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QUALITY IMPROVEMENT IN MANUFACTURING PROCESS THROUGH SIX SIGMA: A CASE STUDY OF INDIAN MSME FIRM

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Abstract: Manufacturing sector is instrumental in driving economic growth of a country. With a vision for India to be a global manufacturing hub, boost the economic development and create ample employment opportunities, the Government of India has taken several steps in the past few years to strengthen the manufacturing capabilities in the country. Besides strengthening the logistic and supply chain infrastructure there is a need to build on the global quality standards and innovation culture for right positioning of Indian produce in the global supply chains. With the support of the Government initiatives, several manufacturing organizations are encouraged to focus on improving the quality of their products and processes. However, MSME organisations had to face several challenges such as limited skills, resources, awareness and lower acceptance of quality management initiatives that limit their scope of quality focus. This study discusses the implementation of a Six Sigma quality improvement project in an Indian MSME organization involved in the production of portable amplifier systems with an aim to reduce the repairs and rejections.

The study provides a systematic roadmap for implementation of quality improvement projects in small scale manufacturing processes. We also illustrate an effective multi-criteria defect prioritization analysis based of Fuzzy-AHP methodology to identify the key defects to prioritize the improvement efforts. Compared to the frequency based prioritization as discussed in the literature, the proposed method prioritizes the key defect considering attributes critical to customers as well as to the manufacturer. The study also illustrates application of several quality management techniques such as cause and effect analysis, current reality tree, SIPOC analysis, and quality control charts in the DMAIC stages.

Keywords: Six Sigma, DMAIC, Fuzzy AHP, Quality, Manufacturing.

MSC: 90B85,90C26.

1. INTRODUCTION

Manufacturing sector in India has witnessed growth in the past few years. Realizing the opportunities underlying this sector for the growth of the Indian economy and the potential to generate large-scale employment, the Government of India launched several initiatives such as Make in India for the growth of this sector. In 2013-14 it is reported that Indian manufacturing sector contributes around 2% to the world's manufacturing output, which is 16-17% of GDP of India [20]. It is expected that India will become the fifth largest manufacturing country in the world by 2025, and the sector will contribute to 25% of GDP creating 100 million jobs [19]. There has been around 33% contribution of Micro, Small, and Medium Enterprises (MSMEs) in the countrys total manufacturing Gross value of output (GVO) during the last five years [21].

MSME sector is instrumental in driving the Indian growth engine given its contribution to employment generation, manufacturing output and industrial development in rural areas at low capital investment and technology requirement. Indian manufacturing (specially the MSME sector) faces several challenges on the account of infrastructure bottlenecks, tedious Government processes, quality of output and restrictive labour laws resulting in poor positioning in global supply chains. The manufacturing organizations in MSME sectors are required to move their focus from low quality and low cost to global quality standards and innovation culture. To sustain the momentum of growth, right positioning of quality of products manufactured in India in global supply chains is utmost important. Barriers of limited skills, resources, awareness, and acceptance of quality management initiatives along with scarcity of literature in this domain add to the challenges of MSME manufacturing sector in taking initiatives for improvement in quality of their products and processes. In the literature, several approaches like Six Sigma, ZED, Lean principles, Quality circles, 5S, and JIT are discussed for achieving the strategic goals for quality management and improvement [11]. The study presented in this manuscript discusses the application of DMAIC Six Sigma methodology in an Indian MSME organization to improve the quality a Portable Amplifiers manufacturing process. The study conducted with the aim to reduce variation and waste in process output finds real life implications by providing a roadmap for similar future projects.

The study presented in this manuscript is part of a quality improvement project undertaken by the firm to improve productivity of the manufacturing process, of the amplifier production process, and the quality of the final output of the product. Limited details of the firm are disclosed here due to commercial confidentiality. The firm is engaged in the B2B sales and has been observing high rejections and repairs from the past few planning periods along with continuous customer demand for improving the quality. Rejection and repairs were accounted for increase in waste and overall cost of the firm's operations. Hence, the firm made the quality improvement efforts, realizing the need of dedicating strategic efforts to sustaine growth through quality improvement and management of overall cost by minimizing the process variations and waste. The manufacturing process of the Portable Amplifier in this organisation is categorized in seven sequential stages named as chassis preparation, anodizing, powder coating, printing, fitting, final fitting, and packaging & dispatch. It is designed following the industry standards and establishing proper quality checks at each stage of the manufacturing. The management formed a team consisting of the quality head, managers of production, purchasing and maintenance, quality control inspectors, and research advisors to investigate the scope of the process improvement. An initial study showed that rejections are accounted to various defects occurring at various stages of the production. The team suggested implementing improvements by handling process variation through sequential efforts and targeting improvement efforts at stages [22, 36]. The study presented in this manuscript discusses Six Sigma study for the quality improvement in the final fitting stage (sixth stage of the process) of the manufacturing process.

