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Research Article

Assessment of Implementation of Six Sigma DMAIC approach in a Casting unit-A case study

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I N F O

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A B S T R A C T

Six-Sigma approach is a management approach of achieving major enhancements in a process through systematic elimination of waste. In this case, the casting unit under study was experiencing a rejection rate of 30%. The main aim of the study is to identify various causes of occurrence of blowholes and identify corresponding remedies for these defects by systematic implementation of DMAIC cycle. Preventive and corrective actions were recommended to reduce the blow holes defect and overall improvement is validated through two-proportion test. Results of investigation demonstrated the net significant reduction of blowhole defect from 28,111 to 9708 PPM (parts per million) which results in the net savings of rupees 12,56,640 anually.

Key words: Six Sigma, DMAIC, Preventive And Corrective Actions, Rejection Rate

Introduction

If an existing process is not meeting customer specifications, use of Six Sigma five-phase methodology DMAIC (Define, Measure, Analyze, Improve, Control) process can be implemented for better effectiveness and efficiency to achieve better productivity levels. These 5 phases are:

- **Define:** First of all, the problem should be defined and requirements of the customers need to be identified. The define phase sets the expectation of the improvement of project and maintenance of focus of Six Sigma strategy on customers' requirement.
- **Measure:** The measure phase identifies the defects in the product, gathers valid baseline information about the process and establishes improvement goals.
- **Analysis:** The analysis phase examines the data collected to generate a prioritised list of source of variation. It is the key component of any defect reducing programme. This is the stage at which new goals are set and route maps created for target performance level.
- **Improvement:** The optimal solution for reducing variation or mean is determined and confirmed in the improve phase. The objective of this phase is to confirm the key process variables, quantify their effects on the critical to quality (CTQ), use of brainstorming, etc. This phase helps to identify and quantify the key process variables and their influence on CTQs and determine acceptable limits to reduce the number of defects in the process.
- **Control:** The final stage of Six Sigma implementation is to hold the gains that have been obtained from the improve stage. Hence, in this stage, the new process considerations are documented and frozen into systems so that the gains are permanent (Jaglan et al., 2013).

Six Sigma has been widely adopted in a variety of industries worldwide and it has become one of the most important subjects of debate in productivity management. Six-Sigma is a well-structured methodology that can help a company achieve expected goals through continuous improvement.

Six Sigma can reduce defects to as low as 3.4 parts per million in an organization (Singh, 2010). This aim of this study is to reduce high rejection rate experienced by small manufacturing industry by systematic application of Six Sigma DMAIC methodology. Further, this study aims to investigate probable causes so that one can easily analyze and understand the real causes for blow holes.

Literature Review

Azis and Osada (2010) investigated that Six-Sigma has a positive and comprehensive impact on changing the management system. Six-Sigma has been harmonizing and synergizing people and processes by establishing a clear linkage among critical factors. This linkage, as a critical strength in innovation, is described by a causal relationships diagram using the system dynamics principle. By comparing with TQM, this paper has identified that Six-Sigma has additional features named as disseminating commitment and sustaining spirit. Further it is suggested that Six-Sigma can potentially be used as an innovation tool for leveraging organizational performance.

Pulakanam and Voges (2010) investigated that organizations are increasingly adopting Six-Sigma in a bid to improve the quality of their processes and products, and thus achieve competitive advantage. However, despite the apparent popularity of Six-Sigma, very little is known about the extent to which Six-Sigma is actually being adopted by organizations. Since 2004, a number of empirical studies have been undertaken in different countries and industry sectors to address these gaps in our knowledge of Six-Sigma adoption. The majority of these studies are reviewed and summarized in this paper and concluded that Six-Sigma is only a distant second to Lean in terms of popularity. During the period 2003 to 2007, Six-Sigma was implemented in 5% to 15% of the organizations.

Aboelmaged (2011) pointed out that there are two major improvement methodologies in applying Six-Sigma in different organizations. The first methodology, DMAIC, is used to improve already existing processes and can be divided into five phases; define, measure, analyze, improve and control. In contrast, the second methodology, DMADV, is used for new processes or when the existing processes are unable to achieve business objectives. This methodology can also be divided into five phases; define measure, analyze, design and verify.

