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A Concise Literature Review on Comparison between Lean Manufacturing and Six Sigma with Their Separate and Combined Applications to a Few Specific Industrial Sectors

Nafiz Afsan, Md. Abdul Aziz and A.R.M. Harunur Rashid
Department of Mechanical and Production Engineering (MPE)
Islamic University of Technology (IUT)
Boardbazar, Gazipur, Dhaka, Bangladesh
nafizafsan@iut-dhaka.edu, abdulaziz31@iut-dhaka.edu, a_rashid@iut-dhaka.edu

Abstract

Lean Manufacturing heavily focuses on reducing waste in order to maximize production. Six Sigma is largely identical to Lean Manufacturing fundamentals, but its main focus is to produce high quality output in consistent manner. Though both methodologies aim at improving manufacturing processes and creating efficiencies, they have their unique set of characteristics that might be best suited when implemented separately. But in the long run, companies have identified the combined implementation of Lean Manufacturing and Six Sigma as the way forward, as it helps to take the advantage of the strengths of both the strategies while providing a comprehensive, effective and suitable solution to various issues related to the improvement of processes and products. This paper focuses on a comparative exploration of lean manufacturing and six-sigma in terms of their different types of applications to various industries. From our study, it has been observed that, Lean Manufacturing and Six Sigma methodologies are actively being implemented in conjunction and thus have coined themselves together as the Lean Six Sigma strategy.

Keywords

Lean Manufacturing, Six Sigma, Lean Six Sigma, TQM.

1. Introduction

The present competitive nature of the world economy has compelled industrial organizations to look for innovative solutions that will give them the cutting edge over their immediate counterparts. Consequently, a large number of companies are looking for modern methodologies related to management that might allow them to upgrade their products and/or service quality, refine their manufacturing processes, reduce costs, enhance the capital's profitability and most importantly ensure customers' satisfaction. This has been attempted through Lean Manufacturing Techniques, Six Sigma Methodologies and their integrated approaches in managerial and production processes in which Lean Manufacturing Techniques focuses on the waste elimination, using simple and visual approaches whenever possible and Six Sigma Methodologies on the control and reduction of process variability, using statistical process control tools.

The literal meaning of the word Lean is thin. The Enterprise Management scheme known as Lean Manufacturing, refers to companies that are agile or flexible and has the ability to combine its performance with the flexibility of being able to optimize and maintain all of its processes, whenever and wherever required. The forerunners of Lean Manufacturing Techniques wanted greater productivity through regular improvement and regular improvement by the process of waste elimination. The employment of lean manufacturing tools in construction related projects and its effect on overall safety in the Gaza Strip were investigated by Enshassi (2014). For better understanding of the viewpoint of contractors and clients in relation to the implementation of lean manufacturing tools in construction projects, a questionnaire survey was also undertaken on them. The theoretical frameworks of constructional management and its tools were deeply scrutinized by Ansah et al (2016). The findings from this paper were that, for coping with the subject of waste in construction projects, models with pragmatic and vigorous techniques will be

required for the project teams. In construction projects, this methodology was used as Lean Construction Methodology and the significance of it has been greatly discussed in literature.

The basics of Six Sigma Methodologies are formulated to upgrade the overall manufacturing process (Chen and Lyu 2009, Cherry 2019). Initially, Six Sigma Methodologies emerged as a branch of quality control specifically dedicated to large scale industries. The main intention was to improve the process mechanisms and reduce the number of defects originated from within the production system. Six Sigma Methodology, which provides the tools that massively improved the capability and reduced the defects in a process, were studied by Prajapati and Desai (2014). Six Sigma Methodology uses some typical quality control tools such as cause and effect diagram, statistical process control, Pareto or control charts and benchmarking to find the root cause of the problem (Breyfogle 2003). The techniques and mechanisms of Six Sigma Methodology gives organizations a chance to visualize strategic areas other than quality and helps them to focus more on customer demands.

