Application of Six Sigma DMAIC Approach in Manufacturing Industry- a literature review

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***Abstract*- In this paper, the details of a literature review carried out to examine the application of DMAIC (stands for define, measure, analyse, improve and control) in manufacturing industry to achieve the goals of Six Sigma concept are presented. While conducting this literature review, the papers containing DMAIC in their titles were gathered and studied. With the high productivity few other factors are also must be taken into consideration such as variety in product range, customer demands in terms of quantity and quality at a specified time of delivery, global competitors. The most recent and dominant philosophy named six sigma has been initiated to compact with all these requirements. This paper presents a review of six sigma case studies put into practice in manufacturing industries.**

***Index terms*- Six Sigma, Manufacturing, DMAIC, Productivity, Quality**

1.INTRODUCTION

An historical overview
Motorola receives the credit for creating Six Sigma,4 but the methodology and concepts are clearly rooted in the quality improvement tradition promoted by Deming's TQM principles and the works of Juran5. Since then, thousands of companies that have embraced this philosophy and have achieved immense success by adopting specific training and project management practices are;-

Table No. 1.1 Companies using six sigma methodology

General Electric	GE Capital	Motorola
Bank One	Lockheed Martin	Dow Chemical
Black & Decker	Federal Express	DuPont
Johnson & Johnson	Microsoft	National Semiconductor
Texas Instruments	Toshiba	United Technologies
Apple Computers	General Dynamics	Allied Signal
American Express	Intel	IBM
Bank of America	Bank of New York	Capital One Financial
Citigroup	Deutsche Bank	Fidelity
Fleet Bank	J.P. Morgan Chase	J.P. Morgan Chase
Morgan Stanley	Tower Group	Wells Fargo
Hewlett Packard	Honeywell	

Six Sigma was heavily inspired by six preceding decades of quality improvement methodologies on the work of pioneers such as Shewhart, Deming, Juran, Ishikawa, Taguchi. Like its predecessor, Six Sigma doctrine asserts that:

- Continuous efforts to achieve stable and predictable process results (i.e., reduce process variation) are of vital importance to business success.
- Manufacturing and business processes have characteristics that can be measured, analyzed, improved and controlled.
- Achieving sustained quality improvement requires commitment from the entire organization, particularly from top-level management.

1.1.1 Origin of Six Sigma:
Six Sigma was born in the 1980's at Motorola. Bill Smith, an engineer at Motorola's Communications sector, was quietly working behind the scenes studying the correlation between product's reliability and how often that product had been repaired during the manufacturing process. He presented a paper, which concluded that if a product was found

defective and correlated during the production process, other defects were bound to be missed and found later by the customer during early use of the product. However, when the product was manufactured error free, it rarely failed during early use by the customer. They also found that the foreign competitors were making more reliable products. As a result, Motorola began to improve the quality and simultaneously reduce the cost by focusing on product design and manufacturing. The Six Sigma architects of Motorola focused on making improvements in all operations within a process. This led to quantum leap in manufacturing technology in Motorola. The company saved $2.2 billion in 4 years. In the year 1988, Motorola received the first Malcolm Baldrige National Quality Award from the US government for its improvement record based on Six Sigma program.

1.1.2 Features of Six Sigma:

It has the following important features:

1. Six sigma shifts the paradigm quality as the cause of good business performance and not the effect. Before 1980's all process and product improvement techniques were aimed at continuous improvement of quality. Six Sigma propagates that all-round quality performance(error free performance excellence with continuous improvement) is bound to result in the attainment of the desired business excellence in terms of reduction in the cost of production, Maximizing of customer satisfaction and return on Investment.
2. The philosophy of Six Sigma is to make fewer mistakes in all the organizational activities and keep on reducing the mistakes.
3. It is a business strategy to reduce the cost by attaining good quality.
4. It is a statistical process control technique aimed at achieving total confidence in the company's products and service performances for the customers as well as the management.
5. It is a philosophy of achieving the ultimate goal of 'Do it right the first time every time'.
6. It is a performance measure. The sigma and Part Per Million(ppm) are correlated as indicated under;

Table No. 1.1 The sigma levels/ Six Sigma value chart

Sigma	Defect Per Million
2	308537
3	66807
4	6210
5	233
6	3.4

Source: www.sixsigmaspc.com

This implies that as compare to the 3 σ performance level, the 4 σ is ten times improvement in performance and as compare to 4 σ performance level; the 6 σ is 1800 times improvement in performance.