Soti et al. (2011) pointed out that Six-Sigma attempts to reduce opportunities to commit mistakes through systematic and statistical driven approach; therefore, business excellence and Six-Sigma go hand-in-hand. Paper attempted to model barriers in Six-Sigma implementation by establishing relationship among them through interpretive structural modelling (ISM). Twelve barriers have been identified through literature survey and later validated through a questionnaire based survey. The ISM model classifies barriers into strategic, tactical and operational category. The driving power and dependency of these barriers are also modelled using MIC-MAC analysis. The result provides insight into the effective approach to counter these barriers.

Omar and Mahmoud (2012) reviewed the main idea of successful leadership to achieve sustainable competitive advantage to ensure quality of service by using Six-Sigma methods. Alternatively, it can only have the sincerity on theoretical basis, and this is what the current study intends to do. The research consisted of two parts; first, brief description of main phases of Six-Sigma and its system operation. Secondly, review the main dimension of sustainable competitive advantage including Operational Efficiency and Effectiveness, knowledge making and cost of poor quality.

Shafer and Moeller (2012) indicated that adopting Six-Sigma positively impacts organizational performance primarily through the efficiency with which employees are deployed. More specifically, enhanced employee productivity results were observed in both static analyses that assessed the performance of the sample Six-Sigma firms relative to their control groups at discrete points in time and dynamic analyses of the Six-Sigma firms‘ rate of improvement relative to the rate of improvement of their control groups. Benefits in terms of improved asset efficiency were not observed. Finally, there was no evidence that Six-Sigma negatively impacts corporate performance.

Gijo and Sarkar (2013) applied Six-Sigma DMAIC approach for quality improvement in wind energy sector. This paper discussed the development of sustainable wind farm roads for an organization engaged in manufacturing, installation and servicing of windmills in India. The systematic and data driven approach of Six-Sigma methodology identified many root causes for road damages and solutions were implemented to ensure sustainable wind farm roads. Six-Sigma has been successfully implemented world over in different business processes ranging from manufacturing to service and health care. However its application is very uncommon in areas like road construction. This article demonstrated the applicability of Six-Sigma methodology in uncommon areas.

Kumar et al. (2013) implemented DMAIC (Define, Measure, Analyze, Improve, and Control)-based Six-Sigma approach to improve the green sand casting process and has made the process more robust to quality variations. Analysis of various critical process parameters of the melt shop is also carried out with the help of Taguchi’s method of experimental design. The proposed techniques optimized control factors, resulting in superior quality and stability of the green sand castings process, which contributes to minimizing the casting defects and improving the sigma level of the industry.

DMAIC Cycle

This section describes the systematic application of DMAIC methodology in the casting unit under study which includes the preventive and corrective actions to improve the manufacturing system processes. The overall foundry rejection of Simpson 3Ø cylinder block is high. It is of utmost priority in the unit manufacturing the cylinder blocks family. The average foundry rejection of this product is 84,000 PPM against the target of 55,000 PPM due to which there occurs a loss of around Rs. 20.2 Lakhs/ Annum. The foundry rejection was observed for the last 1 year. Although a lot of actions were taken during last one year, but problem still persists. Since the cause is unknown, as well as solution is unknown; so DMAIC methodology has been applied.

Define Phase

The Define Phase is about coming up with a focused problem statement and a supporting measure of success or failure. To set the context and objectives for the project-Define the problem, improvement activities, opportunities for improvement, the project goals, and customer (internal and external) requirements. The 4-bore cylinder block is an integrated structure comprising main parts of an internal combustion engine such as:

- Cylinder head
- Coolant passages
- Intake & exhaust passages, and
- Crank case.

For defining the problem, CTQ (Critical To Quality) is identified from the voice of customer and CTP (Critical to Process) is identified from the voice of business, which are to be attended on priority to sustain in the business and shown in figure 1.

In the figure 2, the Pareto analysis of S3 block was done for the period April-June 2017. As per 80:20 concept the defects are marked in graph. It is inferred that Pareto analysis prioritizes 'Blow hole' defects as first & contributes to 36% of overall defects, followed by 'Sand', 'Water Jacket broken' & un-fused chaplet are 27%, 11.2% & 7.2% respectively. In this study we focus more on 'blow hole' defect as it is voice of customer & voice of business as well.

