International Journal for Quality Research 9(4) 577–604
ISSN 1800-6450

Javedhusen Malek [1]
Darshak Desai

REDUCING REJECTION/REWORK IN PRESSURE DIE CASTING PROCESS BY APPLICATION OF DMAIC METHODOLOGY OF SIX SIGMA

Article info:
Received 27.08.2015
Accepted 27.11.2015

UDC – 332.05

Abstract: *In today's ever-changing customer driven market, industries are needed to improve their products and processes to satisfy customer requirements. The Six Sigma approach has set a new paradigm of business excellence. Six Sigma as a process driven improvement methodology has been adopted successfully by many industries. From the review of various literatures, it is revealed that Six Sigma is well adopted in large scale enterprise but having less evidence of adoption in Indian SMEs. This paper is focused on providing path to Indian SMEs for initiating Six Sigma approach in their industries. The paper discusses the real life case where Six Sigma has been successfully applied at one of the Indian small-scale unit to improve rejection/rework rate in manufacturing products by pressure die casting process. This paper describes phase wise application of all the phases of define-measure-analyse-improve-control (DMAIC) which also shows impact of Six Sigma in quality improvement.*

Keywords: *Six Sigma, Indian SMEs, Pressure die casting process, DMAIC methodology*

1. Introduction

In today's world of rapid globalisation and competitive business environment of 21st century, various challenges have put companies under increasing pressure to improve their performance and become a global competitive by achieving business excellence. As the current market is fully customer centric, companies are needed to produce the products which are as per customer requirement. For competing in such a market, companies are required to adopt the continuous improvement methodology which is focused on the quality and capable of producing the products defect free. Six Sigma is a proven successful methodology which is capable of producing the products which are close to customer requirement. Six Sigma is a set of techniques and tools for process improvement. It seeks to improve the quality of process output by identifying and removing the causes of defects and minimizing variability in manufacturing and business process. It uses a set of quality management methods, including statistical and non-statistical tools & techniques and creates a special infrastructure of people within the organization. The fundamental objective of the Six Sigma methodology is the implementation of a measurement-based

[1] Corresponding author: Javedhusen Malek
email: javed_husen@yahoo.com

strategy that focuses on process improvement and variation reduction through the application of Six Sigma improvement project.

In today's global competitive market, industries are trying many improvement strategies such as Toyota Production System, Single Minute Exchange of Dies (SMED), Pokayoke, Lean manufacturing, etc. There are also some techniques with the edge of Quality Engineering and Management such as Statistical Quality Control (SQC), Total Quality Management (TQM), ISO certifications, etc. Despite of capable of producing required results, these technique lacks in their implementation and result after long time. In this globalization each industry needs a break through strategy and that is well provided by Six Sigma (Desai, 2008). From the last two decades the market is changed towards customers and quality centric. In this global market due to increasing importance of supply chain management, big industries are highly dependent on the SMEs. So it is very much required for the SMEs to provide products and services with high quality to the big scale industries. With increase in the demand of high quality products by large organisations has put the SMEs to increase their business performance. Many SMEs think to jump in the higher tier but this cannot achieved expect the improvement in quality of the products and services (Sambhe, 2012).

2. Literature review

2.1 Six Sigma – an overview

Six Sigma's journey was started with an engineer Bill Smith working for the Motorola. So ultimately Six Sigma was developed with initiation by Motorola Company in 1986-87. The savings for Motorola from Six Sigma efforts were more than $16 billion (Andrea 2011). Then this concept was followed by various companies such as Allied Signal, General Electric (GE), Johnson & Johnson and Asea Brown Boveri. Six Sigma is a business strategy that uses data and facts to measure, identify the root cause and improving the performance of process or product through elimination of defects from the process. Six Sigma is a systematic methodology that uses statistical and non-statistical tools and techniques to maximize an organization's return on investment (ROI) through continuous quality improvement of processes by reducing defects and non-conformance (Gholap and Desai, 2012). Six Sigma was a way to express its quality goal of 3.4 DPMO where defect opportunity is a process failure that is critical to the customer. A normal distribution curve has a positive and negative spread of 4.5σ. But, in practice, it is observed that every process has a tendency to have inbuilt variance to the extent of 1.5σ. Due to this phenomenon the spread really is 4.5σ+1.5σ on both sides of the mean. That mean in order to deliver 100% acceptable quality output, the process output must be within 6σ spread on both sides of the mean as shown in Fig. 1(Gopalakrishnan, 2012). Relation between sigma level, output and DPMO is shown in Table 1.

Six Sigma mainly consists of two methodologies that are DMAIC used for process improvement and DFSS used for design improvement. DMAIC is applied to existing processes and DFSS is applied to new process or product development. From the many literatures it is explored that DMAIC is mostly used as compared to DFSS. From review of many different literatures, DMAIC methodology with different processes in each phase is shown in Table 2. If these processes are applied systematically in each phase, company will able to achieve drastic improvement in their business performance.

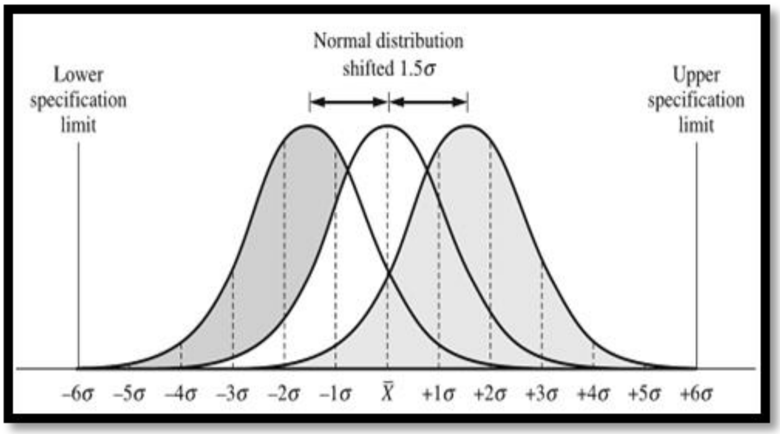

Figure 1. Process Spread on both sides of the mean

Table 1. Performance Measure

Sigma Level	Percent Output	DPMO
1σ	30.23	697700
2σ	69.13	308700
3σ	93.32	66810
4σ	99.3790	6210
5σ	99.97670	233
6σ	99.999660	3.4

Table 2. Phase wise processes

Phases	Key Processes
Define	• Identification of suitable projects based on business objectives • Define the scope and goals of the improvement project in terms of customer requirement • Development of project charter and critical to quality issues
Measure	• Selecting product characteristics and measurement system analysis • Mapping the respective processes and data collection • Recording the results with process capabilities and exploring the performance gap
Analyse	• Detailed analysis to find out various root causes • Validation of the root causes • Prioritizing of most affecting root causes
Improve	• Brainstorming possible alternative improvements for implementation • Implementation of the selected improvements • Verification of key process variables for improved conditions
Control	• Control process variations to meet customer requirement • Develop a strategy to monitor and control the improved process • Verify the project objectives

2.2 Indian SMEs – an overview

According to IDC report (2008), Department of Scientific & Industrial Research (DSIR), small and medium enterprises can be defined as "*Small enterprises are those companies who have an investment between in plant and machinery of up to INR 5 Crores. Medium enterprises are the ones who have an investment between INR 5 Crores to INR 10 Crores in plant and machinery. Companies having a turnover of up to INR 50 Crores were considered as small company and companies with turnover in the range of INR 50 to 250 Crores were considered as medium companies*" (Sambhe, 2012). Six Sigma in Indian industries are not used up to its full extend especially in SMEs. He also provides roadmap for the SMEs to carry out Six Sigma projects in small scale industries by case studies showing financial impact by reducing rejection rate (Desai, 2006) (Desai, 2008). According to Gijo and Rao, (2005) despite of many benefits from Six Sigma implementation still some issues are their which creating obstacles for the Six Sigma implementation, These obstacles are insufficient knowledge of tools and techniques, Improper project selection, Lack of resources, Lack of coordination between functions, Concentration on trivial many rather than the vital few, Short closure of projects, Non-availability of data, Impatience to get results and improper selection of team member for the project (Gijo and Rao, 2005). One of the most favourable benefits of Six Sigma as an improvement drive is the ability to introduce a concept of customer satisfaction which is the aim of any size and type of firm. In global market large organization are highly dependent on SMEs for getting quality products and services. This force from large organization has left no alternative for SMEs except to introduce Six Sigma business strategy (Sambhe, 2012). There are myths that Six Sigma is suitable for large organizations only but, Six Sigma is equally suitable for SMEs too (Desai, 2008). In this context, reflective practice was carried out which states that there is nothing inherent in the Six Sigma concept that it can only be applicable to large-scale industries. This study also explains that a quality problem is a quality problem, variation is variation, waste is waste and an unhappy customer is an unhappy customer. From above it is clear that size of company is not an obstacle for practising Six Sigma concept (Antony 2008).

