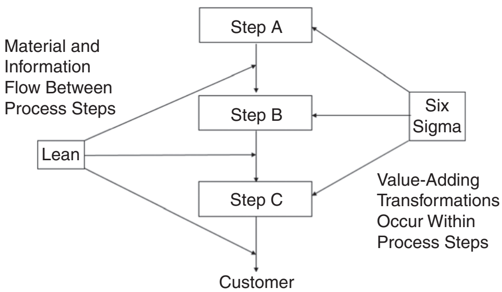

Figure 1.
Process view of lean Six Sigma

published literature with regard to LSS projects applied to large manufacturing companies:

(1) increased financial savings to the bottom line;

(2) increased customer satisfaction;

(3) reduced costs of poor quality (scrap, rework, failures, defects, etc.);

(4) reduced cycle time and lead time; and

(5) reduced inventory.

The top five motivation factors for the implementation of LSS in manufacturing companies include (Albliwi *et al.*, 2015):

(1) stay in competition within the global marketplace;

(2) increase customer satisfaction;

(3) improve product quality and manufacturing operations;

(4) enhance the bottom line savings and top-line growth; and

(5) reduce cost of poor quality.

The top five limitations of LSS in the manufacturing industry include:

(1) absence of a sustainability framework for LSS;

(2) lack of standardized and robust LSS curricula;

(3) no globally accepted standards for certification;

(4) lack of a roadmap to be followed; and

(5) limited number of published case studies on LSS (integrated approach).

LSS for services (financial services)

In services organizations, lean comes in as a methodology to reduce waste (in terms of time) and to allow the process to become more efficient. It requires the examination of the process from the client's perspective, in order to eliminate waste and inefficiency. Six Sigma, however, focuses on refining the process, reducing the variability, to obtain the same result at least 99.9997 percent of the time (Delgado *et al.*, 2010). There are only a handful of papers published on LSS for financial services in the literature. Lieber and Moormann (2004) studied the application of Six Sigma in the top 100 German banks and it was surprising to observe that merely 2 percent of the respondents stated to use Six Sigma. This shows that the application of Six Sigma in the financial services was in its early stages in the early 2000s. However, the study carried out by Chakrabarty and Tan (2007) showed that Six Sigma is increasingly applied in almost all service industries, including financial services. Stoner and Werner (1994) have published a case study from Motorola Finance reporting the application of Six Sigma within an internal auditing process. The results of this study include: cycle time improved; internal and external errors reduced and external audit costs reduced by $1.8 million per annum. The cycle time for monthly closing of the books has been reduced from more than nine days to merely two days and this has resulted in savings of more than $30 million to the business.

Many authors argue that – apart from considerable improvement in bottom line results – increased customer satisfaction, increased employee morale, improved cross-functional teamwork, improved and consistent service levels and increased awareness of problem-solving tools and techniques are the most striking benefits of Six Sigma in service organizations (Chakrabarty and Tan, 2007; Antony, 2004; Sehwall and DeYong, 2003).

Moreover, another recent study executed by Heckl *et al.* (2010) has showed that the applications of Six Sigma in financial services are increasing exponentially. The study has also revealed that British and German banks and insurers are applying Six Sigma intensively compared to Swiss and Austrian banks and insurers. In their study, the authors also found that approximately a quarter of the respondents stated that Six Sigma cannot be used as a catalyst for changing the culture of the financial services. However, about 85 percent of the respondents felt that Six Sigma can be very helpful for optimizing processes. The prime reason for applying Six Sigma is the pressure to reduce operational costs. Furthermore, the exploitation of market opportunities and dissatisfied customers are top motives for its application.

The authors will be looking into some of the key ingredients for making LSS implementation successful in financial services as well some of the fundamental challenges to be encountered in the adoption and deployment of LSS within the financial services sector.