Business case which supports business objective, plan, impact of plan & sigma level defined in opportunity statement, current level and target level in goal statement, project scope, project plan, and team details were defined and sigma level has been calculated. Table-1 shows Sigma level calculations cylinder block measured for the period April-June'17. Whereas the number of units processed are 2,440 Nos., and the defects observed are 205 Nos.; the DPMO is 84,016 and current Sigma Level is calculated as 2.88.

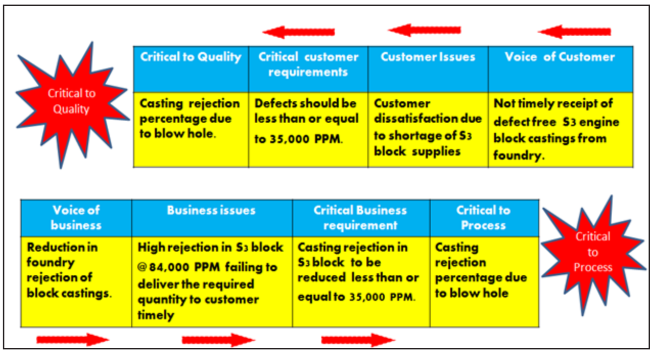


Figure 1.Critical To Quality / Critical to Process Chart

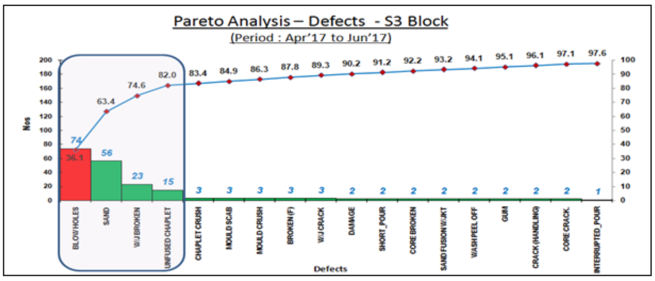


Figure 2.Understanding the Problem – Pareto Analysis of S3 Block

Table 1.Sigma Level Calculations – Apr'17 to Jun'17:

Calculated Sigma Level – Current

(Current data is from Apr'17 to Jun'17)

			enter
1	Number Of Units Processed	N=	2440
2	Total Number Of Defects Made (Include Defects Made And Later Fixed)	D=	205
3	Number Of Defect Opportunities Per Unit	O=	1
4	Solve For Defects Per Million Opportunities		84016
5	Look Up Process Sigma In Abridged Sigma Conversion Table	Sigma level =	2.88

Figure 3 shows the foundry stage rejection PPM trend plotted for the months April-June, 2017. The gap in April'17 is 34,000 PPM, in May'17 is 28,200 PPM and In June'17 is 24,000 PPM. The overall average PPM for the period is 84,000 PPM. The rejection is in decreasing trend but not significantly. As the actual rejection PPM doesn't meet the target PPM even in a single month. Hence it looks like chronic problem.

Table 2 shows severity table of 4 products and scoring has been done based on the five criteria such as (a) impact on customer satisfaction (b) Impact on quality (c) Impact on production & (d) Impact on cost. The cylinder block trending high severity of 31, hence this has been selected for study.

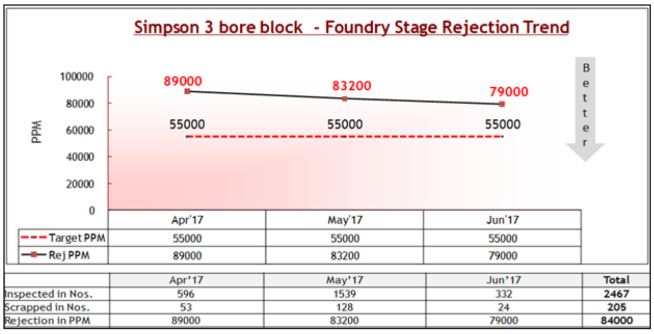


Figure 3.3-bore Block Foundry Rejection Trend

Table 2.Severity Table to Justify the Problem selection

#	Problem Description	Severity (Scale 1 to 10)				
		Impact on Customer Satisfaction	Impact on Quality	Impact on Production	Impact on Cost	Total
1	S3 Block	9	8	6	8	31
2	SJ3 Block	5	5	5	5	20
3	FT35	5	5	3	3	16
4	Bajaj Block	5	5	2	2	14

Measure Phase

The measure phase involves more numerical studies and data analysis than the define phase. This phase focuses on measurement system validation and gathering root causes. The voice of process (VOP) has variation from both the measurement system and the process and all its families (sources) of variation.

