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Engine Assembly Process Quality Improvement using Six Sigma

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Abstract— Manufacturing performances tend to produce defects due to various reasons which can be improved by identifying and eliminating them using six sigma. In the present work, DMAIC (Define, Measure, Analyze, Improve and Control) has been used to reduce the number of vehicle engine rejection. In define phase problem was defined by selecting the core issues concerned. In the measure phase data was collected to determine the current performance and the process capability. During Analyzing phase root causes of engine rejection were identified. In the improvement phase solutions were arrived at and finally in the control phase various tools were implemented for tracking the process and putting it under control.

The study reports process quality improvement through reduction in defects, from 7243 ppm to 687 ppm. Cost of poor quality (COPQ) has been significantly reduced from $ 30, 000 to $ 9, 000 per annum, a reduction of 333%.

***Index Terms*— Six Sigma, DMAIC, Engine assembly, Process Quality, COPQ.**

I. Introduction

Six Sigma is a breakthrough strategy employed to eliminate defects in a process. Six Sigma is aimed at reducing defects and reducing variations at the breakthrough level through practical application of statistical methods. Six Sigma begins by translating a practical problem into a statistical one. Statistics then help in finding the optimal solution which is then implemented as a practical solution in a real life situation. The types of success which can be achieved are broad because the proven benefits of the Six Sigma approach are diverse including Reduction in cost, Improvement in Productivity, Cycle-time reduction, Defect reduction, Increase in market-share, Customer satisfaction, Culture change, Product/service development and much more. Six Sigma offers a wealth of tangible benefits when skillfully applied. This case study was carried out at a large manufacturing enterprise. The company had several complaints of water and oil leakages from engines leading to customer dissatisfaction.

The objective was to significantly reduce these defects. The study hence was taken as a six sigma improvement project.

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II. Six Sigma Project Implementation

The rejection of the engine was a serious concern as evidenced by the customer complaints and an urgent need was felt to fix this problem. A cross functional team representing the personnel's from Testing Department, IHQA, Engine SM, Vehicle MSD, Quality Department was constituted. Time frame for the team was six months for accomplishing the set objectives.

A. Opportunity Statement

During Engine Docking at Vehicle line Engine Quality Defects were reported. Total PPM For Engine Quality was 7243 PPM.

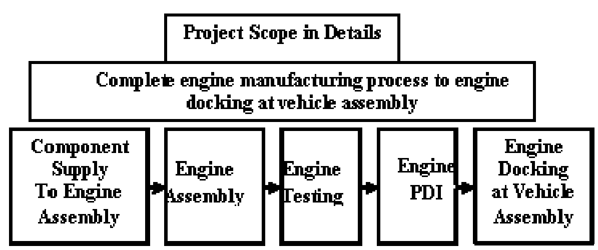
Cost of poor quality was approximated at $ 30,000 per annum.

B. Goal Statement

Problems at Vehicle Main line due to Engine Quality issue to be reduced from 7243 PPM to 700 PPM.

C. Project Scope

A brief idea about the project scope is shown below. The out line was drawn to understand the boundaries of the project.



*D. **Project Scope** Excludes*

Problem at Engine line due to change in Production Plan, Shortage of material and Production facility failure such as machine break down or operator absenteeism are excluded in this study.

E. Project Plan

Project plan, as under, was established after taking into consideration various constraints.

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Milestones	Planned Start Date	Planned End Date	Actual Start Date	Actual End Date
Define	5 Jan	30 Jan	5 Jan	30 Jan
Measure	1 Feb	28 Feb	1 Feb	28 Feb
Analyze	1 Mar	30 Mar	1 Mar	30 Mar
Improve	1 May	30 May	1 May	30 May
Control	1 Jun	30 Jun	1 Jun	30 Jun

COPIS was drawn to understand the process and the boundaries in a better way. The COPIS details are as below.

The Customer (CUSTOMER) was the Vehicle assembly department and their Requirement (OUT PUT) was defect free engine assembly, which can be achieved only after they get a defect free engine. They were expecting a stable Process (PROCESS) for the same.