The study is conducted following the Define-Measure-Analyze-Improve-Control (DMAIC) Six Sigma model for achieving the strategic goals for quality improvement in the final fitting stage. Generally, when conducting a Six Sigma study,i.e., defining the problem and objective of the study, one should first understand the important aspects and practical details of the process under investigation. Subsequent to the fitting stage (fifth stage) of the manufacturing process, each unit is subjected to live testing in the final fitting stage. The final fitting stage has the following steps: (i) mounting of assembled unit in the chassis, (ii) securing nuts and bolts, (iii) application of anti-seize paste on nut joints and (iv) assembly of the complete unit [18] (v) final testing. The output of the final fitting stage is subjected to jerk testing by emulating field use to test the stability of the assembled unit. It is essential to check and verify whether the product is reliable and can withstand all the situations that can arise in its operational life [6, 15].Final fitting stage, along with the whole fitting stage, is crucial in determining the output quality of the manufacturing process [21] as it directly relates to the field failures and can act as a cause for firm's major losses. Product failures during the warranty period add substantial cost burden on the firm. Minimizing the defects encountered while jerk testing, the firm can also optimize its warranty cost.

This study deals with the variations arising in the final fitting stage of the manufacturing process as a result to the jerk testing. DMAIC Six Sigma model has been utilized for reducing these variations in the final fitting stage. The stages of DMAIC model of Six Sigma are executed following the Plan-Do-Check-Act (PDCA) method. Appropriate statistical and managerial tools and techniques are identified through detailed review of literature and implemented in DMAIC stages to achieve the desired objective.

Six Sigma is a data driven statistical approach, embedded in managerial philosophies, that aims at reducing the process variations and improving the bottom line of the process. The pioneer of Six Sigma, Motorola, started its quality initiative programme in 1987. After Motorola, many companies such as General Electric (GE), DuPont, Honeywell, Samsung, Texas Instruments, ICICI adopted Six Sigma methodology for quality improvement [24, 25, 27].Initial applications of Six Sigma projects were primarily in manufacturing sector, later, diversified in different industries with different objectives. In the literature, enormous work is published related to Six Sigma studies. Table 1 lists selected Six Sigma studies along with the objective and scope of the study. Though there is a vast literature of Six Sigma studies, the studies dealing with quality improvement for MSME sector, especially in Indian context, are limited. Undertaking a quality improvement project requires organisations to make efforts particularly with respect to budget, time, skills and involvement of their employees, which remains a challenge for organisations and further limits their initiatives. Our study contributes in by providing a case study of implementation of a Six Sigma study in the Indian MSME sector.

A Six Sigma project is implemented following an appropriate model of Six Sigma. In the literature of Six Sigma, DMAIC model is most widely discussed and used. DMAIC is a linear framework of quality improvement defined in five stages namely, define, measure, analyze, improvement, and control. The DMAIC model [33] aims to improve, optimize, or stabilize an existing process by detecting and removing the defects or inefficiencies in the process, specifically the output defects. The other widely used model of Six Sigma is DMADV (Define, Measure, Analyze, Design and Verify) applicable in the new product, service or process development projects [4, 37]. Other than DMAIC and DMADV several tailored models of DMAIC are proposed in the literature specific to a particular application [5]. Table 1 lists some of the important contributions of Six Sigma implementation in the literature also mentioning the model of Six Sigma followed in the study. Each stage of DMAIC model has a well-defined objective along with a set of inputs and outputs. The objectives of DMAIC stages are met through the application of tools and techniques of quality management based on statistical, mathematical, and managerial methods. A review of the literature presented in Table 1 also lists the tools and techniques embedded in the Six Sigma model. The techniques used in our study are discussed along with the case study in Section 3.