7. Sigma in statistics is used to indicate the standard deviation. A sigma value indicates the ability of a process to perform defect free work. The higher the sigma value, the better the process is performing and the lower the probability that a defect will occur.
8. The Six Sigma reduces the defect and variation in the product by improving the process that produces and delivers the product.
9. The Six Sigma is not delegable. The involvement of the top management is a must.
10. The Six Sigma principles and philosophy are equally applicable to the manufacturing and the services industry.
11. Six Sigma's main objectives are reduction of variation, defects, costs and cycle time, aimed towards maximization of customer satisfaction.
12. The focus of Six Sigma is on the following areas:
    - Independent variable to the process
    - Root cause of any problem and its elimination
    - Focus is on the inputs to the process and not on the output.
    - Focus is on the problem and not on the symptom.
    - Focus is in controlling the problem and not on monitoring.

1.1.3 Objectives of Six Sigma

1. Strategic level: at the strategic level, the goal of six sigma is to align an organization to its market

place and deliver real improvements (in terms of rupees) to the bottom line.

2. Operational level: at the operational level, the six sigma goal is to move the business product or service attributes within the zone of customer specifications and to significantly shrink process variation.

1.1.4 Goals /Purpose of Six Sigma:

1. To reduce variation:- the main objective of six sigma practice is to ensure consistency in performance so that the users and the customers can develop confidence in the quality and reliability in the products and services offered by the organization. Six sigma practice is oriented towards developing a manufacturing and/or service set up which has zero variation in both the product and the process.
2. To reduce defects/rework: the principle objective of the six sigma project is to eliminate or reduce the defects and rejections to practically zero. It is a process control technique. The Japanese mantra of 'Muda' ensures elimination of all wastage. Any rejection of rework, saved gets straightway added to the bottom line in terms of the profit of the organization.
3. To Improve Yield/ Productivity: a single rejection saved is an additional piece produced. Any time saved in reworking is time utilized for effective production of the products and services, which again adds to the productivity. It is also an important objective i.e. to improve the productivity by optimum utilization of the men, machin and material along with the elimination of the seven wastages. Higher productivity leads to more production, lower cost of production and better quality and competitiveness in the marketplace.
4. To enhance customer satisfaction: customers satisfaction is achieved by providing the products and service of right quality, in right quantity at the right time, right place and at right cost, fulfilling the customers' level of customers' satisfaction, which is the prime objective of any organization now a days. By providing defect-free products and services of consistent performance and quality, th six sigma project definitely enhances the customer satisfaction.
5. To improve the bottom Line: the most important objective/goal of Six Sigma is to improve the profitability and return on investment by reduction in the cost of production and processing by continuous process improvement. The Six Sigma activity improves substantially the bottom line, without any investment, just by training and changing the employees' mindset and garnering their greater involvement in their work and the organization.
6. To improve the Top Line: the other immediate purpose or objective of six sigma is improvement of the organizational reputation in the market and society at large by providing products and service of good quality without any deviation in terms of performance and reliability. This creates a strong brand image in the market in the market, leading to an increase in the sales and attainment of the market leadership position. Six Sigma projects alos leads to the development of better work culture, better relationships with customers and employees and improves the top line substantially.

1.1.5 Elements of six sigma:

There are three key elements of six sigma process improvement:

1. Customer: customers define QUALITY. They expect performance, reliability, competitive prices, on-time delivery, service, clear and correct transaction processing.
2. Processes: defining processes and defining metrics and measures for processes is the key element of six sigma. Quality requires looking at business from customer's perspective i.e. one must look at defined processes from the outside-in. By understanding the transaction lifecycle from the customer's needs and processes, one can discover what they are seeing and feeling. This will give chance to identify week areas within a process and then to improve them as per.
3. Employees: The company must involve all employees in six sigma program/project. Company/organization must provide opportunities and incentives for employees to focus their talents and ability to satisfy customers. This is important in six sigma that all

team members should have well-defined role with measurable objectives

2. LITERATURE REVIEW

Concerning the continuous improvement of companies, there are increasing needs to pursue new ways of thinking as a source of competitive advantage. More research in this area is necessary to contribute to the science and practice of implementation of six sigma to create value.

