Sustainable Manufacturing: A Study on Lean Six Sigma (LSS)

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Abstract

A large and growing number of manufacturers are realizing substantial financial and environmental benefits from sustainable business practices. Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources.

Current economic crisis raises the constant demand for profitable solutions that allow organizations to gain competitive advantage. For this reason, more and more companies search for management methodologies that allow them to improve their products and/or service characteristics, perfect their processes, decrease costs, improve the capital's profitability and costumers' satisfaction. This have been attempted through Lean Management and Six Sigma integrated approaches in their managerial and production processes in which, Lean focus mainly on the waste elimination, using simple and visual techniques whenever possible and Six Sigma on the control and processes variability reduction, using statistical tools for this purpose. The present study is a detailed study of the lean sigma and how to improve the manufacturing process and decrease product defects in the production line.

Keywords- Sustainable manufacturing, Lean Manufacturing, Six Sigma, Lean Six Sigma

I. Introduction

Earlier manufacturing was based on certain factors, especially EOQ models, demand and supply and availability of major raw materials. Now, on introduction o the various laws and Act viz., Environmental Act , Consumer Act, Quality Assurance Act, etc, manufacturing process has undergone a lot of changes and which has helped to maintain certain level of all desired things as prescribed in the Act. This new system is called Sustainable Manufacturing.

Sustainable manufacturing is a term used to describe manufacturing practices that do not harm the environment during any part of the manufacturing process. It emphasizes the use of processes that do not pollute the environment or harm consumers, employees, or other members of the community. Sustainable manufacturing includes recycling, conservation, waste management, water supply, environmental protection, regulatory compliance, pollution control and a variety of other related issue. Sustainable Manufacturing is also known by different names like environmentally conscious manufacturing, environmentally benign manufacturing, environmentally responsible manufacturing, and green manufacturing. Sustainable manufacturing emphasis on designing and delivering products that minimize negative effects on the environment through their production, use and disposal. In the current scenario it is better to make product for environmental as well as economic feasibility for the organizations. So sustainable development is a development that meets the needs of the present without comprising the ability of the future generations to meet their own needs.(UN Brundtland Commission). Also the globalization has forced companies to improve their environmental performance.

Sustainability has become a crucial element for the world to generate profit while keeping its citizens to live in a healthy environment. As a key contributor of our society, manufacturing industry not only generates the most profit and employment, but also contributes a lot of violence against human rights and environment. This paper has studied sustainable manufacturing with Six Sigma, which is the most useful tool for continuous improvement, to create a systematical framework for manufacturing practitioners to achieve sustainable manufacturing. This framework has given detailed steps from problem definition to achieving leadership in sustainability in order to maintain the efforts.

II. Methodology of the study

The purpose of this study has arisen by the idea how to ensure sustainable quality and improvement of production processes. The study helps to understand better the need of sustainable manufacturing and lean six- sigma. The study is descriptive in nature and entirely based on secondary data. The source of data collection results from various research papers, journals, articles and internet.

III. Sustainability in manufacturing operations

Sustainable manufacturing mean in practice:

i. Using renewable materials that do not deplete the natural environment
ii. Consuming less materials as inputs and materials should be non hazardous and are recyclable

iii. Modifying production process to use less energy, water and raw materials. The process of production should also have less waste
iv. Reducing product weight, using less packing ,using efficient transport and logistic
v. Product design should be reusable and biodegradable
vi. Expanding the life of the product, Making easier to repair or designing it to use fewer resources during usage

The term sustainable development covers the three dimensions (social, economic and environment) that constitute the triple bottom line (Elkington, 1998). The growing trend of considering sustainability in manufacturing settings is clearly evident in government initiatives, such as the EU’s growth strategy “Europe 2020”, that calls for joint efforts towards a “resource efficient Europe" (European Commission, 2010). This government initiative is aimed at committing both the EU and its member states to this sustainability agenda, supporting the shift towards a low carbon economy, and promoting an increase in the use of renewable energy sources, without compromising energy efficiency (European commission, 2010).