Key ingredients for successful introduction and development of LSS

Brewer and Eighme (2005) have provided the following ingredients that are necessary for the successful development of LSS initiative in any financial services industry:

- Committed leadership: this includes clear direction on overall strategic deployment of LSS, commitment of time, resources (people), etc. for the deployment, clear communication to everyone showing the need for the initiative, insistence on tangible bottom line impact, etc.
- Select the top talent people: assigning top talented people to LSS initiatives justifies the commitment of leadership for the initiative.
- Supporting infrastructure: this should include the use of belt system (Black Belts, Green Belts and Yellow Belts), the active involvement of LSS deployment champions, project sponsors and a management system to sustain the initiative.
- Project selection, prioritization, reporting and tracking system: projects must be doable in three to six months in order to maintain the momentum of the initiative in the first couple of years. Senior management team (SMT) in many organizations loses their interests in projects running longer than six months. There should be a regular project reviews in place with the champion, especially after each stage of the methodology.
- Culture change: if the need for cultural change is not addressed properly at the outset of the initiative, the initiative will eventually fade away and die at the end.

Fundamental challenges in the deployment of LSS within financial services

The authors would like to highlight the following fundamental challenges in the application of LSS methodology in the context of financial services:

- Access to sufficient data: it has been widely reported that gathering and quantifying data from human-centered service processes during the execution of projects is a particular problem service industries in general have to cope with. Moreover, processes are implemented on heterogeneous IT systems can make the data gathering process even more difficult in financial services.
- Insufficient personnel to carry out projects: lack of human resources in terms of both quality and quantity in the execution of LSS projects. In many cases, it is a big challenge to carry out projects and manage the day-to-day roles and responsibilities in the workplace.

- Organizational culture and mindset of workforce: LSS can only be successful if accompanied by changes in an organization's culture, structure and processes.
- Project selection: selecting and executing the first few projects in any organization is very critical for gaining the attention of SMT.
- Know-how of tools and techniques: one of the fundamental challenges in the execution of LSS projects in many service organizations is about when and where to use the tools and techniques.
- LSS roadmap: although some organizations have developed a roadmap internally, there is no standard framework or robust roadmap on LSS applied to financial services developed and published in the existing literature.
- Service process parameters and relevant CTQs: financial services often have problems in identifying relevant process parameters and measurable relevant CTQs. One of the challenges is to have a reliable and sound performance measurement and management system in place.
- Process ownership: once the projects are completed, related to process improvement, it is essential to create process owners who can take care of the improved process and sustain the improved performance. This has been an immense challenge for many service organizations, in particular, financial services.
- Communication: a major issue for the acceptance of LSS in the service organizations in general is communication. In aiming toward the establishment of a sustainable LSS initiative, every employee should be informed about the initiative and sense of urgency must be established by the SMT.

LSS for SMEs

According to Timans *et al.* (2014), only a limited number of studies have been published on the implementation of LSS in SMEs. Kumar *et al.* (2011) has presented a framework showing a roadmap to manage and sustain the change using LSS. McAdam *et al.* (2014) has critically analyzed the development of the Six Sigma theory and practice within SMEs using a multiple-case study approach. Their research make a contribution to the body of knowledge on how smaller companies acquire, assimilate and transform or use Six Sigma and LSS business improvement knowledge and approaches.

Kumar and Antony (2009) have carried a multi-case study analysis within four UK SMEs; two were using Six Sigma and the other two were non-Six Sigma manufacturing SMEs. The results of the study showed that Six Sigma SMEs realized a significant improvement in the performance of operational metrics (scrap rate, throughput yield, cycle time, on-time delivery, etc.) as well as strategic metrics (sales, profit margin, customer satisfaction, etc.) compared to non-Six Sigma manufacturing SMEs.

Prasanna and Vinodh (2013) have provided with a comprehensive literature review on LSS in SMEs. The authors have reported the current status of lean, Six Sigma and LSS in SMEs. Moreover, a hypothetical case study from an Indian context has been presented to show the use of integrated approach with the appropriate use of relevant tools from both disciplines.

Thomas *et al.* (2016) have demonstrated the use of LSS framework in a UK aerospace manufacturing environment. Significant improvements in business performance (e.g.: build time reduction, on-time in full delivery, non-value added time, etc.) have been observed as a result of the application of LSS methodology. An estimated financial savings of £2 m are reported from this case study.