Probable cause of problem

Figure 4 shows cause & effect diagram drawn for the Cylinder block with blow hole defect, the fish bone diagran drawn for four categories- Man, Machine, Method & Material. The possible causes arrived from brainstorming process were fitted on each category of cause & effect diagram. Brainstorming is a group creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its member. The cause-effect diagram also called as fish bone diagram, is a visualization tool for categorizing the potential causes of a problem in order to identify its root causes.

In figure 5, the pareto has been drawn for the possible causes after cause and effect matrix exercise. 80% of the causes taken for data collection are a) Water jacket core gas is high b) Variation in pouring temperature c) high sand-moisture and, d) Low permeability.

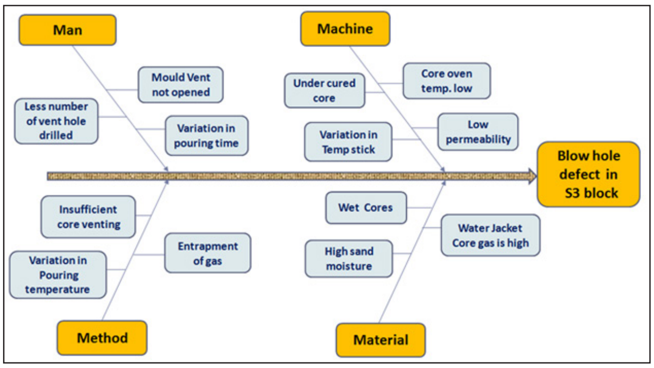


Figure 4.Cause & Effect diagram – Blow hole defect

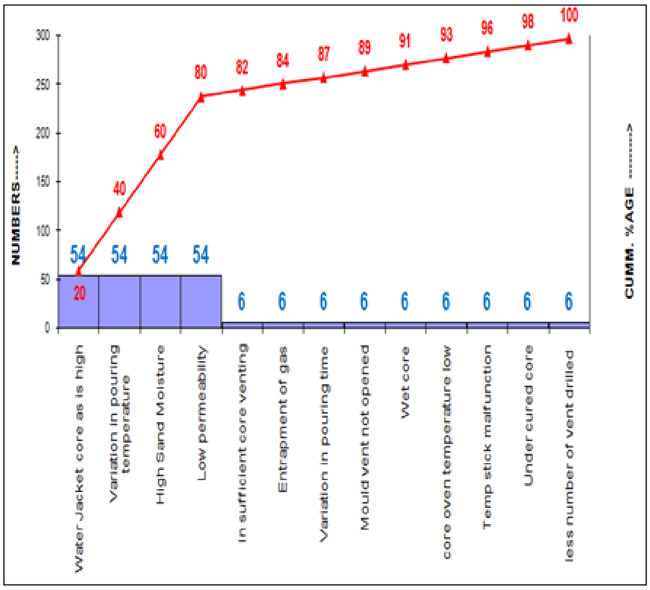


Figure 5.Pareto on possible causes - Blow hole defect

Table 3.Shows the operational definition for Y and X indicators

Table 3.Operational definitions

Sl. No.	Performance Indicator (Y)	Operational definition
Y1	Casting Scrap due to Blow Holes Defect.	Defect in the casting due to Blow Holes & can be identified visually on the cope side surface of casting as per the limit sample. There can be a more than one number of Blow holes on a single Casting surface but it is counted as one defective casting.
Sl. No.	**Process / input indicator (X)**	**Operational definition**
X1	Water Jacket Core Gas is high	Amount of gas in 1 gm of cured core.
X2	Variation in Pouring Temperature	Temperature taken at "Spout of Press Pour " at which a casting is poured.
X3	High sand moisture	Amount of free moisture present in 100 gm of molding sand
X4	Low permeability	Property of mould that allows gases to escape from mould.

