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A Review of Six Sigma DMAIC Methodology, Implementation and Future Research in the Manufacturing Sector

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Abstract – *The objective of this paper is to present a review of six sigma DMAIC Methodology (D-Define, M-Measure, A-Analyses, I- Improve and C-Control). The papers containing DMAIC in their titles were collected and studied during this literature review. The results of the studies reported in this paper have confirmed that DMAIC is a compatible model for the benefit of the Six Sigma concepts in the manufacturing sector. In this background, this paper has been concluded by suggesting future research to examine the application of DMAIC in many areas.*

***Key Words*: Six Sigma, DMAIC, DMADV, DPMO**

1. INTRODUCTION

Modern organizations are trying hard to improve their overall performance to face the ever increasing intensity of competition. While carrying out this task, modern organizations have been striving to apply appropriate strategies in all of their endeavors. One of the strategies that have been finding wide and deep applications in modern organizations is "continuous quality improvement" with the reduce cost, defects and cycle time. By adopting this strategy, modern manufacturing organizations have been striving to improve quality continuously in their endeavors by adopting competitive strategies. One of these competitive strategies is 'Total Quality Management' (TQM). After the emergence of TQM principles in the world, the manufacturing organizations began to adopt tools, techniques and systems to achieve continuous quality improvement. Some of them include 'Cause and Effect Diagram', 'Kaizen', 'Quality Function Deployment' (QFD) and 'ISO 9000' series based quality management systems.

Time and again, researchers and practitioners have reported that these TQM tools, techniques and systems have facilitated manufacturing organizations to achieve "continuous quality improvement". Yet, some practitioners and researchers began to find out that the implementation of TQM principles, tools, techniques and systems often failed to aid the manufacturing organizations towards achieving high profitability. Hence, the practitioners began to realize the need for a TQM model that would facilitate the manufacturing organizations to achieve profitability. As a result of this realization, Six Sigma concept emerged in Motorola in the late 1980.

Six Sigma is the methodology to achieve customer delight by reducing number of defects and cycle time to a level of 3.4 defects per million opportunities in products processes and service and thereby reducing

- Productivity improvement
- Market-share growth
- Customer retention
- Cycle-time reduction
- Defect reduction
- Culture change
- Product/service development

Sigma is a letter in the Greek alphabet which is used to designate the distribution or spread about the mean of any process or procedure. In other words, sigma may be described as the number of standard deviations we can fit between the mean and the nearest specification or measure of the number of defects per opportunity produced by a process.

Sigma level is a business metric used to indicate the performance of a process relative to a specification. The sigma level is used to account for complexity which allows for the comparison of dissimilar goods and services. In other words Sigma level is a statistic used to describe the performance of a process to the specification limits. It is the number of standard deviations from the specification limits to the mean of the process.

2. SIX SIGMA METHODOLOGIES

There are two major methodologies used within Six Sigma, both of which are composed of five sections.
DMAIC – It refers to a data-driven quality strategy for improving processes. This methodology is used to improve an existing business process.

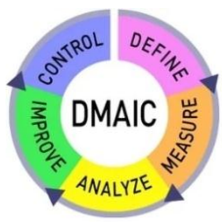

Fig. 1.1. Cycle of DMAIC

- **Define** – Define the problem or project goal that needs to be addressed.
- **Measure** – Measure the problem and process from which it was produced.
- **Analyze** – Analyze data and process to determine root causes of defects and opportunities.
- **Improve** – Improve the process by finding solutions to fix, diminish, and prevent future problems.
- **Control** – Implement, control, and sustain the improvements solutions to keep the process on the new course.

DMADV – It refers to a data-driven quality strategy for designing products & processes. This methodology is used to create new product designs or process designs in such a way that it results in a more predictable, mature and defect free performance.

- **Define** – Define the Problem or Project Goal that needs to be addressed.
- **Measure** – Measure and determine customers needs and specifications.
- **Analyze** – Analyze the process to meet the customer needs.

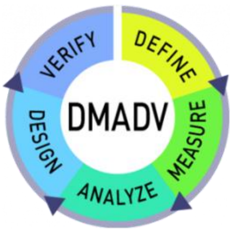

Fig. 1.2. Cycle of DMADV

- **Design** – Design a process that will meet customers' needs.
- **Verify** – Verify the design performance and ability to meet customer needs.