M.Shanmugaraja and M.Nataraj, N.Gunasekaran (2011) This research study proposes an innovative analysis for controlling the defects in aluminium die casting industry. In this analysis, casting process of a two-stroke engine oil pump body is concentrated. The component selected has often rejected due to blow hole defects. Six Sigma, the zero defect approach, is used in this study. Define measure, analyse, improve and control (DMAIC) problem solving methodology is applied for problem analysis. Taguchi's experimental design is used for process validation and improvement. The confirmation experiment showed that the rejection rate was reduced to 4.8% from 17.22%. The application of Six Sigma program with Taguchi technique has developed an innovative cost effective methodology for controlling defects in die casting process in less experimental time.

Ploytip Jirasukprasert, Jose Arturo GarzaReyes, Horacio Soriano-Meier, Luis Rocha- Lona (2012)The Six Sigma's problem solving methodology DMAIC has been one of several techniques used to improve quality. This paper demonstrates the empirical application of Six Sigma and DMAIC to reduce product defects within a rubber gloves manufacturing organisation. The paper follows the DMAIC methodology to investigate defects, root causes and provide a solution to reduce/eliminate these defects. The analysis from employing Six Sigma and DMAIC indicated that the oven's temperature and conveyor's speed influenced the amount of defective gloves produced. In particular, the design of experiments (DOE) and two-way analysis of variance (ANOVA) techniques were combined to statistically determine the correlation of the oven's temperature and conveyor's speed with defects as well as to define their optimum values needed to reduce/eliminate the defects. As a result, a reduction of about 50% in the "leaking" gloves defect was achieved, which helped the organisation studied to reduce its defects per million opportunities (DPMO) from 195,095 to 83,750 and thus improve its Sigma level from 2.4 to 2.9.

Akteekh-ur-Rehmen (2012) The manufacturing company under consideration recorded the high accident rates for last few years. These accidents cause the organization the heavy man-day loss, the production loss and heavy costs of insurance. The objective of health and safety department at the manufacturing company was to set and improve accidents prevention system. The paper presents how does the six-sigma technique will help to evaluate the safety and environmental hazards in per-formance of organizations? It is observed that the study helped the management to measure, analyze and improve over-all safety plan to protect the life and health of the employees.

Shahada, T. M., and Alsyouf, I. (2012). The purpose of this paper is to develop a Lean Six Sigma framework according to the Six Sigma systemic process improvement methodology; Define, Measure, Analyze, Improve and Control (DMAIC). It was implemented and verified at one engineering company in UAE. The results show that the process "Make-to-Order (MTO) projects" has a long lead-time. The main causes of the long lead-time are the subcontractors, the customers, and the company-implemented procedures. Using the framework, it was possible to identify the most significant reason for the long lead-time, analyze the root-cause(s), suggest three relevant solutions and select the most preferred one. Using the framework methodology the user will have a systematic approach for continues improvement. The originality of this methodology was evident in integrating and using tools related to lean-production, six-sigma, balanced scorecard, simulation and cost benefit analysis. The framework allows the user identify the process problem(s) and solve them effectively.

Shashank Soni, Ravindra Mohan, Lokesh Bajpal, S K Katare (2013) In this paper discusses the quality and productivity improvement in a manufacturing enterprise through a case study. The paper deals with an application of Six Sigma DMAIC (Define-MeasureAnalyze-Improve-Control) methodology in an industry which provides a framework to identify, quantify and eliminate sources of variation in an

operational process in question, to optimize the operation variables, improve and quality performance, viz., process yield with well executed control plans. Six Sigma improves the process performance (process yield) of the critical operational process, leading to better utilization of resources, decreases variations and maintains consistent quality of the process output. In this Paper identifies the root causes of failure for a welding process at a manufacturing plant and proposes to use Operational Six Sigma technique to eliminate the problem. In contrast to other method which measure and identify the nonconformance through destructive testing, a technique is proposed to use a mathematical model, which is later charted using SPC technique. The control chart for the mathematical model identifies the failure of the process in real time and will reduce/eliminate the testing process.