Currently, it can be said, in India, only 10 percent of the manufacturing sector is actually on a sustainability framework as businesses are still deciding if they want to adopt sustainable measures or not. In developed countries, due to pressure from either consumers or the government compel Corporations to become sustainable in their approach. In India, the low participation of corporations in Corporate Social Responsibility (CSR) and sustainability initiatives suggests that there is a lack of awareness. Apart from the existing mechanisms such as Clean Development Mechanism, PAT scheme and SEBI guidelines that have been propelling the corporations to incorporate sustainable measures, the government is coming up with different laws, or stricter regulations to ensure sustainable development. In order to be energy efficient, there has also been a push for application of renewable energy which has direct link to the manufacturing sector. On an average, about 75 percent of global economic production takes place in cities and India is no different. The urban production will account for nearly 70 percent of the country's GDP by 2030. Therefore, India needs to ensure that its cities become sustainable by backing sustainable manufacturing in India

The factors motivating companies to embark upon sustainable development include social responsibility and investor demands, government regulations and international standards, and increased customer consciousness. Researchers have tended to focus more on the environmental aspects of sustainable development. One important consideration is the energy consumption and the challenges associated with reducing the carbon footprint. Limited attention has been accorded to the social dimension of sustainability as envisioned by United Nations Division for Sustainable Development (UNDSD) such as fostering equity both economic and gender-related, improving health-care and sanitation facilities, and raising literacy levels among other indicators.

With the increased focus on sustainable manufacturing, the product designer is encumbered with additional responsibility of considering the environmental impact of his/her decisions. Thus, it becomes imperative for the designer to first acclimatize himself/herself with the various issues concerning sustainability. The choice of materials and processes has a significant bearing on the environmental impact.

A product life cycle typically consists of five stages viz. pre-manufacturing, manufacturing, delivery, use and recycling or disposal. *Life-Cycle Assessment* (LCA) helps to incorporate sustainability into the design process by analyzing all aspects of a product like the raw materials used, and wastes generated throughout the life of a product. LCA methods have often been employed in energy management systems to minimize wastes and emissions. Some systems combine these methods with expert systems to improve the accuracy of sustainability models constructed and the parameters estimated. Mathematical models have been developed to facilitate intelligent decision-making regarding product continuation, marketing, new design development etc. during the product’s lifecycle to maximize the overall profit.

Managing operations using lean principles, agility concepts and sustainable production practices continue to remain economically viable and successful at penetrating into newer markets. The use-productivity viz. using innovative techniques to save resources, maximizing utilization ratio of product to resource, and extending the life of the product. Energy consumption in manufacturing processes can be reduced by turning off unwanted machines automatically using multi-objective optimization techniques that take into consideration the arrival rate of parts at the machine and the warm-up times associated with each machine. One mechanism to maximizing utilization ratio of product to resource is to have flexible and reconfigurable products which can be used in multiple applications. This principle of modularity is the central concept behind mass customization. The ability to disassemble and reassemble products as needed is essential to make the product more versatile.

Another more recent approach to sustainable manufacturing is extending the life of the product through recycling, reuse or remanufacturing.

Companies are considered to be “key players on the societal path towards sustainability” (Koplin et al., 2007, p. 1060). In the past, most companies have separated sustainability considerations from their own business strategies and performance evaluation; in this way, economic performance indicators have been the main criteria by which companies have been assessed (Clarkson, 1995). This scenario began to change in the late 1980s when a few manufacturing sectors started adopting practices to help with the minimization or elimination of waste. These were the first signs of sustainable manufacturing (Lazlo et al., 2013; Courtice, 2013).

A study presenting short-term projections of the manufacturing scenario in the United Kingdom (Tennant, 2013) stated that manufacturing strategies largely involve energy and resource efficiency programs. In spite of this bias on focusing on the environmental dimension of sustainability within large organizations, there is an undeniably increasing interest in sustainability from its triple bottom line perspective, from both practitioners and academics. This broad variety of stakeholder pressures for integrating sustainable development into manufacturing, plus the perceived benefits (i.e. economic savings and positive image) derived from environmental and social initiatives (Petrini and Pozzebon, 2010), has shaped the growing trend in firms worldwide for integrating sustainability into their business practices (Jones, 2003; Bielak et al., 2007; Gunasekaran and Spalanzani,2012). The consequences of these pressures and drivers for sustainability produce the existing challenging scenario for manufacturers.

As the pressures grow, there has been a call to clarify what sustainability is from an operational perspective for manufacturers, as well broaden the understanding about the way in which sustainability might be attained within manufacturing organizations. Increasing the knowledge regarding how organizations can operationalize sustainability constitutes a valuable contribution towards the attainment of national and global sustainability goals.

IV. Lean Manufacturing

Lean manufacturing or lean production, often simply "lean", is a systematic method for waste minimization within a manufacturing system without sacrificing productivity. Lean also takes into account waste created through overburden and waste created through unevenness in workloads. Working from the perspective of the client who consumes a product or service, "value" is any action or process that a customer would be willing to pay for.