The various INPUT required for the engine manufacturing process and the SUPPLIERS for the same are as per Table-1

TABLE- 1 INPUTS AND SUPPLIERS

Inputs	Suppliers
Components	Engine supply Module
Standard Operating Procedures (SOP)	Process Engineer
Manpower	HRD
Consumables	Engine supply Module
Tools and equipment	Process Engineer

With the help of the top down charts, functional deployment chart and Qualitative analysis chart Process was mapped.

The processes include Cleaning of Parts, Engine Assembly, Engine Testing and Engine PDI (Pre-Dispatch Inspection).

Top down chart was made listing all activities such as crank case cleaning, cylinder head cleaning, Engine assembly, Engine transportation, operation and testing, Post testing and moving the engine to docking stage. This helped understand the process in minute details.

Potential Quick win opportunity analysis was done and process was remapped with improved solutions implemented on it.

The Define Phase can be summed up as follows:-

Finalized Team charter
Completed Process mapping-
COPIS
Top Down Charts
Functional deployment charts
Process mapping done at the suppliers place.

III. MEASURE PHASE

This phase started with identification of indicators as given in Table-2

TABLE-2 LIST OF INDICATORS

Input Indicators	Process Indicators	Output Indicators
SOP adequacy	QP2 rejection stage	Total engine defects are 7243 PPM
Skill level of assembler	QP3 rejection stage	
Issues related to consumables		
Tools and equipment adequacy		
Schedule change		
Cleaning of components		

Various inspection stages were established during the assembly process of vehicle engine. These inspection stages were labeled as QP1, QP2 and QP3. First inspection stage was selected after cleaning of crankcase, cylinder head and piston crankshaft fitment. Similarly the second inspection stage established after cylinder head sub assembly and ex-manifold fitment and lastly the third stage was after testing of engine and for final visual checking.

After delegation of various activities data was collected as given in Table-3

TABLE- 3 ENGINE QUALITY DEFECTS

Sr. No.	Engine Quality defects at main line	Total Defective Quantity
01	Flywheel threading not OK /missing / Flywheel bolt problem	43
02	Pressure plate mtg. dowel missing	42
03	Engine shortage.	33
04	Engine dowel not ok / problem	26
05	Starter motor stud/bolt problem	17
06	Engine oil pan bolt loose /Engine oil pan leak	12
07	Engine mounting dowel missing	11
08	Rejected engine issued	06
09	Flywheel bush under size	04
10	Miscellaneous	04
Total Engine Quality Defect Quantity		198
Total Production		27335
Total PPM		*7243*

The engine defect data was collected after verifying the adequacy of standard operating procedures (SOP's). Measurement system analysis was also carried out which was found to be satisfactory. The data recorded in Table-3 show that the current process results into engine defects at 7243 PPM.

The cost of poor quality at 7243 PPM was found out to be $ 30 000 per annum. Cause and Effect diagram matrix, as shown in Fig.-1, was made to prioritize the possible indicators responsible for this level of process behavior.

Voice of customer (VOC) was translated to Critical customer requirement (CCR), as described below.

VOC was that this massive defect rate was unacceptable as it was leading to loss of production at the final vehicle assembly line. It was found out that the engine failures were taking place due to leakages and hence the CCR was translated as reduction of quality problems related to leakages in engines at assembly line.

Engine Quality Defect in terms of leakage, aesthetics, missing operation …etc was measured to work out PPM as under-

$$\text{PPM for Engine Quality Defect} = \frac{(\text{Defect}) \times 10,00,000}{(\text{Production})}$$

$$= \frac{198 \times 1000000}{27335}$$

$$= 7243$$

Corresponding Sigma level = 3.9

Measure Phase can be Summed up as follows:-

Input, Process & Output Indicators
Cause & Effect Matrix for Indicators Prioritization
Identified Operational Definition.
Data Measurement plan
Identified Base line definition.

IV. Analyze

The Pareto chart was prepared to prioritize defects and to find out probable causes. Specific data collected was analyzed to prioritize root causes. And the same was validated by using statistical techniques.