Dora and Gellynck (2015) have reported a case study on the use of LSS methodology in a food processing SME environment. The authors have utilized tools from both lean and

Six Sigma tool boxes and the case study has shown a unique application of LSS to reduce overfill and rework to enhance bottom line results. The estimated savings generated from this case study is reported to be over £250 k.

Thomas *et al.* (2014) investigated the migratory nature of LSS implementation and adoption in UK-based manufacturing SMEs. The paper provides research information into the characterization, compatibility and innovativeness of SMEs toward LSS implementation and goes on to provide an implementation classification system and characterizes the dynamical nature of LSS development in manufacturing SMEs.

Achanga *et al.* (2006) have conducted an empirical study which involved the collection of data pertaining to the successful implementation of lean manufacturing paradigm in SME environments. They found that for the successful implementation of lean manufacturing paradigm, the SMEs are required to progress themselves by exhibiting the following characteristics: stronger and committed leadership and management commitment, stronger financial capabilities, enhanced skills and expertise of the personnel and conducive organizational culture. LSS can act as a catalyst for changing SMEs in the quest for business excellence by mobilizing their intellectual capital, provided there is total commitment (Brue, 2006).

Spanyi and Wurtzel (2003) have identified the following elements for the successful launch of a Six Sigma initiative in an SME environment:

- visible management commitment;
- clear definition of customer requirements;
- shared understanding of core business processes and their critical characteristics;
- clear definition of customer requirements;
- rewarding and recognizing the team members;
- communicating the success and failure stories; and
- selecting the right people and the right projects.

The following are some of the key challenges in the implementation of LSS in an SME environment (Antony *et al.*, 2005):

- lack of resources (financial, human, time, etc.);
- lack of leadership;
- poor training/coaching;
- internal resistance (culture of the organization);
- lack of knowledge about LSS methodology;
- poor project selection due to lack of understanding of LSS project selection criteria; and
- lack of LSS champions in the business, etc.

LSS for public sector organizations

Although lean has been widely used by many public sector organizations in Europe, the use of Six Sigma and LSS are in their early stages. The challenge for many public sector organizations today is to reduce spending, while retaining or even improving the efficiency and effectiveness of service delivery. Using LT, we need to reduce waste and maximize the value-added activities for customers and by using Six Sigma we need to deliver consistent services by reducing process variation. Some of the benefits of utilizing LSS in public sector organizations include:

- Costs associated with fire-fighting and misdirected problem-solving efforts with no structured or disciplined methodology could be significantly reduced.
- Increased understanding of the VOC and the associated CTQs which will have the greatest impact on customer satisfaction.
- Reduced number of non-value-added operations through systematic elimination, leading to faster delivery of service, faster lead time, faster cycle time to process critical performance characteristics to customers and stakeholders, etc.
- Transformation of organizational culture from being reactive to proactive thinking/mindset.
- Many managers lack statistical knowledge and the ability to apply statistics to problem solving. LSS provides a fundamental framework for managers to use practical and proven applied statistical tools and techniques for problem solving in public sector organizations.
- Greater responsiveness and flexibility to meet customer needs.

Some of the fundamental challenges in the deployment of LSS in the public sector organizations (for instance, higher education institutions (HEIs)) include (Antony, 2015):

- Uncompromising management commitment and buy-in from the outset of the LSS initiative and without their support and commitment the effort will be absolutely futile.
- The strategy of achieving leanness is not clear to many senior executives in the university sector due to lack of understanding of the benefits of lean and Six Sigma and how to get started on the journey.
- Silo mentality across the departments and faculties (poor communication across the university).
- Process thinking is not at all prevalent in many HEIs – everything is treated as a task or procedure but not processes!!
- LSS initiative should not be viewed as something quick-fix as such attempts will be doomed to fail and eventually will be labelled as another passing management fad. If LSS is seen as a means of quickly cutting costs to meet budget deficits, HEIs will fail to achieve the real benefits.
- The difficulty in understanding the concept of customers and their voices in HEIs is a big challenge.