2.3 Six Sigma and Indian SMEs

In today's market of globalization and competition, Indian industries are needed to adopt advanced breakthrough quality improvement strategy like Six Sigma and other continuous quality improvement techniques. As Indian SMEs are needed to compete in the global market, they must have knowledge about the global standards in terms of quality and customer requirements. To achieve these global standards, Indian industries required to adopt continuous process improvement strategies such as Six Sigma (Sambhe, 2012). It is to be noted that there are many evidence of successful practices of Six Sigma in large-scale industries but very few SMEs have practiced Six Sigma in their industries which is showing the ignorance of impact of Six Sigma in SMEs. A study was carried out regarding the penetration of Six Sigma in Indian industries as well as benefits of the same which indicates that the manufacturing sector has adopted Six Sigma with 69% contribution. Second in the list is Information Technology (IT) with 15% contribution. Manufacturing and service combined and others are same in adopting Six Sigma with 8% contribution. "Reduction in costs" is the largest benefit which is drawn by large-scale industries whereas "increase in profitability" is the largest benefit for SMEs (Desai and Patel, 2009).

One of the attempts to demonstrate the impact of Six Sigma in Indian SMEs was carried out where Six Sigma methodology was successfully applied to a small-scale foundry industry to reduce the rejections and rework in leaf spring manufacturing process. All the critical input variables were optimized by application of Six Sigma project which resulted into reduction of overall rejection from 48.33% to 0.79%. This application of Six Sigma strategy resulted into remarkable breakthrough improvement in terms of annualized savings of USD 8,000/year (Gijo *et al*., 2014).

One more successful practice of Six Sigma implementation in Indian SMEs was carried out to reduce the rework of the track shoe having higher production cost. By optimizing key input variables the sigma level has been increased from 1.51 to 4.15 which resulted into reduction of cost of poor quality (COPQ) from Rs. 22,72,480 to Rs. 20,187 per annum. This application of Six Sigma also resulted into bottom line improvement in terms of savings of Rs. 2,252,293 per year and ROI (Gholap and Desai, 2012).

Some of the good practices are carried out by various authors in Indian SMEs. Six Sigma was successfully deployed in aluminium die casting process to improve quality and productivity which reduces the defect level from 17.22% to 4.8% (Shanmugaraja *et al*., 2011). Six Sigma was well applied to reduce the rejection rate of sleeve which resulted into improvement in productivity and profitability (Desai, 2008). Rejection rate of the piston in one of the category was reduced by application of Six Sigma methodology in Indian foundry (Singh and Khanduja, 2012). Some practices successfully carried out in Indian SMEs are discussed showing improvement in customer delivery commitments and improving productivity and quality (Desai, 2012) (Desai, 2006).

From the above literature reviews, it is to be noted that there are less evidence of Six Sigma implementation in Indian SMEs. Though some practitioners have started initiating Six Sigma projects, still impact of Six Sigma in Indian SMEs have not explored to its full extent. Initiation should carry out with DMAIC methodology. For eliminating the myth that Six Sigma is full package heavy statistical tools & techniques, simple tools & techniques should be utilized for the pilot project.

3. Case study

3.1 The Company

A case study has been carried out in a small-scale industry which is producing various spare parts for the Stenter machines. This company is an ISO 9001:2008 certified and comprising well equipped machine tools straddling across 19000sq.ft area. Their core competence lies in the production of wide range of products like Chains, Clip & Pin Plates of various types of Stenter Machines. This company is manufacturing their various products with first process as pressure die casting carried out on cold chamber pressure die casting machines and they are facing the problem of rejection and rework in their various products. Based on sales value of various products, product named Artos Body is selected for reducing rejection/rework.

3.2 Project objectives

In today’s challenging market, every organization is looking to achieve higher quality and productivity. This can be easily achieved if you focus on the reduction in various defects which causing rejection of the components. This is the most viable strategy and it will also lead the organization towards effectiveness in competitive market. The primary objective of this project is given below.

- To reduce rejection/rework of Artos Body in pressure die casting machine from 15.50% to 7.75% by application of DMAIC methodology of Six Sigma.

By performing this project some secondary objectives are also there which will be achieved together with primary objective.

Secondary objectives for this project are given below.

- To introduce DMAIC methodology of Six Sigma and its benefits in organisation for reducing rejection/rework of the products.
- To increase production rate and enhance delivery commitments which will lead to customer satisfaction.
- To aware the organisation about need of quality improvement.

3.3 Define Phase

This phase of DMAIC methodology defines the project. This phase identifies critical customer requirements and links them to business needs. The aim of Define phase is to define the problem with all details including project title, objective, scope, team composition. This creates a sense of ownership for the project; it also prevents the delivery of mixed messages between team members. As a first step, project charter was prepared including all the required information such as business case, problem statement, project goal, project scope, project key process output variables (KPOVs) and team formed. Project charter helps each member of the team to understand the problem and leads toward objectives of the project. Since one of the critical success factors of the Six Sigma methodology is involvement of top management, Director of the company is acting as Champion for the project. Team also consists of two Black Belts having a required knowledge of the field for the problem in concern. The project charter includes business case, problem statement, project goal and CTQ tree.

Business case

"Company is manufacturing their different products on Pressure Die Casting Machine and they are facing problem of rejection/rework. In these products Artos Body is getting rejection/Rework of 15.50% which resulted into reduced quality and productivity."

Problem statement

"*The rejection/rework rate of Artos Body is 15.50% in pressure die casting process*"

Project goal

*"*Reducing the rejection/rework of Artos Body from 15.50% to 7.75%*"*

The project team has defined the goal statement of the project as. It is very much important for the project team to understand the critical to quality requirements. Artos Body is mainly getting rejected or reworked due to three defects named as Blowhole, Poor surface finish and Improper filling. Since these are the reasons for rejection and rework of the product, these defects are considered as a critical to quality (CTQ). Critical to quality (CTQ) tree tool is used for identifying the critical quality requirements which is shown in Figure 2. For better understanding of the reader, photographs of defects are also shown in Figure 3.

Since there was a team from different knowledge and understanding, it was decided that it was essential to perform a SIPOC (Supplier-Input-Process-Output-Customer) analysis to provide better understanding of the process to all the team members. The SIPOC provides the start point and end point of the process where improvement is to be carried out. This is basically similar to the process flow for understanding the each steps of the process. SIPOC mapping was prepared by the involvement of the each member of the team. By performing SIPOC, the team got the clarity of the project in terms of the scope of the project, inputs, outputs, suppliers and customers of the process. It was clear from the SIPOC that team focused on the pressure die casting process which is carried out on cold chamber pressure die casting machine.

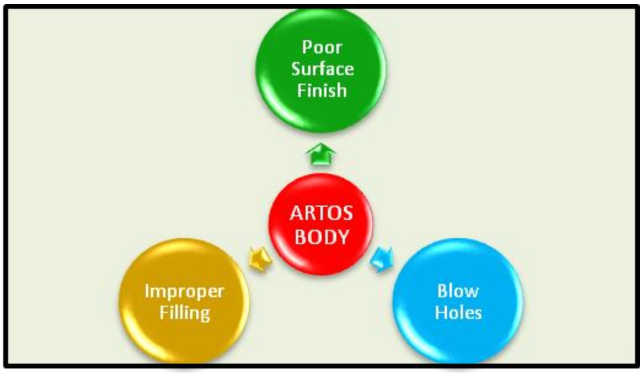

Figure 2. Critical to quality (CTQ) tree

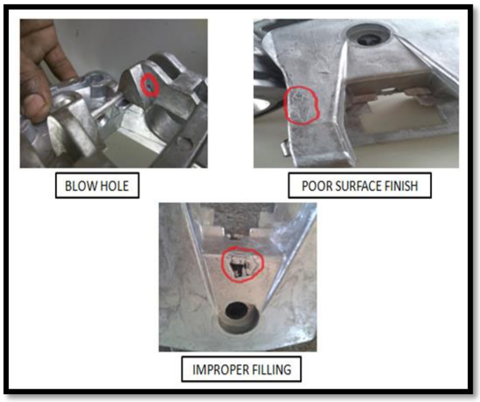

Figure 3. Schematic representation of defects

The entire process mapping in the form of SIPOC was difficult to include so it is not included for simplicity.