After analyzing the data it was found out that 80% of the defects were due to four / five reasons (Refer Fig.2) such as pressure plate mounting dowel missing, engine dowel problem, Flywheel threading and flywheel bolts problems.

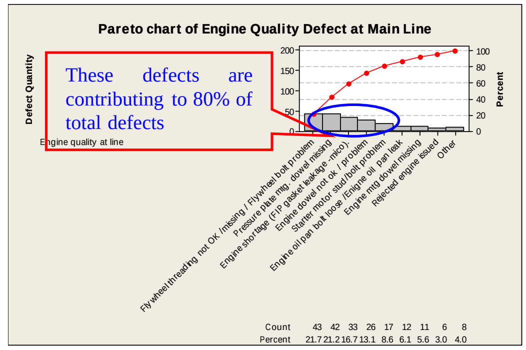

Fig.2 Pareto Chart of Engine Quality Defects

To validate the possible cause that there is some process problem to generate defect of flywheel threading damage, P value was found out with collected data.

Ho Defects rate at receipt stage = Defects rate after testing stage.

Ha Defects rate after testing stage > Defects rate at receipt stage

Test and CI for Two Proportions

Sample	X	N	Sample p
1	257	1400	0.183571
2	43	874	0.049199

Difference = p (1) – p(2) =0.134372

95% lower bound for difference: 0.113529
Test for difference = 0 (vs > 0): Z = 10.60
P Value = 0.000

As the P value is less than 0.05 we fail to accept Ho hence it is clear that In- house process (testing) adds to flywheel threading problem and the defects are not only generated at Vendor's process and the testing process needs to be studied further as to find out cause of defect generation.

Why-Why analysis was carried out to found out the problem of flywheel threading damage.

Problem	Why	Why
Flywheel threading damage found out at QP3	Wrong bolt used in engine testing for fitment of adapter plate on flywheel.	Mix up of bolts at engine testing for fitment of adapter plate in flywheel.

Root Cause Identified: - Mix-up of bolts in Engine Testing for fitment of adapter plate on flywheel was found out to be the main cause and it was taking place due to the reason that there was no identification mark on bolts. All bolts were blackodized. Since two types of bolts were used in Engine Testing. (Full threaded & half threaded) they were not segregated in different bins hence the problem. By carrying out cause and effect analysis various reasons for the problem were found out such as incomplete threading of flywheel, chips were fond out inside the threading, improper tightening of the bolts, loose / excessive tightening force, and wrong bolts on the line. (Refer Fig.3)

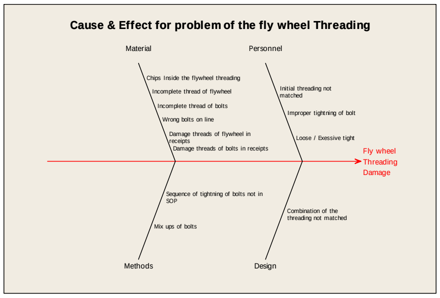

Fig.3 Cause and Effect for problem of flywheel threading

Similarly why-why analysis was carried out for Pressure plate, mounting dowel missing on flywheel of the engine, Mounting gasket leakage, Starter motor stud threading damage. After the analysis root causes were found out and the solutions were implemented.

Similar analysis was carried out on checking oil leakages and the causes were found out such as oil pan flatness was not as per standard, incomplete threads of bolt, incomplete threads inside crankcase, Torquing not done as per procedure.

Failure effect mode analysis (FMEA) was also carried out.

Flywheel Crank shaft bush jamming problem was also tackled and it was found out to be under size.

The various reasons for the same were

Drive shaft OD, Bush OD, CR shaft bore ID were found out be more.

Foreign particle in between matching parts were also creating misalignment of matching part.

Data was collected on 50 bushes after fitting inside the cr. Shaft. Histograms and run charts were used to authenticate the findings.

V. Improvement

The target process was achieved by designing creative solutions to prevent the occurrence of the problems. Some of the Implemented solutions for causes are as follows.