Lean manufacturing makes obvious what adds value, by reducing everything else. Lean is a continuous improvement philosophy which is Synonymous with **Kaizen** or the **Toyota Production System**. The history of lean management or lean manufacturing is traced back to the early years of Toyota and the development of the Toyota Production System after Japan's defeat in WWII when the company was looking for a means to compete with the US car industry through developing and implementing a range of low-cost improvements within their business. In brief, lean management seeks to implement business processes that achieve high quality, safety and worker morale, whilst reducing cost and shortening lead times. This in itself is not unique to Japan. What sets lean management apart, and makes it particularly effective, is that it has at its core a laser-sharp focus on the elimination of all waste from all processes.

In lean manufacturing there are generally considered to be seven types of waste.

1. Over-production against plan
2. Waiting time of operators and machines
3. Unnecessary transportation
4. Waste in the process itself
5. Excess stock of material and components
6. Non value-adding motion
7. Defects in quality

Labour and Equipment Effectiveness

We can typically look at the waste within a business process by considering the labour and equipment effectiveness. For example for labour, there's usually a stark difference between the paid time for a resource and the time that the resource is actually adding value for the customer. We can define this difference through a series of losses.

Figure 1- Series of Losses

Social Loss, for example losses due to meetings, is typically the responsibility of management
Utilisation Loss is generally the supervisor's responsibility, and may occur if parts are not available or the operation is not setup such that the operator can perform at their best.
Performance Loss is the operator's responsibility. This includes not meeting standard times and not following standard operating procedures.
Method Loss is the responsibility of engineering and management across the organisation. For example, if a product was not designed to be easily manufactured then this would be the R&D team's responsibility.

We're often also interested in the availability and effectiveness of equipment being used.
Plan Loss results from scheduling equipment not to run
Stop Loss results from a changeover or breakdown
Speed Loss results from running equipment below the design speed of the machine

Quality Loss results from producing defective parts and materials
Analysis of equipment effectiveness is especially important to focus on when dealing with high-cost equipment, such as in drilling, mining or the airline industry. In these cases a business is only making money or providing value when its equipment is operating.

While lean is seen by many as a generalization of the Toyota Production System into other industries and contexts, there are some acknowledged differences that seem to have developed in implementation:

a. **Seeking profit** is a relentless focus for Toyota exemplified by the profit maximization principle (Price – Cost = Profit) and the need, therefore, to practice systematic cost reduction (through TPS or otherwise) to realize benefit. Lean implementations can tend to de-emphasise this key measure and thus become fixated with the implementation of improvement concepts of "flow" or "pull". However, the emergence of the "value curve analysis" promises to directly tie lean improvements to bottom-line performance measurements.
b. **Tool orientation** is a tendency in many programs to elevate mere tools (standardized work, value stream mapping, visual control, etc.) to an unhealthy status beyond their pragmatic intent. The tools are just different ways to work around certain types of problems but they do not solve them for you or always highlight the underlying cause of many types of problems.
c. **Management technique-** In many companies implementing lean the reverse set of priorities is true. Emphasis is put on developing the specialist, while the supervisor skill level is expected to somehow develop over time on its own.
d. **Lack of understanding** is one of the key reasons that a large share of lean manufacturing projects in the West fail to bring any benefit.

Lean principles have been successfully applied to various sectors and services, such as call centers and healthcare. In the former, lean's waste reduction practices have been used to reduce handle time, within and between agent variation, accent barriers, as well as attain near perfect process adherence.

Lean principles also have applications to software development and maintenance as well as other sectors of information technology (IT). Lean methods are also applicable to the public sector.

V. Six-Sigma Evolution

Six Sigma (6σ) is a set of techniques and tools for process improvement. It was introduced by engineer Bill Smith while working at Motorola in 1986. Jack Welch made it central to his business strategy at General Electric in 1995.

It seeks to improve the quality of the output of a process by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes. It uses a set of quality management methods, mainly empirical, statistical methods, and creates a special infrastructure of people within the organization who are experts in these methods. Each Six Sigma project carried out within an organization follows a defined sequence of steps and has specific value targets, for example: reduce process cycle time, reduce pollution, reduce costs, increase customer satisfaction, and increase profits.