3.4 Measure Phase

The objective of the measure phase is to understand and establish the baseline performance of the process in terms of process capability or sigma rating. In this phase based on the CTQs decided in the previous phase data collection to be done. Before going for data collection it is necessary to see that current measurement system is capable. While collecting the data if the measurement system is not robust, the data collected may not be accurate which will resulted into trouble in the project. For continuous data Gauge repeatability and reproducibility (R&R) studies are carried to check the robustness of the instrument under use. In our case two inspectors did the inspection of the products. There was no instrument involved in the inspection process and it was only visual inspection of the products. Since our data are discrete, we have carried out measurement system analysis for discrete data with the help of MINITAB 17 software. In this we have carried out analysis for the two appraisers, two trials and 10 components with mixture of 5 accepted and 5 rejected. The study was carried out in two trials with different timings so that workers cannot mark the component based on their memory from the first trial. A result of this analysis is shown in Figure 4.

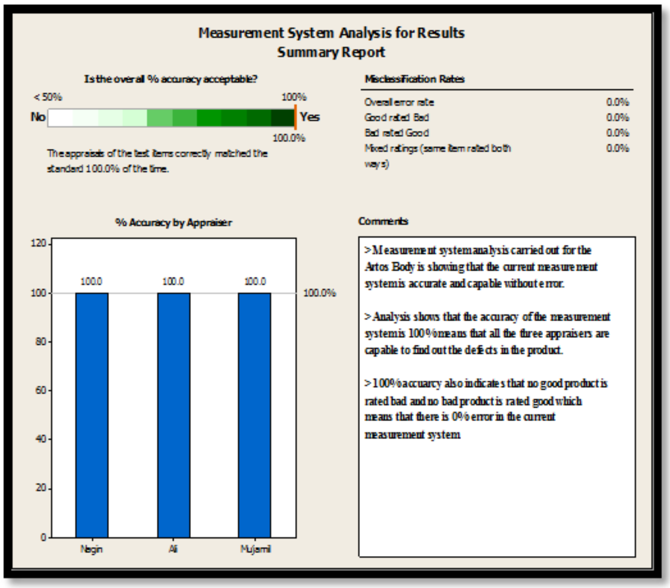

Figure 4. Measurement system analysis

To see the current status of the process, data were collected for the last 12 months which was showing a rejection and rework of 11.41% in the Artos Body. Data collected is shown in Table 3 with month wise production and rejection/rework. To graphically represent the percentage rejection and rework P chart was used. Since our data is containing an unequal sample size in terms of production for each month, we have used P chart to represent the percentage of rejection and rework of the Artos Body for last 12 months. Percentage rejection & rework of Artos Body based on last 12 months data is shown in Figure 5.

Table 3. Last 12 months data

Past Rejection/Rework Data (From Apr-13 - Aug-14)				
Sr. No	**Month**	**Product Name**	**Total Production**	**Total Rejection/ Rework**
1	Apr-13	Artos Body	4408	501
2	May-13	Artos Body	2744	320
3	Jul-13	Artos Body	3512	452
4	Aug-13	Artos Body	3446	480
5	Nov-13	Artos Body	5462	576
6	Dec-13	Artos Body	5174	562
7	Feb-14	Artos Body	5017	557
8	Mar-14	Artos Body	3044	359
9	Apr-14	Artos Body	3840	441
10	May-14	Artos Body	6312	664
11	Jun-14	Artos Body	2929	339
12	Jul-14	Artos Body	6106	680
			51994	5931

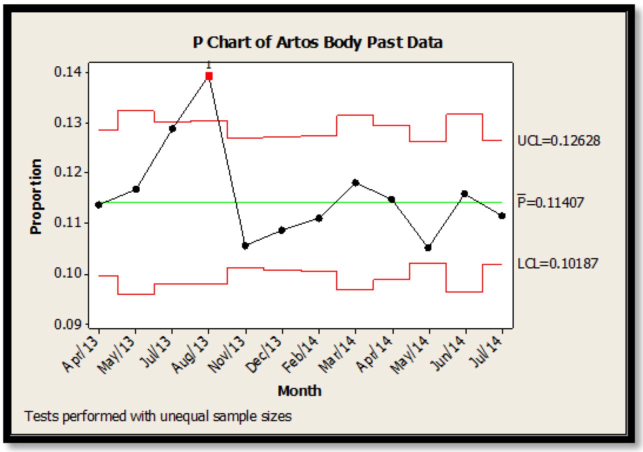

Figure 5. P chart for last 12 month's data

During the project it was observed that percentage rejection/rework is actually more than 11.41% which is of last year. So two months data were collected to identify the actual percentage rejection/rework and based on this data collection goal was revised. Data collection of Feb-March month is shown below in Table 4.

Table 4. Current data of Feb-March 2015

Data Collection of Feb-March 2015				
Sr No	**Date**	**Product Name**	**Total Production**	**Total Rejection/ Rework**
1	09-02-2015	Artos Body	329	36
2	10-02-2015	Artos Body	247	45
3	11-02-2015	Artos Body	305	47
4	12-02-2015	Artos Body	330	40
5	13-02-2015	Artos Body	227	27
6	14-02-2015	Artos Body	345	46
7	17-02-2015	Artos Body	390	53
8	19-02-2015	Artos Body	294	45
9	20-02-2015	Artos Body	277	32
10	25-02-2015	Artos Body	186	77
11	27-02-2015	Artos Body	298	82
12	04-03-2015	Artos Body	439	92
13	05-03-2015	Artos Body	254	75
14	07-03-2015	Artos Body	322	29
15	09-03-2015	Artos Body	297	36
16	10-03-2015	Artos Body	358	38
17	11-03-2015	Artos Body	307	35
18	25-03-2015	Artos Body	339	54
19	26-03-2015	Artos Body	348	42
20	28-03-2015	Artos Body	317	40
21	30-03-2015	Artos Body	276	33
22	31-03-2015	Artos Body	276	44

As earlier same way p chart was drawn for above data shown in Figure 6.

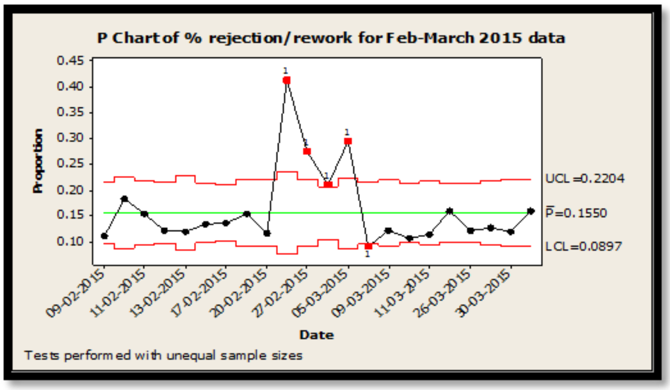

Figure 6. P chart of Feb-March 2015 data

Since our data are discrete, we will calculate our current sigma level by Defect Per Million Opportunities (DPMO) approach with equation shown below:

$$DPMO = \frac{\text{No. of defects} * 1000000}{\text{No. of opportunities} * \text{No. of units produced}}$$

Based on the calculated DPMO, the Sigma level is calculated using the values given in Table 5.

Table 5. Sigma Level vs DPMO

Sigma Level	DPMO
1	691500
1.5	500000
2	308500
2.5	158700
3	66800
3.5	22700
4	6200
4.5	1300
5	230
5.5	30
6	3.4

In our project unit is defined as a component produced. Defect is the any non-conformance. Opportunity is the reason for which component is rejected. Based on this data collection which has been carried out earlier DPMO was calculated and from the chart shown above, current Sigma level for last 12 months was calculated which is shown in Table 6.

Table 6. Sigma value for 12 months data

Current Sigma Level Calculation (Apr-13 to Aug-14)	
Total Number of Units Produced	**51994**
Defects Types	**Nos**
Total Defects	5931
Number of Opportunities	3
DPMO	38024
Existing Sigma Level	3.3

Same way Sigma level was calculated for Feb-March 2015 data shown in Table 7.