3. LITERATURE REVIEW

The literature review being reported here was carried out in papers whose titles contain the phrase DMAIC were downloaded from the websites of leading databases namely Emerald Insight (http://www.emeraldinsight.com), Science Direct (http://www.sciencedirect.com), and IEEE (http://www.ieeexplore.com). On over viewing these papers, it was realised that DMAIC has been applied in different manufacturing sector. After that, these papers were studied and extracts were drawn and reported here, the information and knowledge derived by studying these papers were used to identify future direction of research. The details of these activities are presented in the following sections of this paper.

Pereira et al (2017) applied DMAIC, Statistical process control (SPC) for solving quality problems in tyre production preparation process. This work presents the implementation of SPC to bead production. From an initial process analysis and a Pareto analysis, the tyre non-conformity with the highest rate was retained air. The cause-effect analysis performed, revealed that the cause of retained air originated from the beads production, mostly in the narrow beads. A DMAIC cycle and SPC was applied on that type of bead production, and on the APEX machine that produced it, during a six months' period. Parameters to be controlled were defined as the bead dimensions and weight, as well as the variables to measure them. Twelve experiments were defined and carried out. It was concluded that the value specified for the temperature parameter was 75°C and, for the extrusion speed, 7 rpm, with width, thickness and weight with good Cp and Cpk values. After the project, the number of non-conformities was reduced, and consequently the quality rate increased by 41%, as did the process control and capability. This work proves that the application of lean manufacturing and six sigma to companies improves their business performance, confirming that this philosophy brings profits to companies [2].

Pugna et al. (2016) Using Six Sigma Methodology to improve the assembly Process in an automotive Company. By DMAIC Six Sigma methodology to the riveting process the following conclusions were drawn: the riveting hand tool design was improved allowing a smoother handling, a Poka-Yoke device was installed signaling acoustically and visually when the necessary down force was attained, the riveting process was brought in-control, the riveting process capability was substantially improved on short and long term, C_{pk} increased from 0.96 to 1.72, Sigma Level short-term increased from 2.9 to 5.2, Sigma Level long-term increased from 1.4 to 3.7, DPMO were reduced from 81,000 to 108, improving the riveting process led to ≈ 40% defect reduction, choosing the most suitable supplier led to ≈ 30% defect reduction [1].

S. Suresh, A. L. Moe and A. B. Abu (2015) [28] have used

Six Sigma DMAIC methodology for defects reduction in manufacturing of automobile piston ring. Using the Six Sigma method, the rejection percentage is reduced by 13.2% from the existing 38.1% of rejection. Further improvement in the rejection is expected in the long run after the continuous implementation of all the solutions [9].

Jirasukprasert et al. (2014) reported the implementation of DMAIC methodology for reducing defects in rubber gloves manufacturing process. In define phase, the problem was identified. This problem was that, a large amount of rubber gloves had been rejected by the customers due to defective gloves. In measure phase, the defects were measured, and the gloves that more leaking and dirty were identified. The present level of sigma was found to be 2.4 with 1, 95,095 DPMO. In analyse phase, 'oven's temperature' and 'conveyor speed' were identified as the critical to quality (CTQ) parameters of manufacturing gloves. In improve phase, the design of experiment (DOE) was conducted to identify the best oven's temperature and the best conveyor speed. The analysis of the results of these experiments indicated that, the best oven's temperature would be 230°C and best conveyor speed would be 650 rpm. In the control phase, the trial run was conducted with best values of the CTQ parameters. As a result of applying the best values of CTQ parameters in the manufacturing of gloves, the quantity of gloves leaking was reduced by 50%. The reduction of DPMO was achieved from 1, 95,095 to 83,750, and sigma level improvement from 2.4 to 2.9 were observed [5].

Ghosh and Maiti (2014) proposed a data mining driven DMAIC framework for improving quality of the casting of six-cylinder engine head. During the define phase, it was found that, the rejection and rework of the casting of six-cylinder engine head were more than 20%. The company set the objective to reduce the total defect rate by these castings to less than 5% within six months. A process map was drawn to identify the influential factors. During the measure phase, the cost of poor quality (COPQ) was calculated to estimate the impact of casting defects on business profit. Pareto chart was drawn to identify the major defects. The study of this chart revealed that, results of 80% of rejections were caused due to gas porosity. Further, they conducting of brainstorming. In analysis phase, two data mining-based tools called 'classification and regression tree' (CART) and 'chi-squared automatic interaction and detection' (CHAID) were applied to identify the most significant factors causing gas defects in casting. In improve phase, remedial actions were determined. In control phase, the continuous monitoring of processing stage was carried out for 15 days to identify the process behaviour after the actions were taken. It was observed that, the gas defect has been reduced significantly. The annual savings were calculated to be INR 16 million (US $0.28 million) [4].