Antony *et al.* (2016) present the fundamental challenges in the use of LSS across the UK public sector organizations. The authors also present a number of simple cases taken from three to four different public sector organizations showing the power of lean Six sigma methodology and the associated tools in the context of public sector.

LSS and innovation

Xerox has seen impressive results by pairing its LSS initiatives and innovation teams together to drive product development. Recently, the use of LSS techniques during an innovation project resulted in millions of dollars in total savings and nearly 50 percent return on investment for Xerox (Hildebrand, 2010). As Bisgaard (2008) explains, innovation can be either incremental innovation – making modest enhancements to an existing product or service, or radical, "disruptive" innovation – delivering something totally new to the marketplace. Federal Express, when it introduced overnight mail delivery years ago, was also clearly innovative in a radical way, as no other overnight mail delivery service existed at the time, and many thought such a service would be impossible to implement (Hoerl and Gardner, 2010).

Considerable creativity is needed to think through how to approach each phase of DMAIC, to select the specific tools, and how to interpret the statistical results. LSS is specifically designed to solve problems with unknown solutions. How can someone solve an unsolved problem without using creativity? (Hoerl and Gardner, 2010). While LSS can certainly identify opportunities for incremental innovation, it is not designed to develop the best ideas for radically new products and services, that is, it is not a good process for disruptive innovation.

Antony *et al.* (2014) have carried an exploratory study in ten UK-based companies to explore the relationship between LSS and product/process/service innovation. A multiple-case study design was employed across manufacturing and service companies in the UK of varied size. The companies participated in the study have been involved in LSS implementation for a minimum of three years. The findings of the study have clearly indicated that companies engaging with LSS initiatives experience a positive effect of LSS on incremental innovation and innovation capability.

The study has also looked at the perceived enablers and hinders of innovation in LSS organizations. The perceived enablers include: senior management openness, recognition of the best ideas, a communication system that allows the free-flow of ideas, top management attention and their support, culture of the organization, a learning environment, and so on. The perceived hinders include: organizations with no learning culture, silo mentality, poor or weak leadership that does not support innovation, poor communication, etc.

In addition, the findings from another research carried out in Japan showed that Six Sigma can potentially be used as an innovation tool for leveraging organizational performance (Azis and Osada, 2010). According to these authors, Six Sigma has defined two types of projects which are DMAIC projects for providing corrective action to existing products, services, and business processes and DFSS project for creating new value which provides more radical approach. The authors would argue that the reverse is also true. DFSS has been used to create the product which rarely works as desired when created. Several DMAIC improvement projects may be needed to get the process and product performing as desired.

Standards for LSS certification

LSS has no globally accepted standard for certification: the proliferation of schools, organizations and training providers that now offer some level of certification has led to a wide variation in assessment criteria, leaving many hiring managers, recruiters and CI leaders sceptical of external certifications. Some certifications currently existing on the market do not require to prove some technical competence or to show project work: you can indeed pay to attend a small course and get a certificate, without ever actually doing a project (Laureani and Antony, 2011). In authors' opinion, American Society for Quality Certifications represent a third party and have gained acceptance for MBB as well as BB and GB.

The actual set of tools and theories in the background of LSS, which ultimately stems from the quality management and quality engineering gurus like Deming (1982), Juran (1998), Crosby (1979, 1995), Ishikawa (1990), Feigenbaum (1991) and Taguchi (1987) are the same across industries, hence a common body of knowledge. The differences in application of the principles should be reflected in the body of experience and the type of projects used for certification. As in any other discipline, the evolution of the field, and the emphasis on application of the tools is such that only with constant practice can a certified practitioner retain mastery of the tools: as a result, it is advisable to require practitioners to either re-certify or remain involved in professional development activities to retain certification (Laureani and Antony, 2011).