Table 7. Sigma value for Feb-March 2015 data

Current Sigma Level Calculation (Feb-March 2015)	
Total Number of Units Produced	**6761**
Defects Types	**Nos**
Total Defects	1048
Number of Opportunities	3
DPMO	51669
Existing Sigma Level	3.1

3.5 Analyse Phase

The objective of this phase is to identification of the root causes of the problem or the causes having maximum impact on the CTQs. In this phase, various tools & techniques are used for deciding the vital few causes that must be controlled to improve the performance of the process.

First of all brainstorming session was carried to identify the probable causes of the problem. As a result of brainstorming session 15 probable causes were identified. These probable causes were then bifurcated into groups of man, machine, material and die with the help of cause & effect diagram shown in Figure 7.

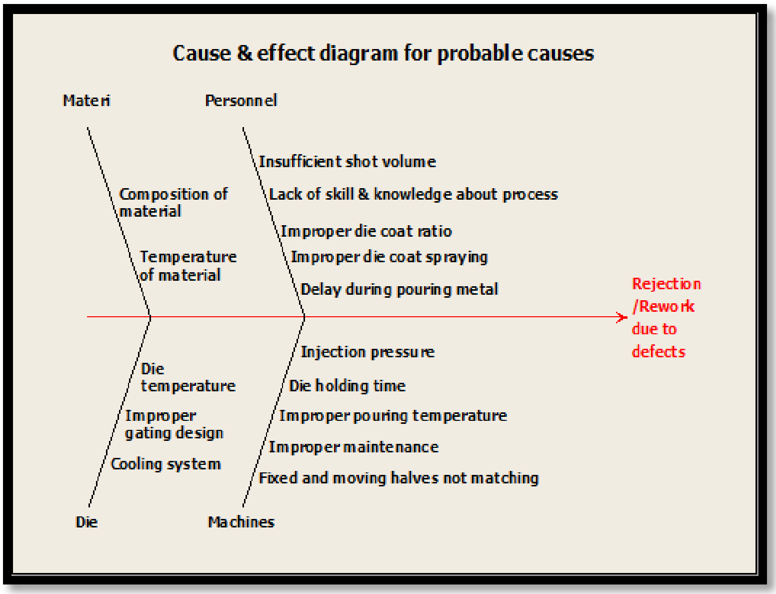

Figure 7. Cause & effect diagram

All the causes shown in the cause & effect diagram is not having equal importance or having equal impact on the CTQs of the problem so it is very much required that these causes should be prioritised based on their impact on the CTQs as per the knowledge and understanding of the team members. To prioritise these all causes, cause & effect matrix was prepared which is shown in the Figure 8.

All the causes which were selected after prioritizing through cause & effect matrix were decided to get validated by various methods through cause validation plan which is shown in Table 8.

The cause insufficient shot volume was decided to validate by Gemba through observation. In pressure die casting process, workers are instructed to use the ladle which is specified for particular product because each having different capacity of volume and each product requires different volume for production. It was observed that whenever the specified ladle is damaged due to any reason, workers start using ladle of the other product which resulted into assumption based pouring which resulted in to defects. For cause lack of skill & knowledge about the process, questions were asked to the workers related to the process steps and importance of the steps.

0	No impact on Y
1	Minor impact on Y
3	Moderate impact on Y
9	High impact on Y

Note: 1. If doubtful about the impact of X on Y, given at least 3 or 9
2. Rating should be based on impact of X on Y irrespective of frequency of occurrence of cause (X)

	Output		
	Defects	#Selected XS	9
Is Y Continuous or Discrete?	Discrete	#Discarded Xs	6
Customer Priority	9		

Sr No.	Process Step	Input	Characteristic of Input (X)		Total	Count 3's	Count 9's	X selected/ Discarded?
a	(In case of an X from the Fishbone Diagram, please mention Fishbone Diagram in this column)	(In case of an X from the Fishbone Diagram, leave this column blank)	(Copy the Input Characteristic column from the Input-Output worksheet and paste in this column. Also add X's from the Fishbone Diagram)					
1	Cause-Effect Diagram		Personnel					
1a			Insufficient shot volume	3	27	1	0	Select the X
1b			Lack of skill & knowledge about process	3	27	1	0	Select the X
1c			Improper die coat ratio	1	9	0	0	Discard the X
1d			Improper die coat spraying	1	9	0	0	Discard the X
1e			Delay during pouring metal	9	81	0	1	Select the X
2			Machine					
2a			Injection pressure	9	81	0	1	Select the X
2b			Die holding time	3	27	1	0	Select the X
2c			Improper pouring temperature	9	81	0	1	Select the X
2d			Improper maintenance	3	27	1	0	Select the X
2e			Fixed and moving halves not matching	0	0	0	0	Discard the X
3			Die					
3a			Die temperature	3	27	1	0	Select the X
3b			Improper gating design	1	9	0	0	Discard the X
3c			Cooling system	1	9	0	0	Discard the X
4			Material					
4a			Composition of material	3	27	1	0	Select the X
4b			Temperature of material	1	9	0	0	Discard the X
			Total	450				

Figure 8. Cause & effect matrix

Table 8. Cause validation plan

Sr No.	Causes	Validation Method
1	Insufficient shot volume	Gemba
2	Lack of skill & knowledge about process	Gemba
3	Delay during pouring metal	Data Collection
4	Injection pressure	Expert View
5	Die holding time	Regression Analysis
6	Improper pouring temperature	Regression Analysis
7	Die temperature	Regression Analysis
8	Composition of material	Testing
9	Improper maintenance	Past Maintenance Report

In concerned cold chamber pressure die casting machine, metal is poured from the furnace manually so while pouring metal if there is delay during the pouring then it can lead to reduction in temperature of metal which will cause rejection/rework of the product. To see if there is such problem in this project, data collection was carried for pouring cycle time for three days which is shown in Table 9.

Table 9. Data collection for delay during pouring metal

Data For Delay in Pouring								
Day 1			**Day 2**			**Day 3**		
Sr No.	**Pouring Time (s)**		**Sr No.**	**Pouring Time (s)**		**Sr No.**	**Pouring Time (s)**	
	Operator A	**Operator B**		**Operator A**	**Operator B**		**Operator A**	**Operator B**
1	1.75	2.19	**1**	1.96	2.1	**1**	2.06	2.13
2	1.85	2.01	**2**	2.05	2.03	**2**	1.76	2.19
3	1.83	2.14	**3**	2.03	2.06	**3**	1.97	2.06
4	1.89	2.01	**4**	1.94	2.08	**4**	1.98	2.15
5	1.73	2.15	**5**	1.86	2.13	**5**	1.82	2.32
6	1.72	2.2	**6**	1.89	1.96	**6**	1.86	2.26
7	1.91	2.52	**7**	1.93	1.98	**7**	1.85	2.12
8	1.6	2.63	**8**	1.95	2.01	**8**	1.98	2.01
9	1.61	2.32	**9**	1.98	2.09	**9**	2.03	2.09
10	1.65	2.36	**10**	2.15	1.98	**10**	2.01	1.98
11	1.75	2.01	**11**	2.12	2.16	**11**	1.99	2.15
12	1.7	2.16	**12**	2.06	2.13	**12**	1.78	2.18
13	1.5	2.11	**13**	2.03	1.95	**13**	1.76	2.01
14	1.72	2.32	**14**	1.96	1.98	**14**	1.94	2.21
15	1.73	2.24	**15**	1.88	2.15	**15**	1.98	2.15
16	1.76	2.15	**16**	1.87	2.01	**16**	1.93	2.04
17	1.65	2.04	**17**	1.96	2.06	**17**	1.95	2.23
18	1.89	2.19	**18**	2.06	2.09	**18**	1.92	2.14
19	1.92	2.01	**19**	1.99	2.16	**19**	1.85	2.09
20	1.75	2.43	**20**	1.95	2.21	**20**	1.96	2.26
21	1.83	2.39	**21**	1.75	2.36	**21**	1.85	2.15
22	1.72	2.14	**22**	1.88	2.25	**22**	1.96	2.06
23	1.75	2.06	**23**	1.96	2.1	**23**	1.98	2.06
24	2.08	2.19	**24**	1.89	2.09	**24**	1.96	2.15
25	2.05	2.05	**25**	1.95	1.95	**25**	1.65	2.29
26	1.85	2.16	**26**	1.87	2.19	**26**	1.78	2.12
27	2.01	2.32	**27**	1.94	2.12	**27**	1.89	2.07
28	1.86	2.09	**28**	1.92	2.15	**28**	1.96	2.17
29	1.59	2.1	**29**	1.86	2.21	**29**	1.65	2.23
30	1.86	2.43	**30**	1.75	2.32	**30**	1.95	2.32

In above data collection, red cell is indicating maximum time taken during pouring metal and green cell indicating minimum time taken during pouring. It means there is only 1.04 seconds difference which is not going to reduce the temperature up to that much that it will lead to rejection/rework of the product. So by this data collection, it is decided that delay during pouring metal is not a root cause.