Both Lean Manufacturing Techniques and Six Sigma Methodologies have intrinsic deficiencies, which necessitates an effective integration of the two popular concepts, for better, improved and optimum operational results, including customer satisfaction. Ultimately, it results in reduction of overall production cost, improved product quality and increased productivity. The merging of these two effective concepts is done with a view to achieving maximum customer satisfaction and improved operational effectiveness by removing non-value-added activities. (Kanakana et al 2010).

The Lean Six Sigma is a method of improving the quality and profitability based on statistical process control. It is a management style that relies on a tightly controlled organizational structure dedicated to project management. Integration of Lean Manufacturing Techniques and Six Sigma Methodologies was started in 1997 when BAE system first introduced the two methodologies in Aerospace Industry (Smith and Adams 2001). It was named Lean Six Sigma approach with a view to protecting market share and planning at reducing variation within the production processes. The IBM Consulting Group also had implemented lean-six-sigma methodology in the inceptive days of LSS (Smith and Adams 2001). Two approaches were used by them to identify the problem within the system. Lean technique was used to identify waste, while six-sigma was adopted to reduce variation and improve reliability. Rockwell Automation Power System employed a value stream mapping approach while applying lean techniques with the 5S program to ease large improvement opportunities and to implement lean flow (Illing 2001). A modified DMAIC approach was adopted in a paper document to the Electronic Copies Convention Company. At every stage of the DMAIC process, lean concepts are introduced to reduce error rate, production cost and enhance productivity (Goyal 2002). Northrop Grumman Company integrated workout with Kaizen and Lean Thinking events. The company also used a six-sigma methodology to validate solutions and to treat with the higher quality problems (McIlroy and Silverstein 2001). Jie et al. (2014) studied the implementation of the new Lean Six Sigma concept. He employed Lean tools added at the analysis phase of the initiatives and used six sigma principles to reduce and then eliminate the variation found. The Conclusion of this paper showed that the adoption of the lean six-sigma framework has provided a systematic and guided approach to help to identify the problem and to provide a feasible solution and sustain the improvement made. The integration of Lean Management Techniques and Six Sigma strategies to improve the performance of production in pharmaceutical industries were studied by Al-Shourah et al. (2018). In this paper, factors related to the utilization of lean six sigma in the improvement of the management related activities and performance of a specific pharmaceutical industry were evaluated. Rathilall and Singh (2018) worked on a lean six sigma framework to enhance the competitiveness in selected automotive component manufacturing organizations. The paper examines the integration of lean and six sigma tools as a unified methodology to improve and develop a functional manufacturing process in the company.

2. Lean Manufacturing

The concept of Lean Manufacturing Techniques emerged in Japan after World War II. It was initially coined by Toyota's Eiji Toyoda and Taiichi Ohno, who were mainly aiming to overcome the challenge of cutting costs while producing small quantities of many types of cars (Womack and Jones 2004).

The definition of the Lean Manufacturing System is given by Ohno (1988) as:

"The elimination of waste and unnecessary elements in order to reduce costs; the basic idea is to produce only what is necessary at the necessary moment and in the quantity required." Ohno (1988, p.23)

Lean Manufacturing focuses on process improvement by streamlining its flow, reducing cycle time, increasing process speed, eliminating waste and emphasizing gains in speed and efficiency. Its goal is the removal of non-value-added process steps or time traps from the process. By aligning activities that create value by eliminating waste, the value stream is advanced smoothly and quickly according to the customer's request and not according to the producer. Lean is a great method to help organize work areas, reduce WIP (Work-In-Process), and speed material flow through the entire manufacturing process. Successful Lean initiatives yield lower inventory cost, higher productivity and flexibility, and faster response time to the customer. Although initiated in manufacturing, the Lean concept can also be deployed in several organizational areas (Locher 2013).