Data Measurement Plan

Table 4 shows the data measurement plan for the performance measure such as for a) Water jacket core gas is high b) High moulding sand moisture c) Low permeability d) Low pouring temperature. Data source, sample size, data collection techniques are indicated.

Table 4.Data Measurement Plan

Process / Input (X)	Operational definition	Data source and location	Sample size	Who will collect the data	When will data be collected	How will data be collected	Other data that should be collected at the same time
Water Jacket Core Gas is High	Refer Previous Page.	Raw Material Test Record & Laboratory	2 Sample from a lot	Lab Operator	In the period from Date - 01.07.2017 to 15.07.2017	Gas Evaluator	–
High Moulding Sand Moisture		Daily Sand testing parameter report SC/F-201	Once in a Lot	Lab tester	In the period from Date - 01.07.2017 to 15.07.2017	Heater & Weighing Balance Apparatus	–
Low permeability		Daily Sand testing parameter report SC/F-201	Once in a Lot	Lab tester	In the period from Date - 01.07.2017 to 15.07.2017	Permeability tester	–
Low Pouring Temperature		Daily auto pouring log sheet Lab/F-12	2-3 Times in a single lot	Lab Tester	In the period from Date - 01.07.2017 to 15.07.2017	Lance & Temp. Meter	–

Analyze Phase

The Analyze phase of DMAIC helps project teams identify problems in the production problem that cause product defects. This phase of six-sigma methodology is loaded with tools to help spot the problems in the production process and to determine if these problems are the root causes of defects.

The validation strategies for Blow hole are:

- Water Jacket core gas is high (Property of Core)
- Variation in Pouring Temperature (Property of Metal)
- High Sand Moisture (Property of Prepared Sand)
- Low Permeability (Property of Moulding Sand)

Test of Validation

To validate the data run chart for pouring temperature, Anderson – Darling Normality Test for Pouring Temperature, run chart for moisture, Anderson – Darling Normality Test for sand moisture, run chart for permeability, Anderson – Darling Normality Test for permeability and Residual plots for Blow holes has been prepared as shown in Figure 6 to Figure 12.

In the figure 6, the run chart of pouring temperature shows that the Data is 'Random distributed' since all 4P's are > 0.05.

In the figure 7., the normality test for pouring temperature shows that the Data is 'normal' since all P value is > 0.05

In the figure 8, the run chart of Sand Moisture shows that the Data is 'Random distributed' since all 4P's are > 0.05

In the figure 9, the normality test for Sand Moisture shows that the Data is 'normal' since all P value is > 0.05.

In the figure 10 the run chart of Sand Permeability shows that the Data is 'Random distributed' since all 4P's are > 0.05.

In the figure 11, the normality test for Sand Permeability shows that the Data is 'normal' since all P value is > 0.05

In the figure 12, the normal probability plot indicates Residual Vs Blow percent is normally distributed; No funnel effect in fitted value Vs Residual; Histogram of residuals follows bell shaped distribution.