In cold chamber pressure die casting process, to produce the quality products it is required that metal should be poured at required temperature. To see the effect of change in pouring temperature on rejection/rework, data collection was carried out for temperature and % rejection/rework shown in Table 10. This data was then used for regression analysis to see relation between %rejection/rework and pouring temperature.

Table 10. Data collection of pouring temperature

Sr No	Temperature (°C)	Total Production	Total Rejection/Rework	Percentage Rejection/ Rework
1	860	36	12	33.33
2	870	36	10	27.77
3	885	40	12	30
4	861	37	11	29.72
5	842	43	3	6.97
6	805	45	3	6.67
7	800	38	5	13.15
8	838	46	4	8.69
9	750	40	5	12.5
10	735	50	2	4
11	776	45	7	15.55
12	790	53	8	15.09
13	850	43	9	20.93
14	765	46	6	13.04
15	805	48	4	8.33

Regression analysis using above data was carried out with the help of MINITAB 17 software. Result of regression analysis is shown below.

```
Regression Analysis: %Rejection/rework (R) versus Temperature (T)
The regression equation is
R = - 102 + 0.145 T
Predictor   Coef     SE Coef    T      P
Constant   -101.85  33.58   -3.03  0.010
T          0.14499  0.04111  3.53  0.004
S = 7.14933 R-Sq = 48.9% R-Sq(adj) = 45.0%
Analysis of Variance
Source          DF   SS      MS     F     P
Regression       1 635.76  635.76 12.44 0.004
Residual Error  13 664.47  51.11
Total           14 1300.23
```

From the above analysis it is to be noted that since p value (0.004) is less than 0.05 which indicating that above regression model is significant but since linearity is only 48.9%, we cannot conclude that variation in temperature is linearly causes %rejection/rework.

To check material composition as per the BS 1490 Grade LM 24, outside test was carried out for confirming the composition material which is shown in Table 11.

Table 11. Outside test result

Outside Test Result		
Elements	Obtained value	Required value
Copper	3.523	3.0-4.0
Iron	0.694	1.3 Max
Silicon	8.127	7.5-9.5
Magnesium	0.3	0.3 Max
Lead	0.067	0.3 Max
Zinc	1.168	3 Max
Tin	0.031	0.2 Max
Nickel	0.047	0.5 Max
Other Ti	0.025	0.2 Max

From above carried out test, it is clear that material supplied by the supplier is as per the standard BS 1490 Grade LM 24. So it is not a root cause. The cause, improper maintenance is validated by the reason that being ISO 9001:2008 Company, they are not following the preventive maintenance concept. They are doing maintenance after the problem arises in the machine.

To validate the cause injection pressure, we took the help of the expert from the pressure die casting machine manufacturer. According to him the machine on which we are working is basic machine with fixed injection pressure so we decided to counterattack the variation in injection pressure by institution of the preventive maintenance.

To check the validation cause die holding time, data collection was done by changing die holding time to various levels which is controlled by PLC. So die holding time was changed to three levels as shown in Table 12 and then regression analysis was carried out to see the relationship between percentage rejection/rework and die holding time.

Table 12. Die Holding Time

Data Collection for Die Holding Time				
Sr No	**Die Holding Time (secs)**	**Total Production**	**Total Rejection/Rework**	**Percentage Rejection/Rework**
1	12	244	40	16.39
2	14	227	33	14.53
3	16	236	28	11.86

Regression analysis of die holding time is shown in Figure 9.

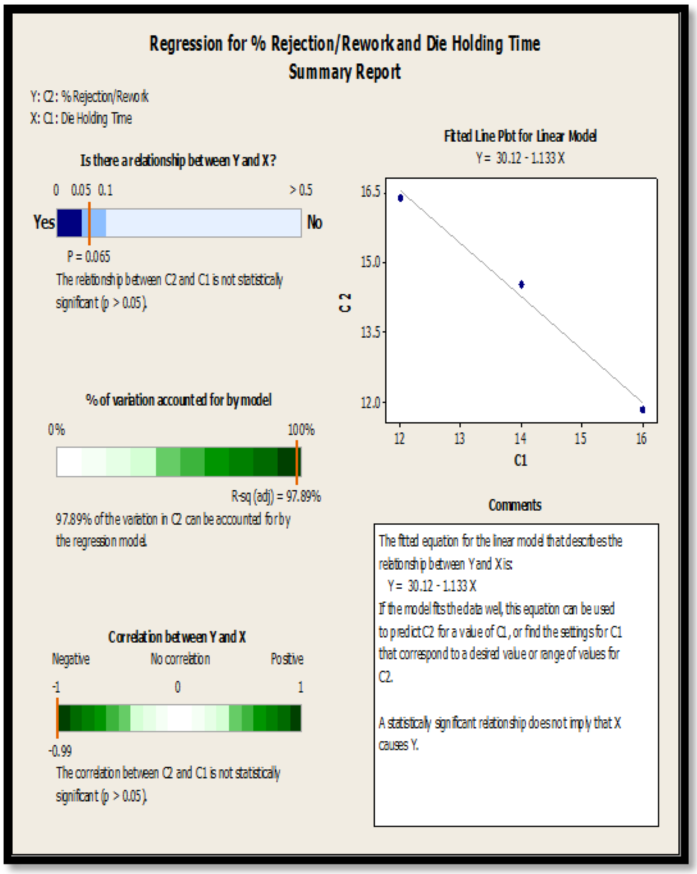

Figure 9. Regression analysis of die holding time

Regression Analysis: %Rejection/Rework (C2) versus Die Holding Time (C1)

```
The regression equation is
C2 = 27.8 - 1.13 C1
Predictor     Coef   SE Coef   T       P
Constant     27.850   1.416  19.67   0.032
C1          -1.1325   0.1169 -9.69   0.065
S = 0.330681 R-Sq = 98.9% R-Sq(adj) = 97.9%
```

Analysis of Variance

```
Source          DF      SS    MS      F      P
Regression       1  10.260  10.260 93.83 0.065
Residual Error 1    0.109   0.109
Total            2  10.370
```

In above regression analysis, p value is more than 0.05 which is showing that model is not statistically significant but R sqr (adj) is 97.89% and Correlation to be -0.99 that means that there is a relationship between percentage rejection/rework and die holding time so this cause was validate from above point of discussion.

From the regular data collection of the rejection/rework of the Artos Body, it was observed that there is more rejection/rework in the morning when the production is started. This data collection also reflects the relationship of die temperature with rejection/rework because die temperature changes with time of production. To confirm this fact, one more analysis was carried out regarding effect of time of production on rejection/rework. For this data was collected on hour basis to see the relation between time and rejection/rework shown in Table 13.

Table 13. Time wise rejection/rework

Time wise Rejection/Rework				
Sr No	**Time**	**Total Production**	**Total Rejection/Rework**	**Percentage Rejection/Rework**
1	8.30 to 10	296	92	31.08
2	10 to 11	300	35	11.66
3	11 to 12	212	37	17.45
4	12 to 13	261	42	16.09
5	13 to 14	272	46	16.91
6	14 to 15	338	33	9.76
7	15 to 16	269	49	18.21
8	16 to 17	332	47	14.15
9	17 to 18	330	66	20
10	18 to 19	342	31	9.06
11	19 to 20	317	16	5.04
12	20 to 21	257	10	3.89
13	21 to 22	315	7	2.22
14	22 to 23	227	8	3.52
15	23 to 24	281	10	3.55
16	24 to 01	204	0	0

❖ **Regression Analysis: %Rejection/Rework (R) versus Time (T)**

```
The regression equation is
 %R = 36.6 - 1.43 T
 Predictor     Coef      SE Coef       T           P
 Constant      36.563    5.297        6.90      0.000
 C1            -1.4347   0.3020      -4.75     0.000
 S = 5.05297   R-Sq = 63.5%   R-Sq (adj) = 60.6%
 Analysis of Variance
 Source             DF      SS        MS         F          P
 Regression          1      576.35    576.35   22.57       0.000
 Residual Error     13      331.92    25.53
 Total              14      908.28
```

Regression analysis of Time and %rejection/rework was carried out which is shown in Figure 10.