The term *Six Sigma* (capitalized because it was written that way when registered as a Motorola trademark on December 28, 1993) originated from terminology associated with statistical modeling of manufacturing processes. The maturity of a manufacturing process can be described by a *sigma* rating indicating its yield or the percentage of defect-free products it creates. A six sigma process is one in which 99.99966% of all opportunities to produce some feature of a part are statistically expected to be free of defects (3.4 defective features per million opportunities). Motorola set a goal of "six sigma" for all of its manufacturing.

Though Fredrick Taylor, Walter Shewhart and Henry Ford played a great role in the evolution of six-sigma in the early twentieth century, it is Bill Smith, Vice President of Motorola Corporation, who is considered as the Father of Six-sigma. Fredrick Taylor came up with the methodology of breaking systems into subsystems in order to increase the efficiency of manufacturing process. Henry Ford followed his four principles, namely continuous flow, interchangeable parts, division of labour and reduction of wasted effort, in order to end up in an affordable priced automobile. The development of control charts by Walter Shewhart laid the base for statistical methods to measure the variability and quality of various processes.

Later during the 1950s, the Japanese Manufacturing sector revolutionized their quality and competitiveness in the world based on the works of Dr. W. Edwards Deming, Dr. Armand Feigenbaum, and Dr. Joseph M Juran. Dr. W. Edwards Deming developed the improvement cycle of ‘Plan-Do- Check-Act’, better known as the PDCA cycle. Dr. Joseph M Juran gave to the world his ‘Quality Trilogy’ and it was Dr. Armand Feigenbaum who initiated the concepts of ‘Total Quality Control’ (TQC). Between 1960 and 1980, the Japanese understood that everyone in an organization is important to maintain quality and so training programs were conducted for almost all employees not considering the department they belong to. Any organization that is dynamically working to build the theme of six-sigma and to put into practice, the concepts of six-sigma, in its daily management activities, with noteworthy improvements in the process performance and customer satisfaction is considered as a six –sigma organization

Application Proceeding of Six Sigma Conception in Enterprises

The choice of enterprises for application of the Six Sigma concept resulted from findings in the questionnaire survey. The focus was on industries where enterprises do not use the SSM and achieve a low performance (ROE). To verify the generality of the SSM, regardless of the level of quality management system, the enterprises with a different level of quality management were chosen.
For the proposed elaboration on how to implement the Six Sigma methodology, the DMAIC phases were followed. In the respective phases of the DMAIC procedures, we carried out a selection of the methods and tools so that all members of the project team would be able to apply them and no special training or methods would be necessary for respective kind of production. The key components of the DMAIC cycle can be seen in Figure 2.

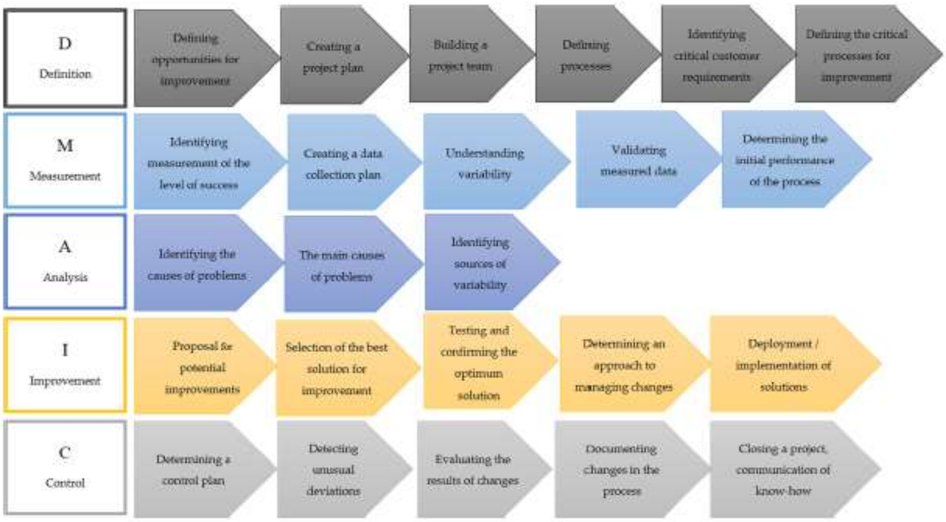

Figure 2 Key components of the DMAIC cycle

In the **Definition** phase it is necessary to identify the problem, the connection of the process with the requirements of the customer, form a project team and define goal and target level of critical characteristics of the process quality.
A critical process and a specific problem in the process were identified by the defect analysis in the process. Defects were divided into material and technological. The DPMO value, the process efficiency as a total output revenue, and a level of Six Sigma were calculated. DPMO (Defects Per Million Opportunities) denominates the number of defects that occur per one million opportunities at the development or manufacturing of a product and can be calculated according to the following formula:

$$\text{DPMO}= \frac{no.\ of\ Defect\ products}{total\ no.of\ products \times no.of\ opportunities\ per\ defects} \times 10^{6}$$

PPM (Parts Per Million) denominates defects rate, i.e., the numerically-identified number of defects, and those that really occurred, after manufacturing. Defects rate (PPM) is expressed by complementary quantity, thus, by the proportion of units without defects to the value one.
OFD (Opportunities For Defects) is a probability of defects of one unit, which describes how many places defects can occur.