2. RESEARCH CONTRIBUTIONS

This study presents a step by step DMAIC Six Sigma implementation roadmap for improving the quality of the final fitting stage of the production process

Citations	Objective/focus	Area of application	Six sigma methodology	Tools/technique used
[10]	Taguchi based Six Sigma approach to optimize plasma cutting process with a result of reducing number of experimental trials.	Manufacturing sector	DMAIC	C&E diagram, Taguchi Design of Experiment
[11]	An application of Six Sigma framework in Indian small scale industry to improve customer delivery commitments in service sector.	MSE firm (Service sector)	DMAIC	CTQs, SIPOC, C&E diagram, Pareto chart, 5 why technique
[14]	To propose a methodological approach to design a Product driven System (PDS) and validate its feasibility and efficiency using a real industrial case.	Service sector	DMADV	Affinity diagram, QFD, C&E diagram
[17]	To reduce the defects and improve the first pass yield of a grinding process in the manufacturing of automotive products.	Automotive supplier company	DMAIC	SIPOC, Regression analysis, Gemba analysis, Design of experiments
[25]	To improve the quality of the credit card account opening process in a bank using Six Sigma methodology.	Banking sector	DMAIC	Project charter, SIPOC, C&E diagram, Pareto chart
[27]	Quality improvement study for an aerospace engine assembly process.	Manufacturing sector	DMAIRC	Moving average Con-trol charts, C&E diagram, FMEA
[28]	DMADV Six Sigma model is used in this paper to design a new dormitory concept at the University of Miami. It is intended to provide a roadmap for conducting a Design for Six Sigma (DFSS) project.	Housing	DMADV	FMEA, Project char-ter, Kano survey, QFD
[30]	A real life case study on summer lodging operation and the objective was consistent to deliver high quality service system in hotel industry.	Hotel industry	DMAIC	C&E diagram, Poke-Yoke, service quality
[31]	To improve the casting process in the foundry by measuring the sigma level.	Founder industry	DMAIC	CTQs, Process map-ping, Taguchi DOE, ANOVA
[34]	This paper presents an effort to explore the adoption of Six Sigma to identify defects and guide process improvements in energy meter-reading in the context of public utilities.	Service sector	DMAIC	Pareto chart, C&E diagram, Affinity diagram, Control charts, Interrelationship diagram
[36]	To identify and eliminate the sources of variations, in order to improve the process productivity of a portable amplifier production process.	MSME firm (manufacturing)	DMAIC	Project charter, SIPOC, Check sheet, p-chart, Pareto chart, C&E diagram, CRT
[38]	To examine the effect of implement-ing Radio Frequency Identification (RFID) technology on improving effectiveness and efficiency of out-patient surgical processes in hospitals.	Health care sector	DMAIC	CTQs, Value Stream Map, Poke-Yoke, Simulation

Table 1: Six sigma studies in different sectors

of portable amplifier in an MSME manufacturing firm in India. Based on the discussion above, the significant contributions of this paper are:

- The existing research focusing on implementation and execution of Six Sigma approach for MSME sector of developing countries is limited. This study presents an application of DMAIC model of Six Sigma with a novel way of analyzing the key defects in the final fitting stage of the production of a portable amplifier process.
- The study aims at identifying the key defects in the process output and reducing the variations in the final fitting stage by analyzing root causes of the defects and suggesting improvement measures. The improvement measures are to be established in terms of achieving targeted Sigma level of the process.
- The existing Six Sigma studies in the literature mainly identifies key defects targeted in the improvement efforts based on frequency, and the defect(s) with highest frequencies are selected to deal in the projects.We focus more on other attributes such as criticality of defects; expected gains in monetary terms, etc.,usually ignored while selecting the key defects. Hence, we propose a Multi Criteria Decision Making (MCDM) approach for identification of key defects considering criticality of defect as per customer requirement, expected monetary and time requirements to deal with a defect, expected improvement in the process and fraction defective value. The selection of key defects based on customers and managements preferences lead to greater customer satisfaction and higher monetary gains.
- It is often observed that decision makers preferences tend to be imprecise and unquantifiable. Unavailability of the past data, absence of appropriate methods of data collection and limited resources in the MSME firms make the decision process even more imprecise. Linguistic preferences of the decision maker help dealing with the imprecision and un-quantification issues. Fuzzy set theory is an effective methodology for addressing the impression of information. In this study we have demonstrated the application of multi-criteria decision methodology (MCDM) Analytical Hierarchy Process (AHP) integrated with fuzzy set theory (named as Fuzzy Analytical Hierarchy Process (FAHP)) for multi-criteria prioritisation of key defects.

3. RESEARCH METHODOLOGY

As discussed in the introduction, the quality improvement project for amplifier manufacturing process using Six Sigma methodology is implemented by handling process variation in manufacturing process through sequential efforts [22, 36]. This study focuses on quality improvement in the final fitting stage of the manufacturing process following DMAIC Six Sigma approach. Several tools and

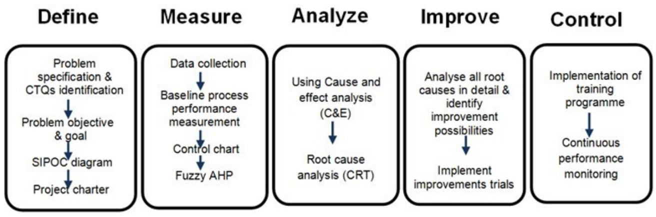

Figure 1: DMAIC Model Framework for Final Fitting Process

techniques have been embedded in the different stages of DMAIC model including Supplier-Input-Process-Output-Customer (SIPOC) analysis, control charts, F-AHP, Cause and Effect (C&E) diagram and Current Reality Tree (CRT) [3, 8, 16, 32] to execute the improvement efforts.