From the literature review, key papers on application of Lean Manufacturing techniques are presented concisely in Table 1. The main management techniques that were used to implement the Lean principles, in the following papers, are: Value Stream Mapping, Evaluation System with well-defined metrics, 5S, Kaizen, Kanban, Standardization, Visual Management and TPM (Total Productive Maintenance).

Table 1. Literature focusing on certain applications of Lean Philosophy

Author	**Topic**	**Case**	**Methodology**	**Result**
Tan et al., 2018	Lean management for enhancing inventory performance	To improve the work-in-progress inventory in a non-lean company seeking to adopt lean management in their Electrical Board Assembly process	Implementation of Value Stream Mapping (VSM) to identify waste from current VSM as well as establishment of three other lean tools like One piece flow (JIT), Kanban Card & supermarket racking.	WIP for the selected production line was monitored from the very beginning and by application of supermarket racking, maximum and minimum inventory level was fixed. VSM helped identify the waste based on lean philosophy and elimination of waste by deploying lean techniques.
Kumar, 2016	Lean management for reducing process wastages in clothing industry	To minimize the process wastages in all sewing related activities in the single jersey knitted trouser product line of a clothing industry in India	Value Stream Mapping technique followed by cellular layout, kaizen and single process flow tools are utilized	Throughput Time is reduced from 6 hours to less than an hour in Lean layout, a huge level of reduction is achieved in Cycle Time and WIP. Lastly, problem of low flexibility is eliminated by cellular layout.
Dawood et al., 2018	Role of Lean manufacturing in soft drink company	To reduce and continuously improve in bottle filling and crowning operations at soft drink companies along with productivity improvement on the assembly line	Value Stream Mapping creation to evaluate Value Added (VA) and Non-Value Added (NVA) time, application of Jidoka using the Andon and Poka-Yoke tools. Pareto charts and Ishikawa diagrams to present the key problems.	The unnecessary labor movement, considered as motion waste, is eliminated. The VD and NVD time as well as cycle efficiency are increased and process inventory delay is observed to be reduced. Solutions were recommended to reduce the waste reduction of several other critical process inputs.
Prajapati and Awasthi 2017	Total Production Time Reduction	To reduce cost and waste by eliminating waste of time from	VSM is constructed to assess the VA and NVA time,	Total NVA activity reduced from 1810 Min to 1191 Min, i.e., total reduced time

	of Electric Control Panel	each step in the production assembly line respective of energy, time, motion and resources	5S is conducted every month with NVA activity present	was 619 Min.
Hüttmeir et al. 2009	Trading off between two lean manufacturing strategies named as Heijunka and Just-in-sequence (JIS) production	To determine whether a manufacturing plant should maximize its leanness or, to maximize its responsiveness	A stylized simulation-based model was constructed at the BMW engine plant and the buildup of WIP inventory and other performance measures are observed under JIS and the heijunka sequencing	The findings indicate that there could be a continuum between the two strategies, rather than choosing one extreme. With heijunka, the most extreme production values can be smoothed out and with JIS, the remainder of production is carried out

3. Six Sigma Methodologies

In traditional terms, 6 Sigma focuses on defect prevention, reduction of cycle times and cost savings. Unlike costly cost cuts, which reduce value and quality, 6-Sigma identifies and eliminates costs of waste, meaning that they do not add value to customers. Companies operating at 3-Sigma or 4-Sigma levels usually spend between 25% and 40% of their revenue to repair or solve problems. This is known as the cost of quality or, more precisely, the cost of poor quality. Companies operating on 6-Sigma generally spend less than 5% of their revenue to fix problems.