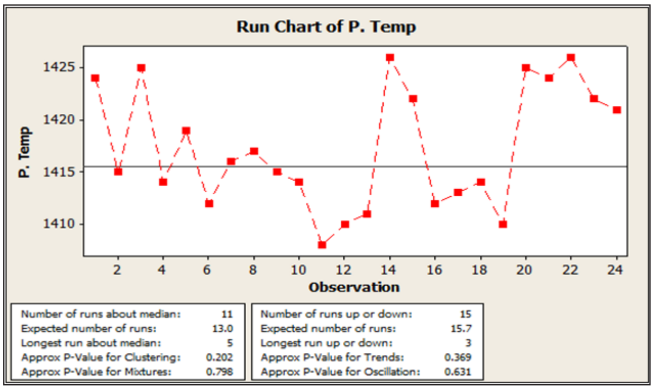


Figure 6.Data Independence Test of Pouring Temperature

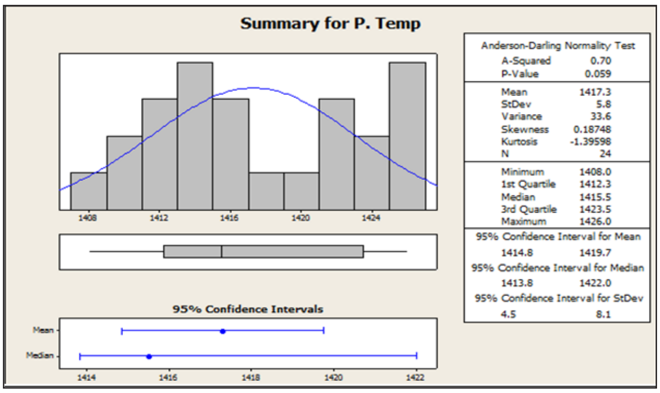


Figure 7.Anderson – Darling Normality Test for Pouring Temperature

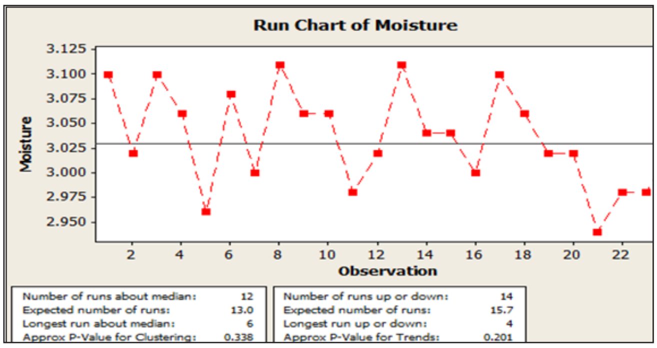


Figure 8.Data Independence Test of Moisture

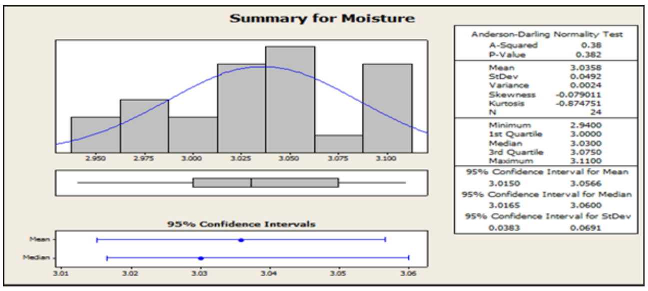


Figure 9.Anderson – Darling Normality Test for Sand Moisture

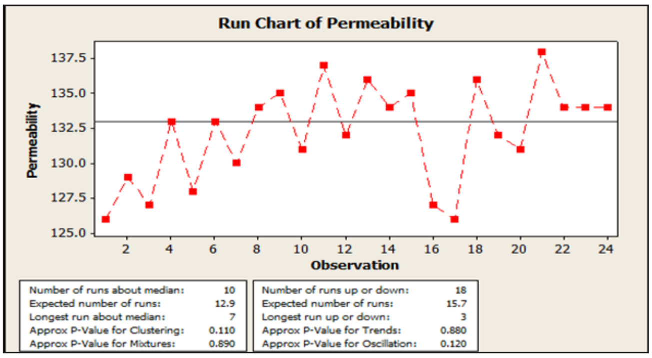


Figure 10.Data Independence Test of Sand Permeability

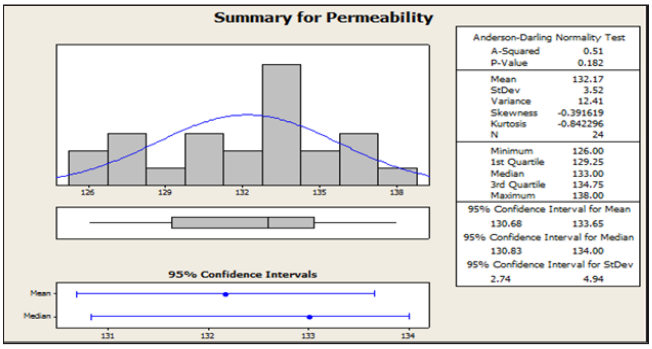


Figure 11.Anderson – Darling Normality Test for Sand Permeability

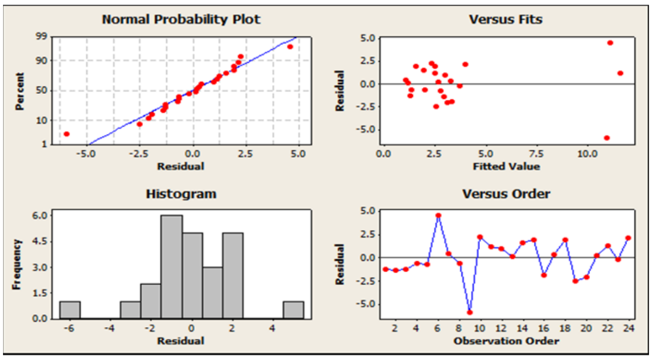


Figure 12.Residual plots for Blow holes

Root Cause of the problem

Table 5 shows the why-why technique to identify the solution for the water jacket area core gas high cause and the solution is 'low gas evolution sand to be used'.

Improve Phase

The focus of this stage is to determine a solution which is based on the uncovered problem in the first three phases.

Table 6 and Table 7 show the three possible solutions. The advantage of using cold box process core of lesser gas evolution (10 to 11 cc/gm) than hot box process, which is 16 to 17 cc/gm. The disadvantage of cold box process is lesser tensile strength i.e. 130 PSI than hot box process core, which is 230 PSI.

From the above trial it was observed that with 30% chromite sand addition the CTS is observed as 210 to 230 PSI, which is comparatively matching with CTS of water jacket as 200 to 220 PSI by hot box process. If the CTS is lower than 200 PSI may lead to water jacket core breakage.

Control Phase

The focus of this stage is to make sure that the action item created in the improve phase is well-implemented and maintained.

Full scale implementation plan

Table 8 shows the full scale implementation on cold box water jacket core with 30% chromite sand. The result of blow hole defect is 5 numbers out of 408 numbers. The sigma level was 3.67% and full scale run is 1.22%, there is a gain of 2.45%.

In the figure- 13 the sigma level calculation of overall rejection before project and after full scale run are 2.88 & 3.28 respectively. There is an improvement in sigma level by 0.40.

