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Implementation of Six Sigma Methodology for Connecting Rod Manufacturing

Amey Patil[1]
College of Engineering, Pune

Sanket Bhosale [2]
D Y Patil College of Engineering, Akurdi

Rohit Masute[3]

***Abstract*—Quality improvement contributes to effective satisfaction of customer which concludes to beneficiary for every organization. It is important to every organization to cope up with the all qualitative issues for surveillance in competitive market. It is also significant for economic growth of the organization. Six-Sigma, mainly based on customer needs & expectation with the use of facts & statistics, analysis & responsible approach to managing & improving current business, manufacturing capacity & services is applicable to such cases. Tools of six sigma methodology are used to improve the process by enhancing the quality of product. This paper draws attention towards adoption of six sigma methodology in manufacturing organization with the case study. This is successfully achieved by implementing DMAIC Methodology.**

Keywords— DMAIC methodology, CTQ, team charter, SIPOC model, Top down chart, Functional deployment map, Cause & effect diagram

I. INTRODUCTION

Customer satisfaction is a key for any successful business.[1] Production methodology is changed from push type to pull type. In such case customer plays role of king who demands for the satisfaction of every aspect. One of the most important aspects of customer is achieved through high quality product, which means low defect product. Quality of the product can be maintained by eliminating factors affecting the quality. Though it seems to be simple but is critical to find out these factors & take appropriate actions over it. Quality & efficiency of manufacturing & services have been greatly improved through continuous improvement methodologies such as six-sigma.

The objective of the research paper is to investigate how six sigma methodology can be successfully implemented in manufacturing projects through case study. It also focuses to calculate process capability index for measuring the performance of six-sigma. Six-sigma uses statistical methods to achieve almost defect free process. If the distance between mean of the process & closest specification limit i.e. boundary set by customer is six standard deviation (plus, minus) then process is consider as six sigma process. The six sigma principle is represented in normally distributed curve. When the mean is located at center of normal distribution curve then lower & upper limits are six times the standard deviation from the center line. This paper represents implementation of DMAIC methodology. Improved results of implementation are plotted over normal distribution curve which clearly indicates the importance of such continuous improvement tools.

Bill smith of Motorola developed & implemented an approach to achieve near perfection in product manufacturing called six sigma.[2] Six sigma's structured improvement procedure is seen as a novel and effective contribution to quality management. Six Sigma improvement drive is the latest and most effective technique in the quality engineering and management spectrum.[3] This improvement procedure is generally known under acronym DMAIC. This stands for Define, Measure, Analyze, Improve and Control. Originally this was described as method for variation reduction. DMAIC is applied in practice as generic problem solving & for improvement approach. Success of six sigma basically depends upon the understanding of customer.[4] This method is built on insight from the quality engineering field incorporating ideas from statistical quality control, total quality management. Method's original task domain was variation reduction especially in manufacturing. This method was originally developed specifically for manufacturing industries but now days widely used for almost all sectors including manufacturing and service industries.

II. CASE STUDY OF USE

DMAIC is five phase closed-loop problem solving pattern that eliminates unproductive steps, and applies technology for continuous improvement. DMAIC is generally used on business process that fails to meet customer requirements. DMAIC methodology is explained in details as follows:

TABLE I STEPS TO IMPLEMENT

DMAIC Methodology	Phases
DEFINE Improvement Opportunities	I. Selection of improvement opportunity
	II. Defining scope of the project. Translating Voice Of Customer (VOC) to Critical to Quality (CTQ)
	III. Developing team charter i.Business Case ii.Opportunity Statement iii.Goal Statement iv.Project Plan v.Team Selection
	IV. Mapping the process i.SIPOC Model
MEASURE Baseline Performance	I. Manage The Measurement i.Develop operational Definition ii.Develop measurement plan
	II.Collect data & Evaluate Variation
	III.Determine the Baseline Performance
ANALYZE Root Causes	I. Identify Potential Root Cause i.Fishbone Diagram ii.Cause & Effect matrix
	II. Why-why Analysis
IMPROVE through Set up Solutions Control Ongoing Performance	I. Identify solution
	II. Implementation
	III. Evaluating improvement

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A. Define Phase

I. Selection of improvement opportunity

Company ABC is supplier of Big Connecting Rod to the company XYZ. ABC has received severe customer complaint regarding big connecting rod supplies.

II. Defining scope of the project.

Translating VOC to CTQ: Understand & analyze VOC and converting to CTQ is important for proper defining of the project.