Six Sigma is a well-established methodology that seeks to identify and eliminate defects, mistakes or failures in business processes or systems by focusing on those process performance characteristics that are of critical importance to customers' (Albliwi et al. 2015). It also focuses on reducing defects and variability within a formalized project management structure. In fact, the management structure for executing and managing projects is a real strength of the Six Sigma approach. It is basically a statistical methodology that aims to reduce variation in any process, reduce costs in manufacturing and services, make savings to the bottom line, increase customer satisfaction, measure defects, improve product quality, and reduce defects to 3.4 parts per million opportunities in an organization (Albliwi et al. 2015, Drohomeretski et al. 2014). For most companies, this is a significant if not radical improvement in quality. When executed well, Six-Sigma can help organizations achieve very significant improvements in quality, reduction of defects, and ultimately lower cost. Six Sigma is not only for manufacturing, but any operation where an opportunity exists for error, including order entry, customer service, sales, HR, etc. From the literature review, key papers on application of Six Sigma methodology are presented concisely in Table 2.

Table 2. Literature focusing on application of Six Sigma methodology

Author	**Topic**	**Case**	**Methodology**	**Result**
Hung and Sung 2011	Applying six-sigma to manufacturing processes in the food industry to reduce quality cost	A food company in Taiwan, afflicted with various issues such as improving customer satisfaction, lowering product defect rates, reducing recruit cycle time, shortening new product development time etc., decided to reduce operational cost	Between the two approaches, DMAIC and DMADV, DMAIC is followed here to solve the two projects of reducing process variation and lowering the associated high defect rate of products	During a six-month implementation period, defect rate fell to below 0.141% (the goal) from 0.45% For the shrinkage rate project, the final results were even better than the original goal, and thus the case company decided to continue implementing Six Sigma projects over the long run.
Kaushik et	Application of	To assess and justify	DMAIC methodology	Profit of the chain

al. 2012	Six Sigma methodology in a small and medium-sized manufacturing enterprise	the useful role of quality management techniques like Six Sigma methodology for Small Enterprises, taking specific case of a bicycle chain manufacturing unit	is applied to reduce a certain cycle chain component- the bush rejection rate and variation, Two sample t-test and process capability analysis are done before and after the six sigma	manufacturing firm is increased by controlling the high rejection rate of chain bush, the process sigma level is brought up to 5.46 from 1.40, which is expected to save around Rs. 0.288 million per annum
McAdam and Evans 2004	The organizational contextual factors affecting the implementation of Six-Sigma in a high technology mass-manufacturing environment	To find out the key determinants and practice of Six-Sigma implementation, two Man case sites are chosen.	A comparative case analysis between the two sites is done, at four different levels in each site, namely: operator, technician, engineer and management levels. Critical factors were evaluated.	Though priority was set on training and development, lacking of communication and measurement systems lowered the rating of operator. Huge need to improve employee involvement and overall, the integration of Six-Sigma into the organization's culture.
Kumar et el. 2008	Using Six Sigma in a financial services operation	To analyze the process of credit initiation, Six-Sigma is used to determine the inefficiencies and improve the days that the process takes to complete	Six-Sigma DMAIC tool is used to decrease variation in the process by identifying and improving certain areas, in addition to cause-and-effect diagrams, histogram, ANOVA and poka-yoke tools are developed	Through ANOVA one way test, process bottlenecks were identified, implementation of new measures is showed through different cause-and-effect diagrams. Lastly, process change for several areas are suggested in the revised credit approval process to achieve a 25% improvement in cycle days
Sadagopan et al. 2005	Six-Sigma transitions and organizational preparedness exercise – today's imperatives for tomorrow's success	To determine an organizational preparedness exercise to implement more successful Six-Sigma, an Indian TQM-cultured manufacturing company is chosen. Production of a component called tension roller was considered	Three transitions that an organization should affect before planting the Six-Sigma program is briefly presented and their practicality is tested with the view of achieving 3.4 Defects Per Million Opportunities (DPMO). Sigma value is calculated.	While trying to assess the levels of three Six-Sigma transitions, a critical to quality project is to be conducted- this will help to implement a more successful Six-Sigma program, as proposed. It is also suggested from the interpretation of the company's sigma level 4.2 that, focusing on three Six-Sigma transition is more practical than three sigma level