N.Venkatesh, C.Sumangala, Lancy D'souza(2013) Manufacturing sector is the back bone of the economy of any country. The economic health of a nation is decided on the basis of financial health of manufacturing sectors. It is mandatory for the manufacturing organizations to control the cost as they do not have the control over the price. To minimize the cost, it is required for them to reduce the defect rate. Six Sigma, a quality management system, is a customer-focused and data-driven quality strategy. It is a rigorous and systematic methodology that utilizes collected information and statistical analysis to reduce defect rate, measure and improve performance. In this paper the role of Six Sigma has been analyzed through case study of manufacturing industry. It is observed through the study that Six Sigma has contributed to the improved financial status, productivity and customer satisfaction. However its contribution towards the welfare of the work force and growth of the company is not significant.

Ratnaningtyas, D. D., and Surendro, K. (2013). Hospital provide a number of health services and proper health facilities for society, one of the healthcare is inpatient. Because of the daily high demand of inpatients healthcare in a day, some hospitals seems too overwhelmed to control the information flow. Mainly, hospital already used Hospital Information System (HIS) for helping managing information flow. But some of it does not really care about the quality of information. Information quality is a key element to determine the level of healthcare in hospital. By the improvement of information quality, the quality of healthcare would improve to support the patient's satisfaction. A method used for information quality improvement is Six Sigma. Six Sigma could be used for reducing information variance in healthcare, especially information that used in Hospital Information System.

P.R.Gajbhiye, A.C Waghmare, R.H.Parikh(2014) The lean manufacturing company under consideration recorded the high accident rates for last few years. These accidents cause the organization the heavy man-day loss, the production loss and heavy costs of insurance. The objective of health and safety department at the manufacturing company was to set and improve accidents prevention system. The paper presents how does the six-sigma technique will help to evaluate the safety and environmental hazards in performance of organizations. It is observed that the study helped the management to measure, analyze and improve overall safety plan to protect the life and health of the employees. The paper discusses real life case where six sigma has been successfully applied at one of the Indian small scale unit to improve safety in processes. The main aim behind this project lies to overcome those problems of the industries which are causing loss due to safety. In order to build up system capabilities and graduate towards higher sigma levels of operation, the backbone exercise of six sigma management system is reached by carrying out the failure mode effect analysis.

Aditya R. Wankhade, Sunil S.Girde, Pankag N.Bandabuche(2014) Industrial, manufacturing and service organizations are interested in improving their products and processes by decreasing the variation, because the competitive environment leaves little room for error. Variation is the enemy of quality which is defined and evaluated by the customers. We must deliver pro ducts and services at the ideal targets demanded by the customers. The traditional evaluation of quality is based on average measures of the process/product and their deviation from the target value. However, customers judge the quality of process/product not only based on the average, but also by the variance in each transaction with the process or use of the product. Customers want consistent, reliable and predictable processes that deliver or exceed the best-in-class level of

quality. This is what the Six Sigma process strives to achieve. Over the last twenty years, Six Sigma has been successfully implemented in many industries, from large manufacturing to small businesses, from financial services, insurance industry to healthcare systems. This paper deals with the implementation of six sigma methodology in service sector.

Amol.J.Gangai, G.R.Naik(2014) Aligning Lean manufacturing by applying six sigma in manufacturing industries gives a upper hand for the organization to reduce cost due to scrap & non value adding activities. Six Sigma is a disciplined, data-driven approach and methodology for eliminating defects in any process – from manufacturing to transactional and from product to service. The fundamental objective of the Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction through the application of Six Sigma improvement projects. This is accomplished through the use of Six Sigma sub-methodologies: DMAIC.The Six Sigma DMAIC process (defines, measure, analyze, improve, control) is an improvement system for existing processes falling below specification and looking for continual improvement. It can also be employed if a current process requires more than just incremental improvement. This paper includes a case study on Six Sigma optimization of thinner consumption. The optimization is carried out using six sigma tool without affecting the quality parameter.

Nunes, I. L. (2015). Lean Six Sigma (LSS) aims to help companies continuous improvement (CI), coping with the strong business competition and gaining organizational effectiveness. Both Ergonomics and LSS are system-oriented approaches and could have a synergistic effect in CI. The integration of Ergonomics and LSS requires a new methodological framework that evolves from their single approaches, which coherently applies the principles of both and simultaneously ensuring gains in productivity and in working conditions. To help SME (99% of all businesses in EU) to realize their full potential a tool that supports the implementation of the mentioned framework is also desirable. A practical tool to fulfill this goal can assume the form of a Decision Support System (DSS). Therefore the objective of this paper is to present the model of a framework and of an associated DSS.

Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., and Benhida, K. (2016). The purpose of this paper is to present a review and an analysis of the literature concerning a possible model for integrating three management systems: lean manufacturing, Six Sigma and sustainability. In particular, we analyzed current proposals and identified at the same time gaps in the existing literature from which we suggested future research directions for developing a specific integrated model, suggesting new opportunities and challenges that should be addressed by future studies. Both academicians and practitioners will find our review useful because it outlines the major lines of research in the field and their limitations.

Alhuraish, I., Robledo, C., and Kobi, A. (2017). Lean manufacturing and six sigma methodologies have been widely used in a large number of companies worldwide. However, many companies have found it difficult to successfully implement and sustain lean manufacturing and six sigma. It is, therefore, very important for companies to identify and understand the critical success factors for successfully implementing either six sigma or lean manufacturing. A comparative examination of lean manufacturing versus six sigma was conducted, and the success factors relevant to these two methodologies were identified. It was found that the most important success factors differed in terms of their significance for six sigma and lean manufacturing. Specifically, for organizations that have successfully implemented six sigma, skills and expertise ranked highest in importance. In contrast, for organizations that have successfully implemented lean manufacturing, employee involvement and culture change ranked highest. This study builds on current knowledge and fills a gap in the literature by providing more insight into the most critical success factors within companies that have already successfully implemented these methodologies. The results of the study will help organizations to make more mature and careful decisions regarding the critical success factors of each method. Therefore, in the pre-implementation stage, organizations can identify how their capabilities and resources can be utilized to accomplish the critical success factors for the implementation of lean manufacturing and six sigma, either simultaneously or sequentially. This is the first study that has conducted an examination to compare lean manufacturing and six sigma in terms of the

importance of the same specific critical success factors.

Costa, T., Silva, F. J. G., & Ferreira, L. P. (2017) Nowadays, market's constant changes require continuous flexibility and adaptation in the supply provided by organizations. In this context, the automotive industry represents one of the most demanding sectors due to the high levels of competition it is exposed to. Therefore, and so that these organizations are able to survive, it is crucial to seek operational excellence. This is undertaken through the constant processes improvement and continuous reduction of costs. This study was developed at a tire manufacturing company with the purpose of improving the rubber extrusion process of two tire semi-products: the tread and the sidewall. By adopting Six Sigma methodology and using the DMAIC cycle (Define-Measure-Analyze-Improve-Control), one was able to implement some improvement procedures whose resulted in a decrease of 0,89% on the indicator of work-off generated by the production system. This approach resulted in a significant financial impact (savings of over 165 000€ per annum) on the company's quality expenses.

Krotov, M., and Mathrani, S. (2017) Achieving the desired quality standard is crucial in manufacturing of nutritional premixes such as infant formulae. Issues of out-of-specifications and presence of foreign matter and/or bacteria are unacceptable in the industry. Six Sigma is a renowned approach for improving quality management through eliminating variation. The main objective of Six Sigma model is to highlight the critical processes that need controlling to attain the required quality for both, internal and external customer. This paper aims to showcase the development and application of Six Sigma framework in improving quality management through the use of appropriate tools in a medium-sized premix manufacturing facility in Auckland. The company is experiencing quality issues in terms of meeting standard specifications of ingredient contamination within end products, leading to late deliveries and impacting business reputation. The proposed framework standardizes the Six Sigma methods Define, Measure, Analyse, Improve and Control for food manufacturing business. Using this framework, the study optimizes the manufacturing process around the blenders: loading, mixing blenders leading towards packaging. The results describe the improvement in meeting specification standards, on-time deliveries and reduction of rework. The research outcome provides a guidance for small- and medium- sized food manufacturing enterprises to effectively adopt a Six Sigma framework to enhance quality management through eliminating variation in the production processes.

3. CONCLUSION

From the above study conclude that Six sigma methodology implemented in manufacturing industries resulted in increase in sigma level, reduced defects, improved productivity, improved safety working environment, reduced safety hazards, improved customer satisfaction. In a developing country like India six sigma is a power full tool which can be initiated in all organizations to improve financial status, growth of the firm. Tools like Lean manufacturing, Triz also can be integrated with six sigma methodology to achieve best results.

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