Overall Improvement and Validation of overall Improvement

- Overall Rejection trend

In the figure 14, the overall rejection trend shows reduction of rejection after quick win improvement and after reduction of blow hole defect. This can be seen during Aug'17 to Oct'17.

Blow hole defect has been reduced from 28,111 PPM to 9,708 PPM, which is even less than the target.

Statistical Problem statement:

Ho: Overall rejection in numbers before project is equal with overall rejection in numbers after project

Ha: Overall rejection in numbers after project is < overall rejection in numbers before project.

In the above figure- 15, Since P value is 0.000 less than 0.05, at 95% confidence level. It shows that null hypothesis is rejected (P Low Null Go) & we conclude that there is a significant improvement after implementing six sigma project.

Cost Benefit Analysis, Conclusions and Limitations

Results of investigation demonstrated that Six Sigma DMAIC approach significantly aimed at reducing rejections or improving sigma level through small improvements in the manufacturing system processes. Six Sigma has proven a universal approach of achieving major enhancements through system simplification and Organizational potential through incremental improvements. In the case under study, Pareto Analysis helped to predict the root cause of the problem and corrective actions have been taken to reduce high core gas area of water jacket. Implementation of DMAIC approach in the unit results in reduction of net PPM from 28,111 to 9,708 which results in net savings of rupees 12,56,640 anually as shown in Table 9.

The selection of industry has been done on convenience sampling technique. The study can be expanded by implementing sophisticated integrated Six Sigma methodology like Lean Six Sigma which is the integration of lean manufacturing and Six Sigma. Moreover, there is possibility of method variance due to restricted area of research.

Table 5.Identified root causes

Valid Probable cause	Why?	Why?	Why?	Action
Water Jacket area core gas is high	Gas evolution by Water Jacket core was more.	The water jacket core is made by hot box process & Gas evolution 16 to 17 cc/gm	Process design	Low gas evolution sand to be used.