TABLE II VOC TO CTQ

Voice of Customer	Key Customer Issue	Critical Customer Requirement	Critical to Quality
•The width of Big end (outer) is undersize (Dimensional Issue) •There is not sufficient material at bolt seating area	•Width of Big end should be within tolerance limit •There should be enough material at bolt seating area (bolt head should not get projected outside of wall)	•Width of Big end should always be within 225mm to 227mm •The wall thickness should never be lesser than 78mm. it should always be within 78mm to 80.5mm	•Width of Big end 225mm to 227mm •Wall thickness at Big End boss 78mm to 80.5mm

III. DEVOLVING TEAM CHARTER

i. Business Case: ABC has 52 % share of XYZ global business. Dissatisfaction in product quality may reduce the current business share & it will be awarded to global competitors. In monetary terms ABC gets revenue around Rs.150-200 million (annually) from respective business. Improved product quality may fetch the additional business which in turns results in increased business for ABC.

ii. Opportunity Statement: Big connecting rod is the product supplied to XYZ. Big connecting rod is failing to meet the customer dimensional requirements.

iii. Goal Statement:

- Improved dimensional accuracy of big connecting rods.
- Big End Outer Width of connecting rod should be within tolerance limit.
- Wall thickness issue should be sorted out.
- Improving process to 5-6 sigma level.

iv. Project Plan

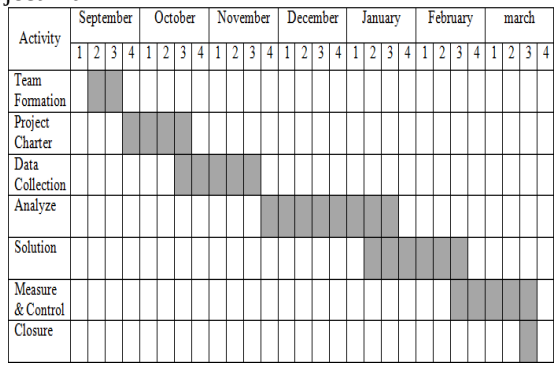

Figure I Project Plan

v. Team Selection

TABLE III TEAM SELECTION

Area	Team Member
Sponsor	Vice President FMD III
Team Leader	Senior manager IQC
Six-Sigma Expert	Green Belt Holder
Planning	Project Trainee
Die Shop	Senior manager Die Shop
Quality Assurance (Production)	Manager FMD III
Production Supervisor	Supervisor FMD III
Quality Assurance (Processing)	Asst. manager IQC
Sales And Marketing	Asst. manager ITD
Costing (Finance)	Asst. manager Finance
Engineering Design	Asst. manager Design

IV. MAPPING THE PROCESS

i. SIPOC Model: SIPOC model entitles most of the involving in process. This gives entire idea about all process in one look. So it is very much easy to focus on prescribed area.

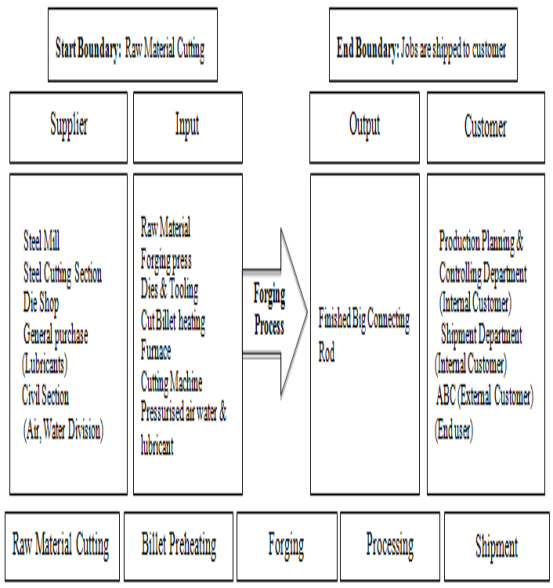

Figure Ii Sipoc Model

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B. Measure Phase

I. Manage the Measurement: Data collected should be managed in a proper way. Data should be problem specific. Collection of irrelevant data will be time consuming and hectic process. Proper management for measurement will lead to time consuming activity. It can be achieved with following stages.

i. Develop operational Definition: An operational definition is that tells how to get value for characteristics of the problem. It describes what to measure. It also mentions the special characteristics while measuring the specific dimension.