Above regression analysis indicating that this model is significant and there is relation between time of production and %rejection/rework at that time

After adopting the various methods for cause validation, final validated causes are shown in Table 14.

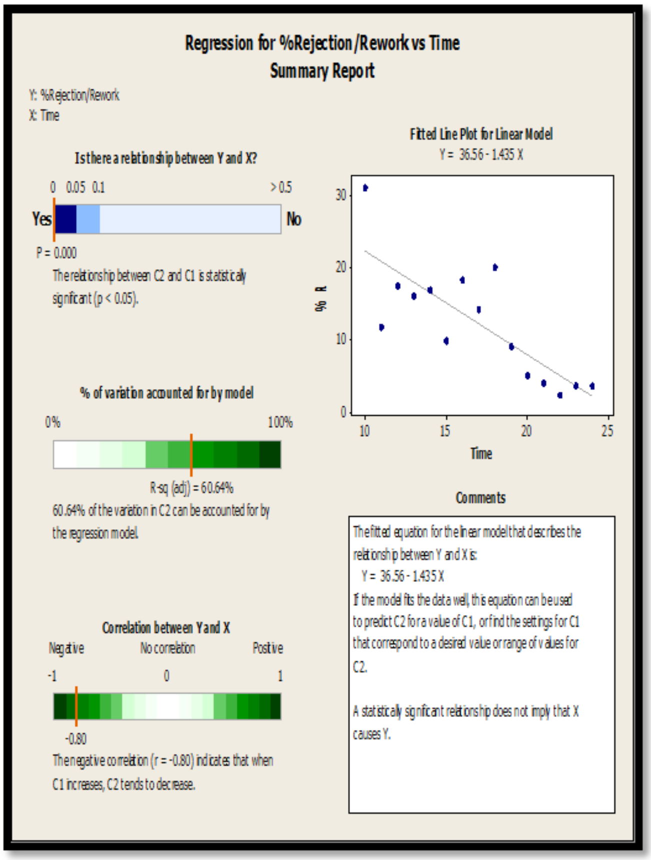

Fig. 10. Regression analysis of time and %rejection/rework

Table 14. Final Validation result

Sr No.	Causes	Validation Method	Validation Result
1	Insufficient shot volume	Gemba	Validate
2	Lack of skill & knowledge about process	Gemba	Validate
3	Delay during pouring metal	Data Collection	Not Validate
4	Injection pressure	Expert View	Not Validate
5	Die holding time	Regression Analysis	Validate
6	Improper pouring temperature	Regression Analysis	Validate
7	Die temperature	Regression Analysis	Validate
8	Composition of material	Testing	Not Validate
9	Improper maintenance	Maintenance Report	Validate

After finalizing validated root causes, now it is required that based on above validated root causes, improvement steps should be decided. Why-Why analysis was carried out for the causes which were validated in the validation plan to identify the base for deciding the improvement steps. Why-Why analysis is shown in Figure 11.

Why-Why analysis of final root causes						
Y	**Causes**	**1st Why**	**2nd Why**	**3rd Why**	**4th Why**	**5th Why**
Rejection/Rework due to defects	Insufficient shot volume	Assumption based pouring	Using some other product's ladle	Non availability of ladle during ladle damage of Artos Body	Not keeping extra ladle of any products	
	Lack of skill & knowledge about process	Not aware about the importance of each process steps	Focus on just process to be carried out	Lack of training about the process importance		
	Improper Die holding time	Not maintaining specific die holding time	Operator changes on his own	Do not know which level to maintain		
	Improper pouring temperature	Not maintaining required temperature	operating on a wide range of temperature	Do not know temperature level to maintain		
	Improper Die temperature	Not maintaining die temperature	No die heating arrangement to maintain die temperature			
	Improper maintenance	No maintenance schedule	operating on breakdown maintenance			

Figure 11. Why-Why Analysis

3.6 Improve Phase

The fourth phase of the DMAIC methodology of Six Sigma is improve phase in which the project team will decide the improvement steps based on final validated root causes in analyse phase. All the improvement steps should also be approved by the top management so that it creates availability of resources in implementation of improvement steps.

After deciding final root causes by the various validation methods, improvements were suggested to the top management so that ease of availability of resources can be there at the time of implementation of improvements. Based on that root causes various improvements were suggested to top management which is shown in Table 15.

Table 15. Improvement Plan

Sr No.	Causes	Suggested Improvements
1	Insufficient shot volume	Keep specific extra ladle cup for specific product
2	Lack of skill & knowledge about process	Training of operators
3	Die holding time	Finding optimum level through Design of Experiment (DOE)
4	Improper pouring temperature	Finding optimum level through Design of Experiment (DOE)
5	Die temperature	Finding optimum level through Design of Experiment (DOE)
6	Improper maintenance	Cleaning-Lubrication-Inspection-Tightening (CLIT) preventive maintenance
7	Temperature difference at start of the production	Preheating of die

After discussing with project team, top management agreed to implement all suggestions suggested to them with their full support. One by one all solutions were carried out which are discussed below.

In pressure die casting process it is required that the ladle cup which is used for pouring molten metal into shot cylinder should be specific to that product so that required amount of metal can be poured. Operators were using another product's ladle cup when the Artos Body cup is damage which is having higher weight so it leads to assumption based pouring which results into rejection/rework of products. So one arrangement was carried to keep one extra ladle of Artos Body so that whenever it will damage they can use the Artos Body's ladle instead of another products ladle. Both the ladle cups are shown in Figure 12.

Artos Body Cup **Monfort Body Cup**

Figure 12. Ladle Cups

Training is very much required to be provided to the workers so that they can understand the importance of each step carried out in the pressure die casting process. During analyse phase it was identified that operators are also cause to be treated so first standard operating procedure (SOP) was prepared and then training was given to the workers on SOP. The aim was to make them aware about the importance of each step in the process as well as to maintain the critical parameters to their optimal level which is discussed in the control phase.

In the morning when machine is started, die will be at room temperature and molten metal will be at higher temperature that will create large temperature difference which leads to rejection/rework of the products and also thermal shock to the die which leads to die breakage. So to avoid this die preheating was done at 175°C before first shot is made which will reduce the temperature difference between die and molten metal and also improve die life. This preheating temperature was then revised to 195°C after performing DOE shown in Figure 13.

Figure 13. Preheating of die

For improper maintenance cause, Cleaning-Lubrication-Inspection-Tightening (CLIT) standard preventive maintenance was prepared. In this standard various parts or components of the machine were bifurcated based on their requirement of cleaning, lubrication, inspection, and tightening. For each of the component, operators were required to check their idle condition as per CLIT standard if not they required to take corrective actions suggested in standard.

There are three operating parameters which were validated to be the root cause of the problem so to optimize these parameters DOE was carried out. DOE was carried out with three level of each of the parameter which is shown in Table 16.

Table 16. DOE Design

Sr No.	Process Parameters	Level 1	Level 2	Level 3
1	Pouring Temperature (°C)	800	850	900
2	Die Holding Time (Sec)	12	14	16
3	Die Temperature (°C)	175	195	215

To carry out DOE for three parameters with three levels, L27 arrangement should follow which is shown in Table 17.