Future of LSS … getting better all the time

Much has changed and much has been accomplished in the world since Six Sigma was introduced by Motorola in 1987. Many organizations around the globe, large and small, have used first Six Sigma and now LSS to become more successful: quality has been improved, delivery times have been reduced, waste has been decreased, and customer satisfaction has been enhanced. A critically important byproduct of this work has been the saving of billions of dollars around the world. LSS has benefitted organizations of all types, including: manufacturing, service, healthcare, government, non-profits and education (McKeon *et al.*, 2010). The expansion of the LSS methodology and application of the approach to improvement will continue as new needs and opportunities are encountered.

Emerging trends

The future of LSS depends on the improvement needs of the organizations involved. The continuing and emerging trends creating these needs and opportunities include:

- globalization and its associated competitive pressures;
- customers becoming more assertive and demanding improved quality, for example, utilizing social media to give immediate and very public feedback on poor performance;
- capability and use of information technology expanding exponentially;
- the Big Data trend emerging as an important byproduct of growing IT capabilities and availability;
- organizations having improvement needs related to large, complex, unstructured problems that cannot be resolved in a single LSS project or even a few such projects; and
- integration of LSS into educational systems.

These trends create the need for better strategies for attacking improvement opportunities. The LSS methodology will also have to be improved to successfully deal with these opportunities.

Needed improvement: advanced and better methods

There are specific advances that can help us continue and accelerate progress made to date, in order to address emerging challenges:

- greater use of strategic thinking;
- enhancing organizational improvement by focusing on holistic improvement;
- identifying and solving mission critical problems using statistical engineering;
- utilizing Big Data to solve problems that were previously thought to be beyond solution;
- sustaining improvement initiatives and results; and
- dealing with human variation.

Let us take a look at each of these advances in some detail. Along the way we will see the need for greater use of strategic thinking, using the fundamentals and thinking about problem solving and organizational impact in new ways.

Greater use of strategic thinking

The limited use of strategic thinking in guiding improvement initiatives has been a problem for a number of years, and has restricted the impact of improvement in general and of LSS in particular. What improvement initiatives we pursue; what projects we select, how we sustain the improvements, etc. are all strategic issues that can benefit from more strategic thought.

Strategic thinking is about looking at the big picture, and determining an overall strategy or approach that will enable us to win; to be successful. A lot of miscellaneous successful projects may not be as impactful as a few, carefully chosen, strategic projects. Strategic thinking is about planning. As Dwight Eisenhower pointed out many years ago, "plans are nothing, planning is everything." Strategic thinking is particularly important when we think about the issues and needs noted above; all of which will have to be dealt with as LSS and other improvement approaches are used in the future.

Holistic improvement strategy and methodology

Holistic improvement views an organization as a system which can be optimized (Snee and Hoerl, 2007; Snee, 2008, 2009). A holistic improvement system can successfully create and sustain significant improvements of any type, in any culture for any type of organization.

Parsing this definition, we find "create and sustain" referring to infrastructure – management systems and resources, CI culture, leadership development and related issues. Here "significant improvements" refer to improving performance as measured quality, cost, delivery, and customer satisfaction in a way that improves the bottom line. "Any type of improvement" refers to improving any measure of performance including flow, variation, optimization, design, improvement and control. "Any culture" refers to any country around the globe and any function within an organization. "Any organization" refers to manufacturing, service, public sector, third sector, etc.

This is a tall order. Clearly we cannot work on all improvement opportunities at once. A strategy is needed to determine priorities: which needs and opportunities are worked in what order, what resources will be utilized and what time frames will be targeted. Strategic thinking is critical to successfully dealing with the holistic nature of the system.

The holistic improvement methodology integrates lean principles with LSS methods and other approaches (e.g. workout, TRIZ, and debottlenecking) that are used as the problem at hand requires. The nature of the problem should guide identification of the approach, rather than assuming that one methodology is ideal for all problems (Hoerl and Snee, 2013). As the old saying goes, "if all you have is a hammer, every problem looks like a nail."

Project identification and selection becomes a critical step, for in this step, the approach to be used to solve the problem becomes apparent. The organization's improvement system must be robust enough to handle any problem the organization encounters in the course of its improvement work. Integration of multiple methodologies is clearly required. Again strategic thinking is required.