Measurement of Big End Outer Width : It should be within specified tolerance limit i.e. 225 < B.E. width < 226.5

Measurement of wall thickness at Big End Boss Area: It should be within tolerance limit i.e. 78.0 to 80.5

Measurement of Billet Temperature, Deformation Force are excluded for measurement as from experiences of senior people, there is hardly any variation observed during the operations due to timely preventive maintenance activities.

ii. Develop measurement plan: A good operational definition provides a clear way to measure characteristic to ensure that results are same for anyone making the measurement. A data collection plan is prepared to collect required data.

II. Collect Data & Evaluate Variation: Quality data collection and evaluation are keys to effective results from the desired improvement process. As per operation definition & measurement plan, data was collected at appropriate places & within set time span. Collected data was evaluated. Data collection is to validate measurement system. Goal is to minimize the controllable factor that could minimize the amount of variation. From the collected data calculate mean, median, mode, range, variance & standard deviation.

III. Determine the Baseline Performance: Case is considered for two different types of problems. So all sample readings as per the measurement plan were collected. From the measurement plan, calculations were done. For two different problems separate charts were prepared. On the basis of which we get two different normal distribution curves.

i. Big End Undersize Issue: Graph clearly indicates that process gets shifted towards lower specification limit. Though it seems that most of readings are falling within the range of upper and lower limit, but cumulative result of process was shifting of the entire curve towards lower limit. Graph clearly indicates mean is shifted with 0.27 towards left.

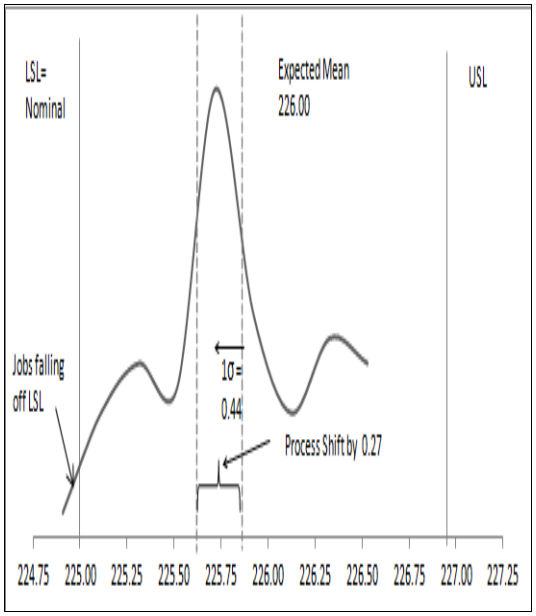

Figure III Normal Distribution Process I

ii. Less Material at Bolt Seating Area: Similarly readings were plotted for second problem. All the readings were plotted in between the upper and lower limit. But majority readings shifted towards lower limit. Therefore mean shifted 0.34 towards left.

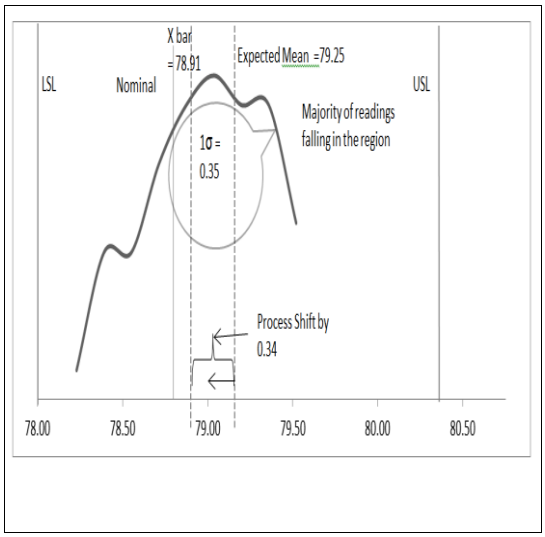

Figure IV Normal Distribution Process II

Current sigma level was calculated for two processes individually. The current sigma level was calculated from data obtained. Mean, median, mode and standard deviation gives the value of capability and capability index. From the capability index sigma level is calculated. This will be the baseline performances for two different processes. 3.15 And 4.1 will current sigma levels.