Define phase of the DMAIC model helps in understanding and documenting the problem. In this paper, project charter and SIPOC diagram have been used in the define phase. Project charter explains a thorough detail of the identified problems, objectives, and goals of the project along with various other elements like background and rationale of the project, project team, project plan, and project timeline [25, 36]. SIPOC diagram documents complete information about the process and their related inputs and outputs [34].

During the Measure phase, based on problem definition, key defects are prioritized and the baseline process performance is measured. FAHP, check sheet data, p-chart and process sigma level [8, 16] have been used in this study to prioritise and measure the process performance. FAHP is useful in prioritizing the alternatives based on several criteria under fuzzy environment. We have used FAHP methodology to prioritize the defects identified in the final fitting process based on linguistic preferences of the decision makers on several attributes. Data collection is done using check sheet, p-chart for fraction defective, used to check whether the final fitting process is under control or not [22], and baseline sigma level is calculated.

Analyze phase of DMAIC model is aimed at identifying the causes and root causes of the key defects. C&E diagram and CRT [13] method have been used to identify the important causes and root causes of the vital defects in the final fitting process.

The improve phase follows the analyze stage wherein the improvement efforts are established and implemented to address the root cause of the problem. The aim is to evaluate the potential solutions of the identified root causes. In the control phase of the Six Sigma DMAIC model, the process is monitored and controls the improvement efforts to sustain the process sigma level. Figure 1 describes the research methodology framework adopted in this paper.

Project Charter	
Project title : Defect reduction in final fitting process	
Project objective and goal : To reduce the displacement of component defect by 50%	
Project location : An Amplifier Production facility in Delhi NCR, India	
Background and Rational for project selection :	
In the baseline process, Prioritize the defects in which displacement of component failure has found to be highest priority as compared to the other defects based on expected values of multiple factors like cost, time, quality improvement etc.	
Project team :	Quality Head
	Managers from Production, Purchasing and Maintenance
	Quality control inspector
	Research advisor and associates
	Floor operator
Expected benefits : Reduction in the defects due to displacement of component failure	
Project plan : Application of DMAIC model of Six-Sigma	
Project timeline : Six months	

Figure 2: Project charter

4. CASE STUDY

This section demonstrates the application of DMAIC model of Six Sigma for the quality improvement of the portable amplifier manufacturing units final fitting stage. The project is carried to reduce the cost of repair and the rejects by minimizing the output defects.

4.1. Define

Define is the first phase of DMAIC model that helps understanding and defining the problem. In this phase, one starts with understanding the process design, flows, input and outputs where improvement is targeted, and a process map is prepared. This step is utmost important before a project can be put in action. Field observation and discussion with the field operators, managers, and customers play an important role here. As the output of this stage, a project charter Figure 2 is prepared, defining the problem, setting up the project team and time-line, defining responsibilities and roles to the team members and stating the desired outputs that can be synchronized with the business demand and customer's requirements [4]. The team for the study undertaken consisted of one member from each department, associated with the manufacturing process like head production, head quality control, head maintenance, and the research associates.

Other than the project charter, a SIPOC diagram is prepared to map process activities in detail. The SIPOC diagram maps flows, enumerating the supplier, input, output, and customers that help further investigation of the problem [39]. In the process part of the SIPOC diagram, we mapped both fitting and final fitting stages of the production in order to build a clear understanding of the activities at both stages.

The final fitting production process is a five-step process defined as component mounting on the chassis, fastening of all screws and nuts, application of anti-seize paste on the nut joints, assembly of the unit, and jerk testing. The jerk testing