4. Lean Six Sigma Methodologies

The combination of Lean and Six Sigma tools can be viewed as useful methodology for the operation of the system for improvement, innovation and routine management that integrate the system of business management. Routine

management, process standardization and the study of times and movements to eliminate waste are key features of Lean Manufacturing, while finding the root cause for problem solving requires further deepening and analysis in Six Sigma. The companies have implemented Lean Manufacturing with the aim of improving the elimination of waste in the processes. Companies using Six Sigma have found that by selecting projects and assigning them to teams, after a monitoring, the results would appear. Companies that implement Lean Six Sigma are often aware of the teams, seeking projects from different scopes with the focus of improving the structure of processes and achieving the results. Over time, companies have realized that these methodologies are complementary and since then, much has been written about combining Lean with Six Sigma as a process improvement approach, using best practices from each. For some authors like George (Baker 2003) the union of these two methodologies maximizes the value of the company.

Before beginning the integration between Lean and Six Sigma, it is prudent to understand their similarities and divergences, according to Laureaniet al. (2010), to enhance the work of the team in the reality of the organization:

Similarities:

- Both targets core functioning processes in an organization
- Applicable in manufacturing activities as well as other type of services
- Management support is crucial
- Customer focused activities
- Multifunctional teams are needed
- The tools are complementary operatable

Divergences:

- Six Sigma demands more intensive training compared to Lean Manufacturing
- Lean Manufacturing focuses to reduce waste while Six Sigma to reduce variability
- More investment is required to implement Six Sigma compared to Lean Manufacturing
- Lean Manufacturing targets to streamline the flow of processes while Six Sigma aims to increase customer-driven capacity
- Lean Manufacturing has more flexibility for implementation than Six Sigma
- Team empowerment for Six Sigma has specific designations

Though in implementation, Six Sigma supports Lean Manufacturing but it does not have any structured intrinsic method for troubleshooting. This is mainly because of the fact that Six Sigma does not focus on factors like-improving process speed, reducing lead time or, eliminating waste, which are aspects of Lean Manufacturing.

Many ways have been investigated and experimented to combine these two methodologies, which will be later explored concisely in tabular form. According to Corrêa and Gianesi (1993) in the Western world there has been a growing movement to adopt the strategic role of manufacturing in cost reduction and production process optimization. Bendel (2005) says that the imperatives for implementing Lean Six Sigma depend primarily on the problems the company is currently facing and the nature of its business, as well as the goal of the company and its employees' aspirations. It is also stated by some authors that Lean means ensuring speed and quick operations by reducing unnecessary factors and Six Sigma refers to eliminating defects. Thus, Lean Six Sigma Engineering means best-in-class. It creates value in the manufacturing or service organization to meet its customers' satisfaction and to save money (Sokovic and Pavletic 2008). This is why they are considered as reference models. Santos et al. (2018) indicates that evidence about the potentiality of best approaches tells that, different actors worldwide have been proposing and promoting variety of reference models. Generally, these models serve as references for decision-makers in implementing practices to be used in operations and organizational processes usually associated with quality awards, certificates, or consultancies. For Chaurasia et al. (2016) the shift from traditional manufacturing processes to Lean Six Sigma processes (LSS) implies more positive results for companies in relation to the generation of revenues, customer and employee satisfaction, increased productivity, reduced waste and design of a quality product at low cost. From the literature review, key papers on application of combined Lean Six Sigma methodology are presented concisely in Table 3.