Measurements of the defect frequency, according to the DPMO, and Sigma criteria can distinguish the level of the process in regard of the defect frequency at the output and identify critical, bottleneck points in the processes.
Subsequently, a critical process map, SIPOC, was elaborated (Suppliers-Inputs-Process- Outputs-Customers). SIPOC is a process map that helps understand and identify process boundaries and key processes to ensure focus only on the customer.
The target of the defined critical process and the final level of Six Sigma was determined in the project charter proposal. The project charter contains an outline for the problem definition, project team, time duration, and project target.
The objective of the phase **Measurement** is to gain relevant data about critical processes by measurement of the key process attributes so that the problem area could be defined. In this phase, potential sources for non–conformity in the process are identified. In the first phase, the quality index of the critical process was determined and a number of measurements were done to find out the capability of the process. The following methods were used:
- The measurement plan by Pande et al: five-phase methodology for measurement plan.
- Capability indexes Cp and Cpk: critical process capability evaluation in terms of keeping specified or expected limits and an average value.
- Histograms as a visual synthesis of frequency distribution and process variability.
Modules of descriptive statistics, industrial statistics, and Sigma process analysis were used for the calculations.
In the phase **Analysis**, the attention is given to the data analysis and dependence verification of type cause and effect, process comprehension with the objective to find out the key problem causes.
The following methods were used at the application in enterprises:

- Brainstorming: looking for causes of critical process incapability.
- Diagram of causes and effects—Ishikawa diagram: graphical visualization of coherence between the problem and causes or possible solutions.
- Method FMEA (Failure Mode and Effect Analysis): analysis of the occurrence of failures, possible causes and effects for the customer.

In the phase **Improvement**, solutions to eliminate problem causes are proposed, carried out and verified. The applied methods:
- An action plan and diagram: solutions to eliminate the identified cause of failures and an improvement of the critical process.
- Repetitive measurement of the critical process and the calculation of process capability indexes.

In the final phase **Control**, the results from the previous phases are evaluated, processes are continually followed and the process control is carried out so that any variation from the target value would be corrected before the effect of failure (non-conformity) occurs. The appropriate implementation of the changes and improvements with the objective of the sustainable improved condition is controlled. The applied methods include:
- QFD method (Quality Function Deployment): customer requirements are deployed into the product characteristics and critical process outputs.
- Affinity diagram serves for identification of logical or causal connections between the problem elements.

The applied procedure of the SSM in the companies was verified by the efficiency evaluation of Six Sigma in the companies with a different level of quality management. For that purpose, the hypothesis was tested: "Implementation of Six Sigma methodology would decrease the cost on claims and non-conformities by at least 10%". Verification of the hypothesis was carried out through economic evaluation of the proposal based on the calculation of the cost of defects and through the calculation of DPMO, process efficiency, and Sigma level after the application of the model. We used the method of economic results comparison to compare the original and current situation of the critical processes.

VI. Lean Six Sigma (LSS)

Lean Six Sigma is a synergized managerial concept of Lean and Six Sigma. Lean traditionally focuses on the elimination of the eight kinds of waste classified as defects, over-production, waiting, non-utilized talent, transportation, inventory, motion and extra-processing. Six Sigma seeks to improve the quality of process outputs by identifying and removing the causes of defects (errors) and minimizing variability in (manufacturing and business) processes. Synergistically, Lean aims to achieve continuous flow by tightening the linkages between process steps while Six Sigma focuses on reducing process variation (in all its forms) for the process steps thereby enabling a tightening of those linkages. In short, Lean exposes sources of process variation and Six Sigma aims to reduce that variation enabling a virtuous cycle of iterative improvements towards the goal of continuous flow.