After deliberation, it was decided to use single type flange head yellow passivated bolts with same thread & length for fitment of adapter plate on flywheel in Engine Testing.

Dowel Bush ID was revised and revised drawing released.

Standard tool provided for locking flywheel to avoid dent on Engine mounting dowel.

New process for gasket assembly on to Mounting Flange using Dendrite (adhesive)

Fixture provided for alignment of the gasket on to the Mounting Flange.

One threaded bolt socket of M.S resulted in less exposure of brass stud to battery voltage & avoided burning /damaging studs.

Standard tool to be made for locking flywheel.

Within the target dates, the implemented solutions provided the desired results, which are tabulated below.

Table.4 Results after implementation of solutions

Sr. No	Engine quality defects at main line	Defects Before solution	Defects After solution
01	Flywheel threading not ok / missing/ Flywheel bolt problem	43	02
02	Pressure plate mtg. dowel missing	42	0
03	Engine shortage.	33	0
04	Engine dowel not ok / problem	26	0
05	Starter motor stud/bolt problem	17	0
06	Engine oil pan bolt loose /Engine oil pan leak	12	0
07	Engine mounting dowel missing	11	0
08	Rejected engine issued	06	0
09	Flywheel bush under size	04	0
10	Miscellaneous	04	0
Total Engine Quality defect Quantity		198	02
Vehicle Production		27335	2910
Total PPM		7243	687

Statistical evaluation of implemented solution was carried out.

Ho-Defectives proportion before solution implementation = Defectives proportion after solution implementation

Ha-Defectives proportion before solution implementation > Defectives proportion after solution implementation

Test and CI for Two Proportions

Sample	X	N	Sample p
1	198	27335	0.007243
2	2	2910	0.000687

Difference = p (1) - p (2)
Estimate for difference: 0.006556
95% lower bound for difference: 0.00539415
Test for difference = 0 (vs. > 0): Z = 9.28
P-Value = 0.000

Result: P value is <0.05 So, Ho is rejected.

It shows that after implementation of solutions at various stages of Engine manufacturing there is significant improvement at Vehicle assembly line.

Various evaluation criteria set were evaluated as under.

1) SIGMA IMPACT

This criterion describes the main goal of this project that was to reduce the problems at Vehicle Main Line due to Engine Quality Issue and to improve the sigma level. After calculation Sigma level was found out to be improved considerably. (Table.4)

$$\text{PPM for Engine Quality Defect} = \frac{2 \ X \ 1000000}{2910} = 687.25$$

The corresponding sigma value was tabulated from the chart and found out to be 4.7. Sigma Improved considerably from 3.9 to 4.7 within the defined period satisfying the defined target.

2) CUSTOMER SATISFACTION IMPACT

Engine assembly line Department was able to assemble more defect free engines than the earlier period. Problem at main engine line due to Defects related to Engine quality issues reduce from Avg. 7243 PPM to 687 PPM per month.

The benefit is that there are no single defects reported at Final inspection stage (QP3) after implementation of action plan.

Competency of the team members enhanced while working with the sigma team.

3) TIME IMPACT

Time impact is also important to this project, the benefits obtained are intangible.

Considerable time was saved by not producing the defective engines and rework of the same.

4) COST / BENEFIT IMPACT

Cost of poor quality (COPQ) has been significantly reduced from $ 30,000 to $ 9,000 per annum, a reduction of 333%.

VI. Control

During control phase the implemented solutions were monitored with the help of various charts such as Eye charts, daily, weekly and monthly reports, Daily production report, and process and product audit on sample basis.

The improvements should be adhered to by providing training to the staff, implementing various incentives schemes and adhering to the modified systems.

VII. Conclusion

The study reported six sigma implementation on engine assembly line resulting into huge savings and other associated benefits leading to improved and robust process. Such improvements are possible with many processes in various application areas in both manufacturing and service sectors. The structured DMAIC process leads to all round improvement in a systematic manner and the evolution of many statistical softwares has made the analysis and application of various tools look simple and easy.

It may hence, be concluded that Six Sigma methodology has potential to address many Quality and productivity Improvement problems of modern times.

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