Mission critical projects

LSS as currently practiced in many, many areas tends to miss the large, so called "mission critical" problems that face the organization. These problems typically take a large amount of time and effort to identify and solve because they show up as large, complex and unstructured (Hoerl and Snee, 2010, 2012). They are too big to be solved by one LSS project.

This is exactly the type of problem statistical engineering was designed to handle. A special issue of *Quality Engineering* is devoted to the methodology providing descriptions on the methodology, critical assessment and case studies (Anderson-Cook and Lu, 2012). Some examples of large, complex unstructured problems include development of a corporation's product quality management system a fill weight targeting system for a corporation's hundreds of products (Brenneman and Joner, 2012) and NASA's system for planetary entry, decent and landing (Commo and Parker, 2012).

Statistical engineering's five building blocks for such problems are: problem identification, creation of structure, understanding the context of the problem, development of an overall strategy, and creation of tactics. Large complex unstructured problems typically require several projects to solve, which is a result of the strategy and tactics building blocks. LSS concepts, methods and tools have a role to play in the last two building blocks.

Taking advantage of big data

Data mining has been in vogue for the last 15-20 years. Around 2005 the trend picked up steam with advent of the "Big Data" which was and will continue to be fueled by the ubiquitous availability of the internet and IT hardware and software. We are now talking about terabytes and petabytes of data, and we now have the software that can help us "tame" Big Data. The Big Data focus, as with all new developments, is a good news – bad news situation.

The Big Data revolution is breathing new life into lean principles and Six Sigma standards. In effect, it provides back-door entry into a data-rich realm of reasoning that can unlock infinite efficiencies and savings when approached in the right way. Big Data offers the opportunity for professionals to solve problems previously thought to be unsolvable. While much progress has been made in medical research and internet marketing, one area overlooked to date is the use of Big Data in the design and improvement of products, services and process quality. Customer surveys can help us better understand customer needs and experiences. The collection of manufacturing data and integrating it with customer data can help improve products and processes.

The bad news is that most data used in data mining and Big Data studies are what are called "observational data," in that they are passively collected, rather than produced by carefully designed and randomized experiments. Such data require a close assessment of the data pedigree as typically no study design is used to assure that good data and the right data needed to solve the problem are collected (Snee and Hoerl, 2012). These data often have many limitations which need to be taken into account (Hoerl and Snee, 2012).

On the other hand, many have adopted a philosophy of "Big Data + Fancy Algorithms = Great Results." If things were only so easy! This view ignores what has been learned over the years regarding fundamentals of data analysis:

- Problem context: a proper understanding of the problem context enhances the probability that the improvement project will be successful.
- Sequential nature of problem solving: studies are rarely completed with a single data set, but typically require the sequential analysis of several data sets over time.
- Strategic thinking: is needed to identify a strategy for how the project will be executed and how the data analysis will proceed.
- Data pedigree: must be assessed to determine the value of the data for solving the problem, quality of the data and how the data should be analyzed.
- Subject matter knowledge: should be used to help define the problem, assess the data pedigree, guide analysis and interpret the results.

These fundamentals are all part of the statistical engineering philosophy and methodology. Indeed Big Data is frequently associated with a large, complex, unstructured problem. As a result, statistical engineering provides the concepts, methods and tools to deal with Big Data problems (Hoerl *et al.*, 2014; Snee *et al.*, 2014).

Sustainability

Sustainability has a broader meaning today and will have growing importance in the years to come. At the high level we have come to recognize that we have to sustain our world in three macro arenas: social, environmental and economic. As we evaluate sustainability in these areas we will find improvements that will be needed to be made and sustained over time. The LSS framework is an effective way to identify and make these improvements.

As we initiate improvements in our businesses and in the world in general we need to think about improvement sustainability at two levels; project sustainability – sustaining the individual project improvements over time, and also initiative sustainability – sustaining the improvement initiative over time. At the project level LSS is uniquely set up to help insure project sustainability due to the Control Phase of DMAIC. This is one of the truly novel aspects of LSS.