Table 17. L27 Design

Design of Experiments for three factors with levels						
EX. Run Order	**Pouring Temperature (°C)**	**Die temperature (°C)**	**Die Holding Time (Sec)**	**Total Production**	**Total Rejection/Rework**	**Percentage Rejection/Rework**
1	900	195	14	200	18	9
2	900	215	16	200	22	11
3	900	195	16	200	20	10
4	850	175	16	200	21	10.5
5	800	215	16	200	18	9
6	900	195	12	200	16	8
7	900	215	14	200	19	9.5
8	800	195	16	200	17	8.5
9	900	175	12	200	15	7.5
10	800	175	14	200	16	8
11	800	215	14	200	17	8.5
12	850	215	12	200	17	8.5
13	850	215	14	200	16	8
14	900	215	12	200	18	9
15	900	175	14	200	16	8

Design of Experiments for three factors with levels						
EX. Run Order	Pouring Temperature (°C)	Die temperature (°C)	Die Holding Time (Sec)	Total Production	Total Rejection/Rework	Percentage Rejection/Rework
16	800	215	12	200	17	8.5
17	900	175	16	200	19	9.5
18	850	195	14	200	17	8.5
19	800	175	16	200	16	8
20	850	175	12	200	15	7.5
21	800	195	14	200	17	8.5
22	800	175	12	200	15	7.5
23	850	195	16	200	19	9.5
24	800	195	12	200	10	5
25	850	195	12	200	9	4.5
26	850	215	16	200	20	10
27	850	175	14	200	17	8.5

To see the significance of this DOE experiments, ANOVA was used with general linear model in MINITAB 17 software which showing the following result.

❖ **General Linear Model: % rejection/rework versus Pouring Temperature, Die Temperature, Die Holding Time**

```
Factor               Type  Levels    Values
Pouring Temperature  fixed   3    800, 850, 900
Die Temperature      fixed   3    175, 195, 215
Die Holding Time     fixed   3    12, 14, 16
```

Analysis of Variance for %rejection/rework, using Adjusted SS for Tests

```
Source              DF  Seq SS  Adj SS  Adj MS   F      P
Pouring Temperature 2   5.6296  5.6296  2.8148  3.36  0.055
Die Temperature     2   6.3519  6.3519  3.1759  3.79  0.040
Die Holding Time    2  22.2407  22.2407 11.1204 13.29 0.000
Error               20  16.7407 16.7407 0.8370
Total               26  50.9630
S = 0.914897   R-Sq = 67.15%   R-Sq(adj) = 57.30%
```

From the above result it can be seen that P value Die temperature and Die holding time is below 0.05 which means they are significantly affecting the % rejection/rework. It is also to be noted that P value of pouring temperature is 0.055 which is also can be taken as significant factor because it is almost 0.05.

Now from this point we are required to select the optimal level of each of the parameters. To decide the optimal level of these parameters main effect plot was drawn which is shown in Figure 14.

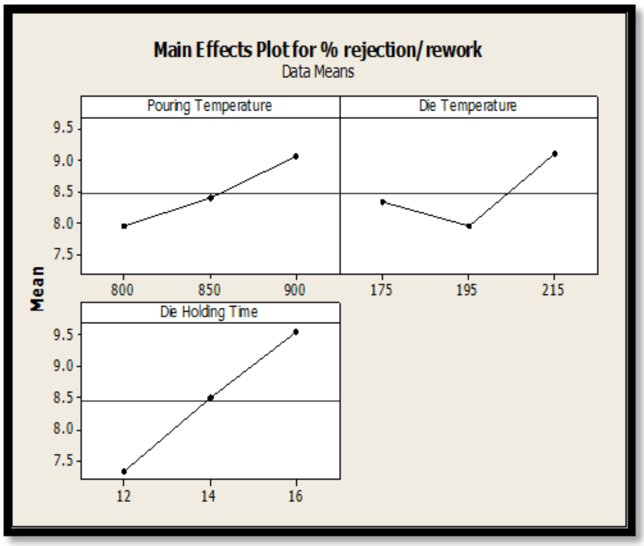

Figure 14. Main effect plot for % rejection/rework

From the above chart we conclude that following parameters are the best from the rejection/rework point of view:

- Poring Temperature → 800°C
- Die Temperature → 195°C
- Die Holding time → 12 Sec

The levels decided above are based on the individual effect of each parameter on % rejection/rework but there is also possibility of interaction between these three parameters. To check the presence of interaction among three factors, interaction plot was carried out which is shown in Figure 15.

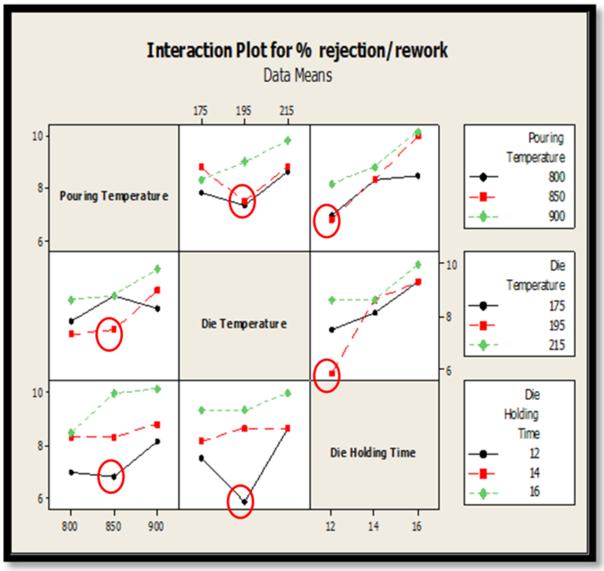

Figure 15. Interaction plot for % rejection/rework

From the above chart we conclude that an interaction effect is there in the process. So, we have to select best optimum interaction to reduce the rejection/rework level in pressure die casting machine.

Interaction between Pouring temperature and Die Temperature = Pouring Temperature 800°C or 850°C is better with die temperature of 195°C.

Interaction between Pouring temperature and Die Holding Time = Pouring Temperature 800°C or 850°C is better with die holding time 12 Sec.

Interaction between Die temperature and Die Holding Time = Die temperature 195°C is better with Die Holding Time 12 Sec.

From the above interaction after analyzing all interaction plot following optimal levels were decided for three factors shown in Table 18.

Table 18. Decided optimal level

Sr No	Parameters	Optimal level
1	Pouring Temperature (°C)	850
2	Die Temperature (°C)	195
3	Die Holding Time (sec)	12

After deciding optimal levels for all three factors, it was discussed with top management for getting permission for confirmation run. After getting permission, this optimal level experiment was run which is shown below.

❖ **Confirmation Run**

The confirmation run was successful with all three parameters optimal level then these parameters were set to that level and after that data collection was done to identify the improvement in rejection/rework which is shown in Table 19.

Table 19. Data after Improvements

Data Collection of Rejection/Rework After Improvement			
Die Temperature (195°C)		**Pouring Temperature (850°C)**	**Die Holding Time (12 sec)**
Sr No	**Date**	**Total Production**	**Total Rejection/Rework**
1	13-04-2015	470	26
2	14-04-2015	500	21
3	17-04-2015	440	27
4	18-04-2015	400	22
5	20-04-2015	485	15
6	21-04-2015	480	13
7	22-04-2015	457	34
8	23-04-2015	347	3
9	24-04-2015	527	24
10	25-04-2015	498	20
11	27-04-2015	477	26
12	28-04-2015	533	20

After above data collection, comparison was done for this data and past data of Feb-March 2015 to identify the improvements achieved after implementation of the various improvements. Comparison shows that percentage rejection/rework is reduced from 15.50% to 4.47% which is 71.2% improvement as shown in combined Figure 16 and 17.

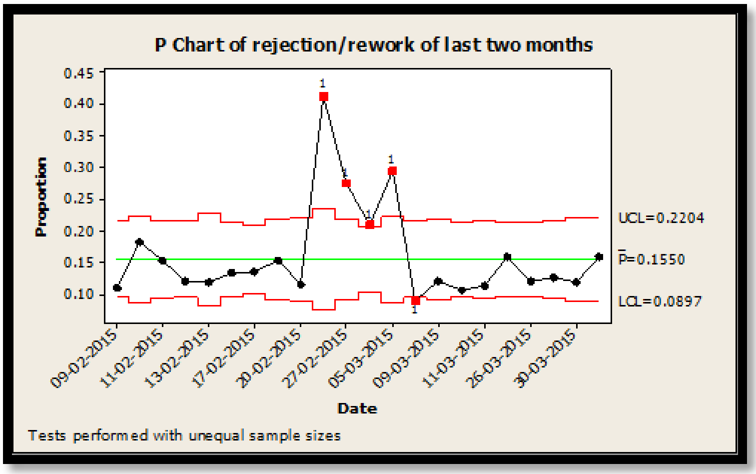

Figure 16. P chart before improvement

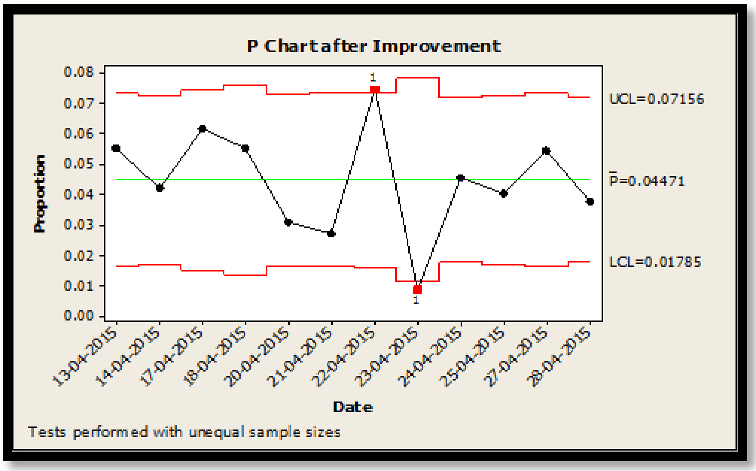

Figure 17. P chart after improvement

For the data of confirmation run, Sigma level was also calculated for comparison which was showing that sigma level was improved from 3.1σ to 3.7σ.