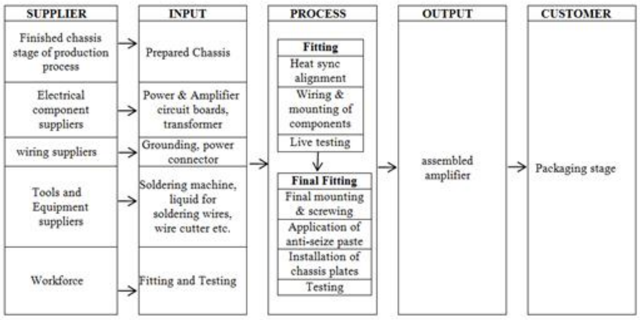

Figure 3: SIPOC diagram of the final fitting process

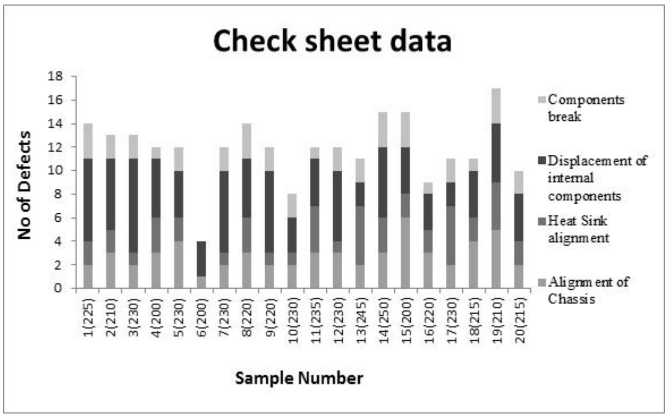

Figure 4: Sampling data (measure phase)

after the assembly is conducted to emulate field use and test the stability of the assembled unit. The output of this stage is the ready amplifier that goes to the packaging stage for packaging into the finished product ready for customer orders.

Discussion with the testing team and inspection of the defective pieces available in the inventory lead to the identification of four types of defect - alignment of chassis, components break, displacement of internal components, and heat sync alignment. The objective of the study is to find the key defects in the process output and recommend process improvement by analysing the root cause of the defects. The improvement is to be established in terms of the Sigma level of the process. The time-line for the study was set to six months.

4.2. Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the four defects identified in the

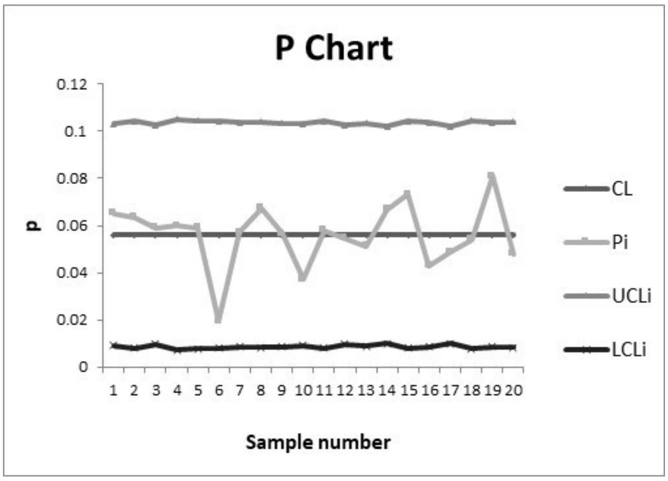

Figure 5: P-chart (measure phase)

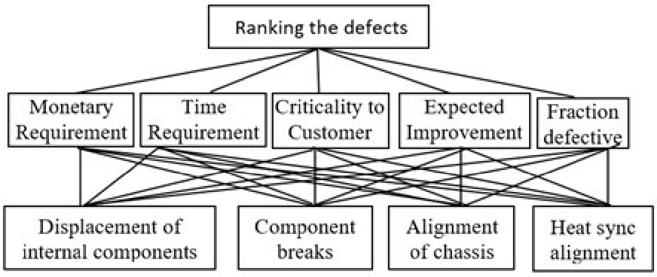

Figure 6: Conceptual framework for F-AHP

define stage is established, followed by multi criteria defect prioritization. The process output is sampled for 20 days following 100% sampling [33]. Process specifications are followed to inspect the items for four types of defect. The items are labelled as defective due to the presence of any of these defects. In total, 4,224 units were observed in 20 days sampling that resulted into identification of 237 defective units. The sampling data were recorded using check sheets (shown in Figure 4). The baseline sigma level of the process is estimated to be 3.088 (56,107.95 parts per million) [5, 17]. To check whether process is in control or not, p-charts for fraction defective are drawn [22] as shown in Figure 5. The p-chart shows that the final fitting process is in control with average fraction defective value 0.0561.

Based on the learning from the past projects and considering limited availability of resources and time, the team decided to target the improvement efforts only to the major defects. The research team was also of the opinion that targeting several improvements simultaneously may lead to instability in the process

Linguistic variable	Triangular fuzzy number
Just Equal (JE)	(1,1,1)
Equally Important (EI)	(1/2,1,3/2)
Weakly More Important (WMI)	(1,3/2,2)
Strongly More Important (SMI)	(3/2,2,5/2)
Very Strongly More Important (VSMI)	(2,5/2,3)
Absolutely More Important (AMI)	(5/2,3,7/2)

Table 2: Linguistic and triangular fuzzy scale for F-AHP

operation.