Lean Six Sigma uses the DMAIC phases similar to that of Six Sigma. Lean Six Sigma projects comprise aspects of Lean's waste elimination and the Six Sigma focus on reducing defects, based on critical to quality characteristics. The DMAIC toolkit of Lean Six Sigma comprises all the Lean and Six Sigma tools. The training for Lean Six Sigma is provided through the belt based training system similar to that of Six Sigma. The belt personnel are designated as white belts, yellow belts, green belts, black belts and master black belts, similar to judo.

Lean six sigma organizes lean and six sigma to cut production costs, improve quality, speed up, stay competitive, and save money. From six sigma they gain the reduced variation on parts. Also, lean focuses on saving money for the company by focusing on the types of waste and how to reduce the waste. The two approach coming into lean six sigma to better each other creating a well balanced and organized solution to save money and produce better parts consistently.

Tools for lean and Six sigma:

Lean: Kaizen, Value Stream Process Mapping, 5s, Kanban, Error Proofing, Productive Maintenance, Set Up Time Reduction, Reduce Lot Sizes, Line Balancing, Schedule Leveling, Standardized work, and Visual Management.

Six Sigma: Recognize, Define, Measure, Analyze, Improve, Control, Standardize, and Integrate.

5S

5S is a lean practice used to keep production workspace orderly and keep the workforce committed to maintaining order.

5S (Japanese)	5S (English)	Definition
Seiri	Separate or Sort	Separating needed tools, parts, and instructions from unnecessary items
Seiton	Set in Order	Setting things in order, creating optimal boundaries, and locations for each item in

		a work area
Seiso	Shine	Cleanliness of the work space after each day to maintain order
Seiketsu	Standardize	Reminds people to conduct Seiri, Seiton, and Seiso to maintain the work place and pristine condition
Shitsuke	Sustain	Ensuring that the organization has the discipline to sustain the habitat of sorting, organizing, and cleaning.

(Source: Wikipedia)

Lean Six Sigma (LSS) has been seen as a business improvement methodology (Pamfilie, Petcu and Draghici, 2012) integrating two distinctive management philosophies: Lean and Six-sigma (Pepper and Spedding, 2010) complementing each other in order to improve enterprises processes and results. This integration has been achieved blending their methods and principles (George, 2003) using the DMAIC (define, measure, analyze, improve, control) cycle as the conjoint continuous improvement framework (Cheng and Chang, 2012) and conjointly making efforts to reduce production defects and process variability along with process simplification and standardization and waste reduction (Qu, Ma and Zhang, 2011).
Some attempts to enlarge the DMAIC cycle to project management practices and process improvement have already been proposed. For example Puga, Soler, Maximiano and Wagner (2005) argue that Six Sigma initiatives are projects carried out to create a single result, such as the project management, whereas there is a great potential for integration between the DMAIC and project management practices, in which DMAIC will focused on finding solutions to problems and opportunities based on data sustained decisions and project management standards will provide the formal procedure for the implementation of these solutions. Also for Rever (2010) the incorporation of DMAIC steps in each project should help project managers to become not only more effective but also to achieve innovative results, arguing that Six Sigma can be added to project management providing:

• Suitable statistical process knowledge to better understand and improve future results;
• A set of solid step and tools for process improvement;
• Variability knowledge in order to reduce instinctive reactions;
• Based decisions on facts and concrete quantitative analysis.

VII. Conclusion

The lean six-sigma framework provides an impetus for establishing best practice with the company. It also provides the company with a performance benchmark on which it could base its future performance enhancement programs. As it has been observed that the level of its sigma is not satisfactory, there is no way to improve this by DMAIC. The implementation of lean six-sigma will save money which will result higher profit of the organization. As the businesses are influenced by globalization, the competition is arising more and more and so, to sustain in the global business every organization needs to maintain appropriate quality level. This study will contribute to a new management approach on improving business process for both efficiency and consistent quality customer service. After reviewing the benefits behind Lean Six Sigma, a company should determine whether or not Lean Six Sigma is for them. A clear trend is that Lean Six Sigma is diversifying into large service oriented organizations. In a case, a SME organization it is noted that the production capacity is 100 LEDs in 8 hours. The management promised incentives to increase the production to 140 LEDs. Hence the workers are very busy to produce their expected amount in the minimum amount of time. Almost all time they perform repetitive task which waste time. As a result, sometimes they produce defective LEDs. By applying 5s in SME, it is possible to reduce repetitive task by saving time. Consequently, there is less possibility for producing defective LEDs which is the main target of six-sigma. On the other hand by applying line balancing, productivity increases from 100 to 140 per day by reducing defect. Finally it is said that, it is possible to improve productivity by using lean six-sigma which is the main purpose of this study.

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