It is one of the critical success factor of Six Sigma that project should link with the financial savings. Financial savings of this project were due to two improvements. One improvement is reduction of rejection/rework from 15.50% to 4.47% which results into financial savings of INR 12,72,242 per annum.

Another improvement is improving production rate. Earlier they were using die holding time to 14 sec and after carrying out DOE, optimization level came 12 sec which is saving of 2 sec in each operation cycle. The total cycle time of pressure die casting process is 1 minute. This improvement result into saving of 7488 minutes per annum which is saving of INR 5,55,160 per annum.

Total financial saving of this project is INR 18,27,402 per annum.

3.7 Control phase

The fifth phase of the DMAIC methodology of Six Sigma is control phase in which the project team will take the actions in the direction of sustaining the improvements which are achieved in improve phase. This phase is crucial because it is easy to improve something but difficult to sustain that improvement Project team will also prepare control plan and documentation of the improvements so that can be followed easily by operators.

For this purpose, control plan was prepared which should be followed by all the responsible persons. Control plan is shown in Table 20.

Table 20. Control plan

Attributes	Actions to be taken
Track the monthly Rejection/Rework	P Chart should drawn to identify rejection/rework with daily data collection
Training	Training should given to operators based on SOP provided
Machine Maintenance	CLIT preventive maintenance should be included in the ISO quality management programme
Monitoring	Continuous monitoring should be done and all the critical process parameters should maintained as specified

After implementing all the solutions it is very much required that it should be documented in a way that it can be helpful to the operators to carry out their work with ease. For sustaining the improvements and setting standard way of work for operators, standard operating procedure (SOP) was prepared for the operators and training was also provided to them on SOP. The main aim of SOP was to guide operators regarding way of carried out process and also maintaining the critical three parameters to their specified level for sustaining the benefits. In SOP all parameters were shown with their levels.

4. Concluding remarks

The aim of this paper is to explore the possibility of implementing Six Sigma in Indian SMEs. The Six Sigma application in SMEs is a new paradigm for improving quality which is practised by many academics. This paper is an attempt to provide road map application of Six Sigma in SMEs which are normally presumed to be in the section of large industries. This case study will help the Indian SMEs to carry out such projects which can lead them towards business improvement.

This paper presents a case study from pressure die casting section demonstrating how the implementation of Six Sigma can bring breakthrough improvement in the performance of the process as well as in business. The industry was not aware about such improvements in the pressure die casting process which can be carried out. The application of the DMAIC methodology has been utilized in reducing the rejection of the die casted product named Artos Body. In this case study, the performance of the pressure die casting process was improved from 3.1σ to 3.7σ by reducing the rejection rate from 15.50% to 4.47% which is 71.2% improvement. The estimated annual savings generated from this project were at least INR 18,27,402. One of the solutions that were preheating also brought improvements in die life. They were facing problem of die breakage which was also solved. After achieving such results, top management of this industry was convinced with such initiation and they have decide to explore the Six Sigma projects in their other processes which is good step toward making them quality conscious. If Six Sigma methodology is linked with the business strategy of the company they can achieve more benefits out of such projects.

5. Managerial implications

Current status of adopting Six Sigma in Indian SMEs is not up to the required level. The aim of this study was to deploy Six Sigma in one of the Indian SMEs and provide path for others to initiate the same. If Six Sigma is applied to critical processes with correct tools & techniques in each phase of DMAIC methodology then Six Sigma has a capability to improve the process and give drastically improvement in the performance of the process. As stated earlier in literature review that Six Sigma is not explored that much in small scale industries so this is a real life case study which is applied in small scale industry for improving one of their core process.

This project also creates awareness for industry to look into the requirement of quality consciousness and improve the performance of processes. One of the critical success factor of the Six Sigma that is top management commitment was realized in this project because every time whenever there is requirement resources, top management always supported up to their extend which makes this project to be implemented successfully.

6. Future scope

This project was focusing on their most critical product manufacturing from the pressure die casting process. Their business is also running on some more critical products manufacturing from different processes such as blanking, bending etc. So they can extend the exploration of Six Sigma in their firm by applying it into critical processes and products. There is also requirement to change the die of different products where they are wasting their time in die setup so they can link the lean tools with Six Sigma to reduce setup time as well as lead time of different products to improve the customer satisfaction by on time delivery.

Acknowledgments: The authors are thankful to the top management of the company where this project is carried out for their permission and support throughout the project. We are also thankful to the whole team concerned in this project. The authors duly acknowledge the research works, project reports, books, website, etc., whose reference were taken in forming this research paper. All works are appropriately cited and referred at the reference section of this paper.

References:

Antony, J. (2008). Can Six Sigma be effectively implemented in SMEs?. *Int J Productivity & Perf Mgmt*, *57*(5), 420-423. http://dx.doi.org/10.1108/17410400810881863

Chiarini, A. (2011). Japanese total quality control, TQM, Deming's system of profound knowledge, BPR, Lean and Six Sigma. *Lean Six Sigma Journal*, *2*(4), 332-355. http://dx.doi.org/10.1108/20401461111189425

Desai, D. (2006). Improving customer delivery commitments the Six Sigma way: case study of an Indian small scale industry. *International Journal of Six Sigma and Competitive Advantage*, *2*(1), 23-47.

Desai, D. (2008). Improving productivity and profitability through Six Sigma: experience of a small-scale jobbing industry. *International Journal of Productivity and Quality Management*, *3*(3), 290-310.

Desai, D., & Patel, M. (2009). Impact of Six Sigma in a developing economy: analysis on benefits drawn by Indian industries. *Journal of Industrial Engineering and Management, 2*(3), 517-538.

Gholap, P.C., & Desai, T.N. (2012). Reduction of rework the Six Sigma way: case study of an Indian small scale industry. *International Journal of Six Sigma and Competitive Advantage, 7*(1), 92-116.

Gijo, E., Bhat, S., & Jnanesh, N. (2014). Application of Six Sigma methodology in a small-scale foundry industry. *Lean Six Sigma Journal*, *5*(2), 193-211. http://dx.doi.org/10.1108/ijlss-09-2013-0052

Gijo, E.V., & Rao, T.S. (2005). Six Sigma Implementation – Hurdles and More Hurdles. *Total Quality Management*, *16*(6), 721-725.

Gopalakrishnan, N. (2012). *Simplified Six Sigma: Methodology, Tools and Implementation*, 1st edition. PHI learning Private Limited..

Sambhe, D. (2012). Six Sigma practice for quality improvement – A case study of Indian auto ancillary unit. *Journal of Mechanical and Civil Engineering*, *4*(4), 26-42.

Shanmugaraja, M., Nataraj, M., & Gunasekaran, N. (2011). Quality and productivity improvement using Six Sigma and Taguchi methods. *International Journal of Business Excellence, 4*(5), 544-572.

Singh, B.J., & Khanduja, D. (2012). Ambience of Six Sigma in Indian foundries – an empirical investigation. *International of Six Sigma and Competitive Advantage*, *7*(1), 12-40.

Javedhusen Malek
G H Patel College of
Engineering & Technology
India
javed_husen@yahoo.com

Darshak Desai
G H Patel College of
Engineering & Technology
India
darshakdesai@gcet.ac.in