As discussed earlier, compared to the existing literature that mainly employ frequency based decision to identify the key defects that are dealt in the projects, a multi criteria defect prioritization analysis is conducted to prioritize the defect [34].Frequency based approach limits the gains realized from the project that considers attributes such as criticality of defects, expected gains in monetary terms etc. Here we have conducted the defect prioritization considering criticality of defect as per customer requirement, expected monetary and time requirements to deal with a defect, expected improvement in the process and fraction defective value. As criteria based on customers and managements preferences are employed in fault prioritization, the project is expected to yield better results, greater customer satisfaction, and higher monetary gains.

The data for prioritization of criteria, as well as the defect based on these criteria, were collected from the expert opinion, and the analysis was performed using MCDM methodology F-AHP. Since the expert opinion can be subjected to imprecision of human judgement, expert responses were recorded in linguistic variables [9], transformed into triangular fuzzy numbers (TFN) [8] and analysed using F-AHP (see Table 2). Figure 6 depicts the conceptual framework for F-AHP methodology. F-AHP questionnaire was prepared based on the linguistic scale and responses were collected from 5 experts including project leader, two managers of the firm and two BTB customers. F-AHP computations were performed on the geometric mean of the expert responses [8, 35]. Results of F-AHP criteria and defect prioritization are listed in Tables 3. The defect displacement of internal components during the jerk testing was ranked as the major defect in the process output according to F-AHP results. The team discussed the results with the higher management and decided to target the improvement efforts only to the defect with the highest ranking.

Criteria	Monetary requirement	Time requirement	Criticality to customer	Expected improvement in quality	Fraction defective	Overall priorities
Criteria Ranks	0.1870	0.1473	0.2779	0.3281	0.0597	
	Defect priorities with respect to criteria					
Displacement of internal components	0.3841	0.3219	0.3307	0.3152	0.3658	0.3555
Component breaks	0.2564	0.2992	0.2562	0.2800	0.3189	0.2834
Alignment of chassis	0.2280	0.1930	0.1828	0.2189	0.1325	0.2086
Heat synch alignments	0.1312	0.0915	0.2628	0.1831	0.0597	0.1524

Table 3: Defect prioritisation results based on F-AHP analysis

4.3. Analyse

Displacement of the internal components during jerk testing is found to be the most critical defect based on the multi criteria analysis. The analyse phase of the DMAIC process aims to uncover the likely causes for this defect and then identify the Root Causes. C&E analysis was conducted and a C&E diagram categorizing the causes in six generic categories was prepared as shown in Figure 7 [23]. Learning from the review of literature and specification documents, field observations, discussion with operators and engineers, we formed the basis of listing the causes which were further analysed to identify the Root Causes of the problem. Various techniques are discussed in literature for Root Cause analysis [1, 13, 36]. In this study we explored each of the identified cause, simultaneously exploring the possible interrelations between the potential causes and their undesirable effects using the Root Cause analysis method CRT [13]. The CRT analysis is depicted in the Figure 8. The boxes highlighted in light grey color boxes represent the Root Causes for the defect in consideration.

4.4. Improve

The improve phase aims to establish provisions to eliminate the identified Root Causes that included: poor quality of the anti-seize paste, sophisticated specification document/manual, workstation designing and maintenance issues, and training issues. Further investigation of each of the Root Cause was undertaken to identify and implement the improvement measures. The units identified as defective in the jerk testing were investigated. The team observed the removal of the anti-seize paste from the various locations, which was collected as foreign material from the assembled unit. Removal of the anti-seize past was leading to alignment issues in the assembly. The quality of anti-seize paste was discussed