Initiative sustainability is more difficult. Hardly a month goes by without seeing one to two articles related to sustaining improvement initiatives. There are many reasons for the lack of sustainment including: the new procedures not followed, important projects are not identified and worked on, lack of management attention, top talent not assigned. The list goes on and on. Again, this is a strategic issue that must be addressed at the beginning and given attention through regular management reviews. Many organizations know what to do; they just do not do it. Our proposed approach is to transition from being a formal initiative to simply the way we work. This has to be done carefully, however, to ensure that we don't throw out the baby with the bath water. That is, we have to keep some of the infrastructure in place, with formal accountabilities for keeping the improvements coming in, even after LSS is no longer a formal initiative.

Human variation

Recent world disasters make it clear that improvement initiatives need to pay closer attention to human error, which is better characterized as "human variation." Humans are arguably the largest source of variation on the face of the planet. Airplane crashes, train derailments, chemical plant explosions and the like continue to happen, even when we know what to do to prevent them from happening. Unfortunately, knowledgeable humans don't always do what they have the knowledge to do.

Our improvement strategies and LSS methodologies must do a better job of dealing with human variation. Sometimes the solutions are simple and easy to implement. Gawande (2010) showed how effective checklists are in reducing surgery infection. Checklists, when used, can be very effective in reducing human variation. Mistake proofing and visual management are other useful tools. But the problem continues to happen. Improvement professionals need to do more here.

Integration of LSS into educational systems

Private sector organizations and governmental agencies has obviously invested large sums of money into LSS efforts, especially for training of employees. It is logical to ask if university programs should provide some degree of education and training in LSS, such as within engineering schools, for example. Most universities strive to produce graduates that are sought after by potential employers. Further, such education and training in LSS would give graduates an advantage over other candidates who lack such training.

This thought is not new; several schools have launched LSS training efforts. While many of these are oriented toward the private sector, some schools have added courses in structured improvement efforts in their regular curricula. For example, in the US Arizona State, North Carolina State, and Virginia Tech have each added problem-solving courses to their engineering and statistics curricula that are heavily based on LSS (Anderson-Cook *et al.*, 2005).

We anticipate that such formal educational programs will continue and expand. It is obviously in both the school's and students' best interests to do so. While engineering curricula are notoriously packed already, solving problems is core to what practicing engineers do on a day-to-day basis. Formal training and some practical experience, via internships, for example, would certainly better prepare engineers to do just this.

To be continued

The work continues. Improvement and LSS are still important and will continue to be in the future. There are new and better ways to accelerate QI. The internet and IT in general, is a major ally. Taking advantage of the new technology, building on the fundamentals, thinking strategically and aggressively pursuing the opportunities will improve quality and strengthen our organizations in the process. The future for LSS and improvement is bright!

Conclusion

The authors have reviewed and commented on the past and present of LSS use in process and organizational improvement to provide context on what the future may bring. It has been learned that the critical ingredients are: committed leadership by management, involvement of top talent, supporting infrastructure and a holistic approach to improvement including area of application and methodology used.

We have seen that LSS has broad applicability including not only manufacturing but also service, healthcare, government, non-profits and education. It is useful in small- and medium-size organizations as well as large organizations. But more is needed and more is possible.

The integration of lean and Six Sigma is important as lean focuses on improving the flow of information and materials between the steps in the process and Six Sigma works to improve the value-adding transformations which occur with in the process steps. The appropriate blend of lean and Six Sigma tools useful on any one problem therefore depends on the nature of the specific problem being solved.

As we look to the future we see emerging trends that will place greater demands on organizations to improve. There trends and associated demands include: globalization and its associated competitive pressures, customers demanding more in terms of quality, service and lower costs; and organizations having improvement needs related to large, complex unstructured problems. These trends result in the need for better and more advanced improvement methods. Such approaches will need to address the following challenges: greater use of strategic thinking, a focus on holistic improvement, identifying and solving mission critical problems including the use of Big Data, dealing with human variation and sustaining the gains of improvement initiatives. This suggests that the future of LSS will be demanding and exciting for all involved, practitioners and developers alike.

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