Table 6.List of possible solutions

-	Xs validated	Possible solutions
1.	Water jacket core gas is high	1.1. Low gas evolution cold box sand (10 to 11 cc/gm)
		1.2. Low gas evolution cold box sand + 20% chromate sand addition
		1.3. Low gas evolution cold box sand + 20% chromate sand addition

Table 7.List of possible solutions

Scope	-	Trial	Trail Date	Core Tensile Strength in PSI	Status
S3 Block – Water Jacket Core	1.1	Cold box sand (10 to 11cc/gm)	1st week of Aug'17	120 to 130	Core distortion observed very high, core dimensionally got rejected.
	1.2	Cold box sand + 20% Chromite sand addition	1st week of Aug'17	190 to 210	Core distortion observed moderately, core, core dimensionally got rejected.
	1.3	Cold box sand + 30% Chromite sand addition	1st week of Aug'17	210 to 230	No Core distortion, Core dimensionally ok.

Table 8.Full scale implementation Plan

Output indicator	Average	Standard deviation	Cp	Cpk	Sigma Level	DPMO	Action Plan
Y1 (Blow) - Before	3.67%				3.29	36670	
Y1 (Blow) – Full scale run	1.22 %				3.75	12255	

Sigma level before and after improvement

Worksheet For Calculating Sigma Performance

Overall Rejection - BEFORE PROJECT (Jun to Aug'15)

			enter
1	Number Of Units Processed	N=	2440
2	Total Number Of Defects Made (Include Defects Made And Later Fixed)	D=	205
3	Number Of Defect Opportunities Per Unit	O=	1
4	Solve For Defects Per Million Opportunities		84016
5	Look Up Process Sigma In Abridged Sigma Conversion Table	Sigma level =	2.88

Worksheet For Calculating Sigma Performance

Overall Rejection - AFTER IMPROVEMENT (Oct'15 to Apr16)

			enter
1	Number Of Units Processed	N=	860
2	Total Number Of Defects Made (Include Defects Made And Later Fixed)	D=	32
3	Number Of Defect Opportunities Per Unit	O=	1
4	Solve For Defects Per Million Opportunities		37209
5	Look Up Process Sigma In Abridged Sigma Conversion Table	Sigma level =	3.28

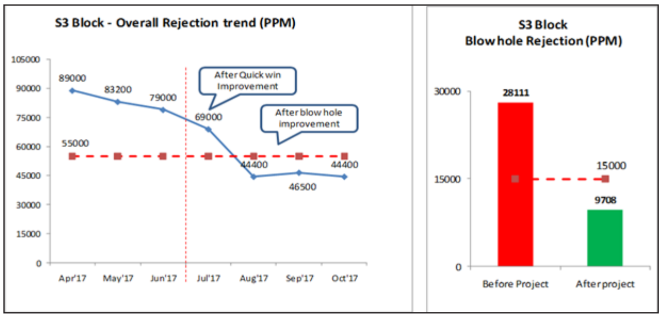
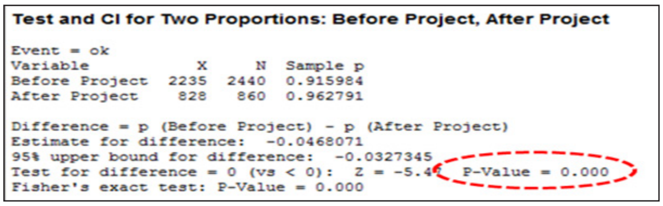


Figure 14.Results of Overall Rejection Analysis



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Test and CI for Two Proportions: Before Project, After Project

Event = ok
Variable            X     N  Sample p
Before Project   2235  2440  0.915984
After Project     828   860  0.962791

Difference = p (Before Project) - p (After Project)
Estimate for difference:  -0.0468071
95% upper bound for difference:  -0.0327345
Test for difference = 0 (vs < 0):  Z = -5.47  P-Value = 0.000
Fisher's exact test: P-Value = 0.000
```

Figure 15.Two Proportion Test for Overall Rejection

Table 9.Cost Benefit Analysis

Casting Weight	77 kg
Selling price/kg	Rupees 75
Current level of blow holes	8.37% (Average of Apr'17 to Jun'17)
Achieved level of blow holes	5.08%(Average of Jul'17 to Oct'17)
Recovery of metal/kg	Rupees(75-35)=Rupees 40
Reduction in defects	8.4% -5.08%=3.35%
Production plan/month	1000 No's
Rejection/Month	(1000/100)*3.35=34 Nos.
Savings/Annum	(77 kg *rupees 40 *34 Nos.)*12 Rupees 12,56,640

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