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Table Iv Current Six Sigma Level

Parameter	B.E. outer width undersize Issue	Less material at bolt seating area Issue
1.Process Capability $(C_p)=\frac{Voice\ Of\ Customer}{Voice\ Of\ Process}$ $=\frac{(U.S.L.-L.S.L.)}{6\sigma}$	$=\frac{227-225}{6*0.44}$ =0.76	$=\frac{80.50-78}{6*0.35}$ =1.19
2.Process Capability Index $(C_{pk})=min\left[\frac{USL-x}{3\sigma},\frac{x-LSL}{3\sigma}\right]$	$=min\left[\frac{227-225.73}{3*0.44},\frac{227-225.73}{3*0.44}\right]$ $=min[0.96,0.55]$ =0.55	$=min\left[\frac{80.5-78.91}{3*0.35},\frac{78.91-78}{3*0.35}\right]$ $=min[1.51,0.87]$ =0.87
3. Sigma Level = (From the Sigma Calculation table)	$\sigma = 3.15$	$\sigma = 4.1$

C. *Analyze Phase*

I. Identify Potential Root Cause

i. Fishbone Diagram: Six major parameters are considered. Machine, Material, Method, Men, Technology, Environment these are major parameters. All the parameters are further branched with sub-parameters. These parameters were selected depending on their correlation with major parameters. All other parameters other than environment affect directly to process and end result.

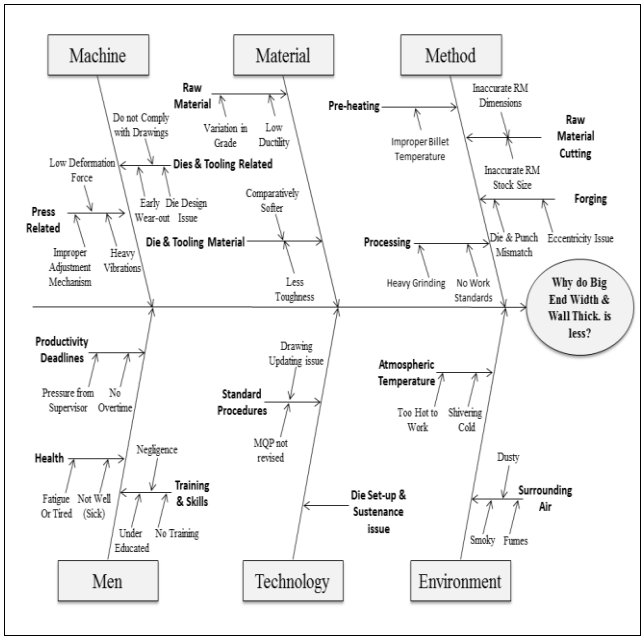

Figure V Fishbone Diagram

ii. Cause & Effect matrix: In the cause and effect matrix possible reasons for both problems were listed. Ratings for the possible reasons were given. Rating range was from 0-9. Rating range was decided in brainstorming session.

TABLE V CAUSE & EFFECT MATRIX

Input process indicators	BE width Issue	BE Wall thick. Issue	Output Indicator total
Importance →	10	8	
Variation in RM grade	1	1	18
Dies & tooling compliance	9	9	162
Cut billet dimensions	1	3	34
Deformation force	3	1	38
Operator skill	3	9	102
Billet Temperature	1	3	34

Ratings for Cause & Effect matrix:
0=No correlation 3= Moderate correlation 1= Low correlation 9= Strong Correlation

From the derived data two major affecting factors were obtained. Those were dies & tooling compliance, operator skill.

These two factors are encircled in the fishbone diagram.

II. Why-Why Analysis

Why-why analysis means asking the Why question periodically to previous answer. This can delve into the problem deeply enough to understand ultimate root cause. 4th& 5th Why will give ultimate answer for problem.

i. Big End Undersize Issue

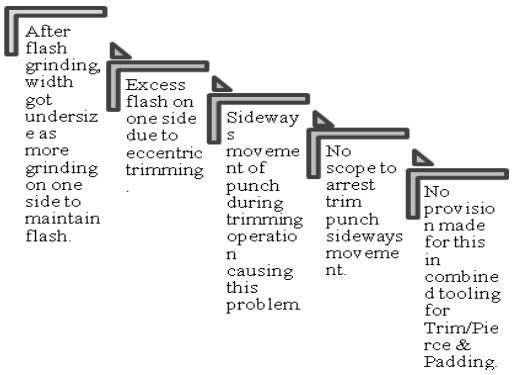

Figure Vi Why-Why Analysis I

Root cause for Big end undersize was due to no provision for constraints at punch. So ultimately providing constraints at punch will eliminate the problem.

ii. Less Material at Bolt Seating Area

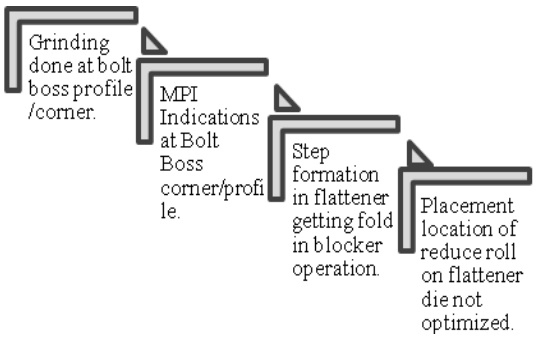

Figure VII Why-Why Analysis II

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Root cause for less material at bolt seating area was improper shape of flattener. This can be eliminated with correcting the shape of flattener.