Kumaravadivel and Natarajan (2013) carried out a research to reduce the defects while manufacturing the casting of flywheel by using DMAIC methodology. The tools used during the pursuance of this research were process map, cause and effect diagram and failure mode effect analysis (FMEA). During the define phase, it was found that, 6.94% of the casting of the flywheels manufactured were rejected. The reasons for rejecting these castings were attributed to sand inclusions, blow holes and slag. In measure phase, the supplier, input, process, output and customer (SIPOC) diagram was drawn to map the flywheel casting process. Subsequently, voice of customer (VOC) was applied to identify CTQ parameters. The intensiveness of these CTQ parameters was checked by considering these variables under the names 'key process input variables' (KPIV) and 'key process output variables' (KPOV). At the end of this phase, Pareto diagram was drawn. This diagram indicated that, blow holes, slag and sand inclusion caused 24, 36 and 40% of defects respectively in the total defects in the casting of the flywheel. These three defects were considered for overcoming the same and improving the quality of flywheel casting process. During this phase, the sigma value was found to be 3.49. During analyse phase, cause and effect matrix, FMEA and cause and effect diagram were used to identify KPIV and KPOV against the selected CTQ parameters. During the execution of improve phase, RSM and analysis of variance (ANOVA) were applied to determine the solutions for achieving quality improvement of flywheel casting process. At the end of executing this phase, 15 remedial actions were suggested to improve the quality of flywheel casting make the process as robust as possible. In the control phase, the solutions evolved in the previous phase were applied in practice. This application resulted in the decreasing of the rejection level from 6.94% to 4.69% and increase in the sigma level from 3.49 to 3.65 [7].

Kaushik et al. (2012) reported that, the implementation of Six Sigma methodology in small and medium-sized enterprise (SME) by using DMAIC as a tool to control the variation in the processing stages of the product. The DMAIC methodology was applied to solve the high rejection of bushes in bi-cycle chain assembly. In define phase, process map and a SIPOC diagram were developed to document the manufacturing sequence of bush and to identify the process or product for achieving improvement. The sigma level was found to be 1.4. After the implementation of DMAIC phases in this bicycle manufacturing unit, the sigma level increased from 1.40 to 5.46. In the end, the application of DMAIC in this company gave rise to the annual monetary savings of INR 0.288 million [6].

Li et al. (2011) reported the application of DMAIC methodology for improving the efficiency of information technology (IT) help desk service quality through e-Help-desk system of the Company in Taiwan. In define phase, it was found that, the IT help desk system needed improvement since the average processing time was as high as 168 minutes, and also the processors were unable to handle the multiple requests at a time. In measure phase, it was measured that, 74% of the processing time accounted for the data transfer through personal computer (PC), electronic network and e-mail. The SIPOC diagram was drawn to determine the time between the submission of the request by the users and processing of the requests by the helpdesk. From the process capability chart, it was found that, the current sigma level of the company was 0.84. In analyse phase, it was confirmed that the waiting time accounted for 79% of the total processing time. In improve phase, the solution conception (e-Help-desk system) was developed by using the cause and effect diagram. The eHelp-desk system was generated and implemented. In control phase, the performance of the IT help-desk system was assessed by drawing data by supplying a questionnaire among the users. The eHelp-desk system showed a drastic improvement in sigma level from 0.84 to 2.07. The waiting time was reduced from 131 to 71 minutes and also the monetary savings of New Taiwan Dollars (NTD) 26,856 per month was achieved [8].

Chen et al. (2009) have reported a research in which, DMAIC phases were applied to determine the optimum process parameters while using the plasma-cutting machine. This research was conducted in an electrical switchboard manufacturing company. In define phase, brainstorming sessions were conducted to investigate the deviations encountered in the process of making hole by using the plasma-cutting machine. In measure and analysis phases, the Taguchi experiments were carried out to evolve solutions for preventing the occurrence of bevel and smallest diameter deviations. The optimum values of the parameters were found out. Subsequently, response graphs were drawn. Then t-test was conducted. Using this test, the significance of the factors was examined. In improve phase, a confirmation test was conducted by applying the solutions evolved in the previous phase. The examination of the holes cut by applying these solutions indicated that, the bevelness and roundness deviation fell within the admissible levels. In control phase, the details of parameters and their optimum values were informed to the production department of the company. The Six Sigma team of this department was required to apply these values in real time practice. If necessary, the real-time Taguchi experiments would have to be conducted further to reduce bevelness and roundness deviations[3].