Table 3. Literature on methodology tools and application of lean six sigma

Author	Topic	Case	Methodology	Result
Al-Shourah et al. 2018	The integration of lean management and six sigma strategies	To improve the performance of production in a Pharmaceutical Industry	Alpha Cronback and Regression analysis (ANOVA test)	In production efficiency, 85.1%was achieved.
Ghaleb et al. 2017	Implementation of lean six sigma techniques to enhance productivity	To reduce cycle time, defects and to increase sigma level in Small and Medium scale Industries	DMAIC, VSM, SIPOC, Process Capability, Cause and effect diagram	2.3% Sigma level with increased in the net profit of the company per year were achieved
Ramakrishnan and Jayaprakash 2015	Application of lean six sigma tools for reduction of defects in pump manufacturing	To reduce defects in pump manufacturing in a pump industry	Pareto chart, P-chart, Run-chart, Cause and effect diagram	Cost reduction
Elbermawy et al. 2014	Implementation of lean six sigma for improving supply chain processes	To improve supply chain processes in a pharmaceutical industry	DMAIC, Project charter, Value stream Mapping, SIPOC, Control chart, Cause and effect diagram	Reduction in lead time and cycle time. Elimination of over motion for physical flow and non-value added process. Improved performance of supply chain process
Maleszka and Linke 2016	Implementation of management process by using lean six sigma tools	To evaluate the impact of lean six sigma on management processes in a food industry	DMAIC, VSM, Visualization, 5S, Poka yoke, SMED	Cost reduction with increased profit margin
Bubshait and Al-Dosary 2014	Application of lean six-sigma methodology	To reduce the failure rate of choke valves and to make recommendations in oil and gas field	DMAIC, SIPOC, Cause and effect diagram, Bar chart, Cause and effect matrix, Process capability, Pareto chart, Failure mode and effect analysis, 5-ways analysis	Four main causes of choke valves failures identified and recommendations for both short and long-term solution for each cause proposed
Rathilall and Singh 2018	A lean six sigma frame work to enhance the competitiveness in selected automotive component	To determine how to improve on existing processes for automotive component production	SPSS, Cronbach's Alpha	Low success rate of LSS adoption as standalone system.

5. Conclusion

Lean Six Sigma (LSS) is an extremely powerful technology which is used to identify and eliminate waste, improve operational performance, efficiency and maximize customer satisfaction to sustain in the highly competitive manufacturing and nonmanufacturing environment. The focus of this paper was to explore Lean Manufacturing Techniques, Six Sigma Methodologies and their combined applications in a range of industrial sectors. This systematic comprehensive review aims to synthesize, organize and structure the stock of knowledge relating to Lean Six Sigma. The identified tools and techniques, methodologies, frameworks, success and failure factors and

strategies can be effectively used as a roadmap in the manufacturing sector. This is also identified that the LSS has been implemented worldwide and in all type of manufacturing organizations for achieving the utmost excellence. They have successfully achieved their LSS objectives. But various challenges and barriers are faced by organizations during the deployment of LSS that can be addressed in future studies.

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Biographies

Nafiz Afsan is a final year undergraduate student, pursuing his Bachelor of Science degree in Mechanical Engineering from Islamic University of Technology (IUT). His fields of interest include Advanced Manufacturing Systems, Supply Chain Management, Lean Six Sigma Methodologies and Industrial Safety.

Md. Abdul Aziz is an undergraduate student, currently pursuing his Bachelor of Science degree in Mechanical Engineering from Islamic University of Technology (IUT). His field of interest include Digital Manufacturing, Lean Management, Sustainability and Industry 4.0 technologies.

Dr. A R M Harunur Rashid is an Associate professor of Department of Mechanical and Production Engineering (MPE) at the Islamic University of Technology (IUT). He earned his Ph.D. from Dublin City University (DCU) and B.Sc. in Mechanical Engineering from Bangladesh University of Engineering and Technology (BUET). His research activities include the area of Quality Engineering, Ergonomics, Sustainable Product Design, Operations Research & Management, Maintenance Engineering, Life Cycle Analysis and Renewable Energy. He is actively involved with the activities of IEOM Society and has been serving as the Honorary General Secretary of IEOM Society Bangladesh Chapter since 2016.