D. Improve Phase

Improve is the fourth phase in Six-Sigma methodology. It is most important phase in the methodology. The purpose of this step is to identify, test and implement a solution to the problem; in part or in whole. Identify creative solutions to eliminate the key root causes in order to fix and prevent process problems.

I. Identify Solutions

Peoples involved in process were gone for brainstorming and work on root cause identified in analysis. The goal of this step was to determine appropriate solution for problem occurred. All possible solutions were taken into account.

II. Implementation

Solution obtained in brainstorming session is implemented in this step. As in the prior step, it is a good idea to involve the people who work on the process that is being improved, be included in the decisions regarding which potential improvements to implement.

III. Evaluating improvement

Pilot run gives better idea for improvement results. The benefit of pilot test is that team can ensure the changes result in desired improvement before full run. In addition team can gain insight to allow more effective implementation during full run. Results obtained during pilot run were plotted against the previous reading, which gave transparent result for improvement.

E. Control Phase

Control is fifth phase in Six-Sigma methodology. Primary objective of control phase is to ensure that gains obtained during improve phase are maintained long after project has ended.

i. Control plan:

Control plan is guide for process monitoring person to assist tracking and correcting the performance. Objective of this was to clarify key input and key outputs for the improvement of the process. The monitoring plan clarifies how the process performance will be continuously monitored, who will be notified if there will a problem and how that will happen and what response is required. If the process performance stays out of control it is important to take corrective action and continuous monitor the process. For this purpose person have to take periodic effort for monitoring. Control plan will standardize these efforts and allow quick analysis for current performance. This was last stage for DMAIC implementation.

TABLE VI RESULT OF IMPROVEMENT

Parameter	B.E. outer width undersize Issue	Less material at bolt seating area Issue
1.Process Capability $(C_p)=\frac{Voice\ Of\ Customer}{Voice\ Of\ Process}=\frac{(U.S.L-L.S.L)}{6\sigma}$	$=\frac{227-225}{6*0.23}$ $=1.43$	$=\frac{80.50-78}{6*0.30}$ $=1.37$
2.Process Capability Index $(C_{pk})=min\left[\frac{USL-x}{3\sigma},\frac{x-LSL}{3\sigma}\right]$	$=min\left[\frac{227-225.73}{3*0.23},\frac{227-225.73}{3*0.23}\right]$ $=min[1.81,1.04]$ $=1.04$	$=min\left[\frac{80.5-78.91}{3*0.30},\frac{78.91-78}{3*0.30}\right]$ $=min[1.60,1.14]$ $=1.14$
3. Sigma Level = (From the Sigma Calculation table)	$\sigma = 4.6$	$\sigma = 4.9$

Results clearly indicate that sigma level was improved for both processes. For first case it was 3.15 to 4.6 and later one is from 4.1 to 4.9 sigma levels. Target was achieved up-to some extent.

III. CONCLUSION

DMAIC Methodology is a very systematic approach that provides a pathway to go to the roots of the problems gives opportunities for improvement & moreover helps us to monitor improved performance through controlling mechanism. On Surface everything appears smooth & fine but we dig down deep, then only problem areas tend to surface out. The tools like Fishbone Diagram, Cause & Effect Matrix, FDC, and Qualitative Analysis are really informative that explore the possible causes of failure to a great extent. The Standard Deviation & process capability, process capability index approach is really helpful which gives the present status of process capability. Earlier no such tool was used to evaluate & monitor the performance of process in such a detail. The Senior & Experienced Team Members play a vital role in overall success of the project. The experienced Team Members really narrow down the number of possibilities that we search for in Analyze phase & we go in the right direction to hit on the nail. Standard Deviation &process capability, process capability index approach is really helpful which gives the present status of process capability. Earlier no such tool was used to evaluate & monitor the performance of process in such a detail.

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