Tong et al. (2004) presented a case study in which the quality of printed circuit board (PCB) was improved by applying the DMAIC approach. In define phase, the solder paste volume (height) on the solder pads of the screening process was identified as CTQ characteristic. In measure phase, the Cyberoptics Cybersentry system was used to measure the solder paste height on five PCBs for every four hours. Subsequently, the solder paste height data were recorded in the statistical process control (SPC) data record sheet by the operators. Further, X-R control chart was plotted. In analyse phase, the process capability for solder paste height in all six semi-automatic screening machines was analysed against the current printing performance. In improve phase, DOE was conducted to determine the optimal settings of all CTQ factors in the screening process. The parameters considered while conducting DOE were solder paste viscosity, speed of squeegee, and pressure of the squeegee, age of stencil, solder paste volume, blade type and side of the stencil. In the control phase, the control strategies were recommended to sustain the improvement of the sigma level in the screening process. The sigma level of the screening process could be improved from 1.162 to 5.924. Thus, the Six Sigma level was nearly achieved [10].

Tushar N Desai and Dr. R L shrivastava (2008) [15], in their paper they have discussed the quality and productivity improvement in a manufacturing enterprise through a case study. The paper deals with an application of Six Sigma DMAIC 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 sustain performance viz. process yield with well-executed control plans. The process yield was improved as a result of implementing this methodology. It has effect of improved and better utilization of resources and decreased variations. It also helped in maintaining consistent quality of the process output [11].

On the whole, the authors of the above papers have claimed that the application of DMAIC resulted in an increase of sigma values in the performance of the manufacturing companies in which case studies have been conducted. Some authors have also pointed out that, DMAIC application facilitates to achieve substantial financial savings.

4. CONCLUSION AND AREAS FOR FUTURE

RESEARCH

The objective of review was to understand the status of Six Sigma as on yesterday, today and tomorrow. The conclusion is based on the review of journals. The trend implies that Six Sigma research activities have increased significantly after 2005. Six Sigma research has scattered in a wide range across various journals domains and fields has attracted the attention of academics and practitioner. During last decade, Six Sigma has achieved a reasonable maturity and there has been substantial contribution made in Six Sigma framework to extend application from manufacturing to services context. Although the review does on claim to be exhaustive, it does provide reasonable insight in to state of art Six Sigma research. Based on the literature review presented in the paper, we identify following directions of future research:

1. There has been a considerable research on Six Sigma fundamentals in last decade. Instead of discussing much about the Six Sigma basics and comparison of Six Sigma with other quality initiatives, more focus should be on how to integrate other quality efforts in to Six Sigma to achieve quantum gains.
2. There is a need to have more case studies clearly presenting the application of Six Sigma within each domain in a proposed framework.
3. More research is to be conducted on user experiences reflecting pros and cons of Six Sigma in such context.
4. There is great potential for research on Six Sigma and its linkages with other initiatives, Six Sigma and Statistical thinking, Six Sigma in Supply Chain Management.
5. In service sector education and healthcare are two major are areas where Six Sigma is either not visible or is at very nascent stage. Six Sigma implementation

strategies and critical success factors for successful deployment of Six Sigma project are other areas for future research. Applications of Six Sigma projects in Indian states and central government run organizations and administration have also not been explored.

6. The areas for further research can be summarized as Applications of Six Sigma in manufacturing & service sectors areas which are not explored yet with full potential, areas of Six Sigma enhancement and integration of Six Sigma with other quality initiatives, critical success factors for successful deployment of Six Sigma and Six Sigma implementation strategies. In Six Sigma projects true and quantum gains can be achieved by customizing the problem and paying attention to each and every variable which is responsible for manufacturing the desired product/services at minimum possible cost. The integration of Six Sigma with lean manufacturing and supply chain management and other innovative management techniques will be ideal solution for achieving maximum productivity. Six Sigma will be prevailing in industries as long as Six Sigma projects yield measurable or quantifiable bottom line results in financial or monetary terms.

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