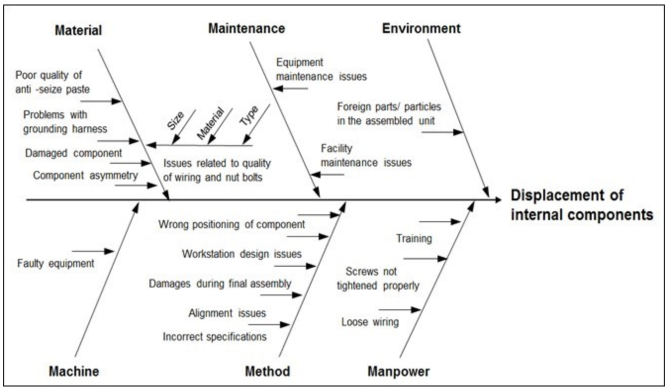

Figure 7: Cause & effect diagram for displacement of internal components

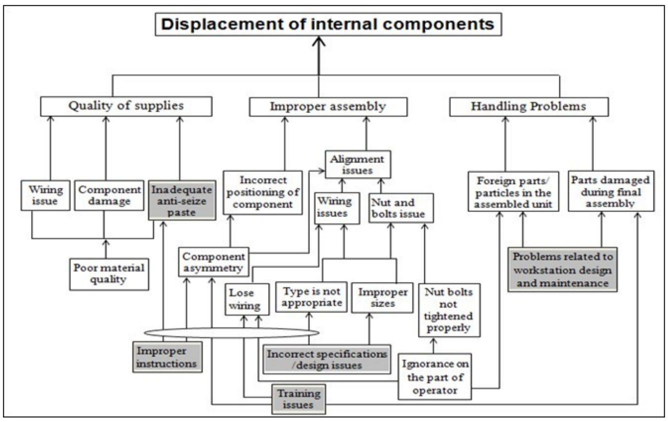

Figure 8: Current reality tree for displacement of internal components defect

with the supplier, and the supplier recommended replacement of current supplies with a superior quality product. The team decided to replace the current supplies with a better quality product and observed the improvement in quality.

Most of the operators working in the assembly were low skilled. Discussions with the shop floor operators, and analysis of their working through shop floor observations lead to identification of the issues related to the instructions and training. Though specification and instruction were listed correctly in the manuals, a gap was observed in readability and user friendliness of these documents. The instructions were presented sophisticatedly due to which the operators at times used incorrect types, sizes of wires and nut bolts in the assembly taht was leading the alignment issues and displacement of components during testing. The research team recommended displaying simple step by step assembly instructions with visuals in display cards near the operators. It was suggested that the display cards will help them follow the standard assembly instructions and provide with correct visualization of the assembled units. Further, a training program was organized to train the workers in the assembly process.

Workstation designing and maintenance issues were also identified as the Root Cause of the problem. While observing the working of the shop floor operators, the team observed that the workstations were cluttered and components of the assembly specially wires and nut bolts were not kept in an organized manner. This was causing the use of wrong types, sizes of wires and nut bolts in the assembly by the workers. The research team put efforts to organize the workstations and conducted workshops for the operators to make them understand the requirement of an organized workstation in improving the quality of the assembly process. They were also trained to work in an organized manner.

4.5. Control

The control phase of the DMAIC model aims to bring the process to stable operations after the improvement efforts are implemented. This stage of the model plays an important role in sustaining achieved improvements as the improvement measures imply changes in the process operations that may observe operator's resistance or may result in more process variations. To stabilize the process operation after the improve phase, the process was observed and controlled during 10 days. Then the process output was re-sampled for 20 days with 100 per cent sampling to record the defectives. The data pertaining to defects were recorded on check sheets as shown in Figure 9. p-charts for fraction defective were drawn to check the process control level (shown in Figure 10). The p-chart showed the process continue to remain in control after improvements. The short-term sigma level of the improved process was calculated to be 4.077 compared to 3.33 the sigma level of the base-level performance. After the improvement phase, 49% reduction was achieved in the defect displacement of the internal components.
The project team suggested the quality management team to continuously monitor the process performance by sampling and monitoring the process control. Further, it was suggested to maintain the record of the sampling data and process performance, and to rectify problems as and when encountered.

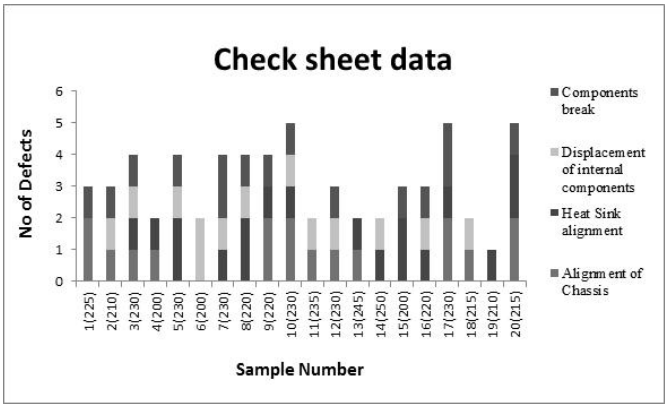

Figure 9: Sampling data (control phase)

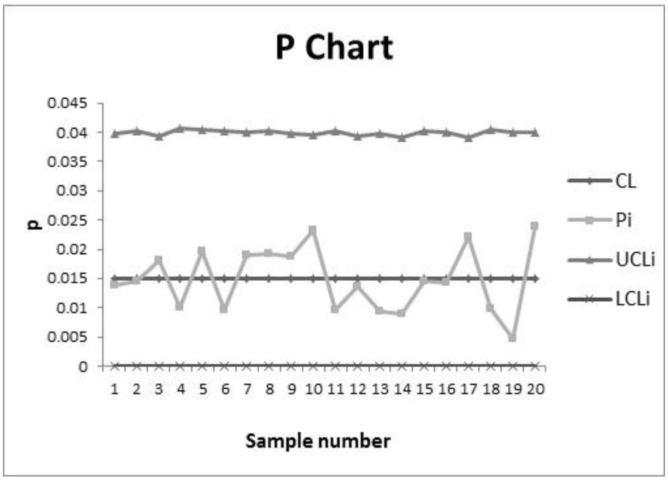

Figure 10: P-chart (control phase)

5. THEORETICAL AND MANAGERIAL IMPLICATIONS

This study discusses a case study of quality improvement project of a portable amplifier production process in a micro scale sound system industry. The final fitting process is the last step in the manufacturing of portable amplifier production. For quality improvement of the final fitting stage, DMAIC model of Six Sigma methodology was employed. The improvement resulted in the reduction of the key defect, displacement of internal components, by 56%. It was clear from the result that with the execution of the DMAIC cycle, the desired goal of reducing key defects up to 50% was achieved and also the accounted short term Sigma level was obtained to be 4.1, which is notable improvement from the baseline level of 3.57.

Our study contributes to the management for quality improvement in the following:

- The most important is the illustration of the implementation of DMAIC Six Sigma model through a practical case study of the final fitting process of a portable amplifier manufacturing process of a MSME firm operating in emerging market like India. As indicated earlier, the literature focusing on the quality management initiatives with reference to small scale firms in developing economies is limited [26, 29]. Hence, our study is not only valuable for a similar industry but can also be useful for other manufacturing industries as it provides a roadmap for quality improvement projects in small scale manufacturing processes. It is evident the lack of literature supporting the successful implementation of quality initiatives also add to the challenges undertaking such initiatives in these firms [2, 36]. The quality improvement efforts demonstrated in this study will be helpful to the management in executing quality improvement projects with visible improvement in the final product and process quality, increased customer satisfaction and monetary gains.

- An effective multi criteria defect prioritization analysis under fuzzy environment has been demonstrated to prioritize the defects. The analysis was performed using FAHP approach. Since the selection of key defects has been done on the basis of the opinion of various decision makers like managers, customers, operators, etc., and considering multiple factors that describe the criticality of defects, the outcomes of the project are expected to be more effective, compared to frequency based technique like Pareto analysis. Since customer opinion is also acknowledged in the fault prioritization, the proposed approach for fault prioritization is more centred to customer and would lead to higher customer satisfaction along with waste minimization and monetary gain for the firm. Therefore, the use of MCDM technique helps in selecting the critical defect from customers, as well as the firms, point of view.

- The use of Fuzzy environment for decision making helps the user in capturing the vague judgements of the decision makers. It has been proven that decision makers are more comfortable in providing linguistic judgements rather than the crisp values. Fuzzy numbers help in representing these linguistic judgements in mathematical form. Therefore, use of Fuzzy environment helps the management in capturing actual judgements of decision makers. The proposed method for fault prioritization well account to the imprecision and un-quantification issues.

6. CONCLUSION

This study presents an application of a Six Sigma project for improving the productivity of a final fitting stage of the amplifier production process of a small scale manufacturing firm. The DMAIC approach was adopted to evaluate causes of non-conformities and establish improvement measures. Four types of defect were identified in the assembly process and the baseline process performance was measured in term of sigma level through sampling. The improvement efforts were directed to the key defect prioritized using F-AHP technique. Displacement of internal components was found to be the priority defect in the process. Two-fold analysis was employed to first uncover the causes of the key defect using C&E diagram, and then, the root cause using CRT method. The analysis leads to identification of four Root Causes of the problem. Improvement efforts were established to rectify the Root Causes. The corrective measures were implemented and process control was established to stabilize the process operation. The short-term Sigma level of the improved process was measured to be 4.077 compared to 3.33 in the baseline performance. The study was limited to the quality improvement initiatives only for the final fitting stage of the process targeted to key defect displacement of internal components. As a future scope of improvement quality efforts could be targeted to other causes of non-conformities. Further, issues with the workstation design and maintenance were among the Root Causes of the problem. So, in this study, efforts were made to organize the workstations and workshop for the operators to train them to work in organized manner, which was appreciated by both the operators and management.

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