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Analysis of Six Sigma- DMAIC Methodology and Tools Used At Various Phases of DMAIC and Critical Success Factors in Foundries

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Abstract: The fast-changing business conditions such as global competition, customer demand for world quality product, wide range product variety with reduced lead– time, declining profit margin, reduced product lifecycle etc. had a major influence on foundry industries. To respond to these needs various industrial engineering and quality management approaches and techniques such as Statistical Quality Control (SQC), ISO 9000, Quality Circle, TQM, Kaizen, JIT manufacturing, Enterprise Resource Planning(ERP), Process Capability Study, Failure Mode Effects Analysis (FMEA),Lean manufacturing etc. were developed. A new paradigm in this area of manufacturing strategies is six sigma DMAIC methodologies. The Six Sigma approach has been more and more adopted globally in the foundry sector in order to boost productivity and quality performance and to make the process robust to quality variations. Six Sigma is statistical and scientific methods to reduce the defect rates and achieve improved quality Six Sigma within small- and medium-sized enterprises (SMEs) is rapidly emerging as the new wave of change in Six Sigma The methodology adopted is Define, Measure, Analyze, Improve, and Control (DMAIC) of Six Sigma is more successful in large-scale industries. This review paper discusses use of DMAIC methodology in casting foundry with its tools at each phase used by various researchers; benefits achieved an improvement in six sigma level with critical success factors.
Keywords: Six Sigma, DMAIC, Sand casting, Foundry, Critical Success Factors

I. INTRODUCTION

Six Sigma is a methodology with techniques and tools for process improvement. It was introduced by engineer Bill Smith when he was working at Motorola in 1986. Jack Welch made it principal to his business strategy at General Electric in 1995.ix Sigma is an organized & systematic method for strategic process improvement that depends on statistical & scientific methods to reduce the defect rates and to achieve significant quality level up- gradation (M. Haary et al 2000).The name of the “Six Sigma” methodology comes from statistics where sigma means standard deviation. The term “Six Sigma” refers to the ability of highly-capable processes to produce output within specification. , particularly processes that work with six sigma quality produces at defect levels below 3.4 defects per (one) million opportunities (Al-Agha et al 2015).he Six Sigma Methodology is a mainly also based on customer. It is customer focused continuous improvement approach that decreases defects and variation towards an achievement of 3.4 defects per million opportunities in product design, production, and administrative process. (Adan Valles et al 2009).In recent years one of the outstanding issues with regard to quality is six sigma. (Tekin M, 2013, p.459).Six Sigma can be defined as the process quality management that leads towards pathway for excellent quality level via continual improvement of processes. (Tekin M, 2013, p.459) In the current ever-changing and highly competitive environment in this era, it is vital that the companies continuously improve themselves for survival and growth of their business. Quality and cost are the two key factors for the success of any manufacturing industry or foundry industry. Industries are adopting different systems such as the Statistical quality control Quality circle, ISO 9000, TQM, etc. to improve quality. But, these schemes failed to bring in the financial section of the businesses into attention and care. Six Sigma is a business improvement initiative instead of than a quality initiative. It is a customer-focused business improvement methodology driven by data than assumptions with breakthrough performance improvements validated by bottom line result. Defects per million opportunities (DPMO) cam be defined as the mean number of defects per unit detected during an average production run divided by the number of opportunities to make a defect on the product under study during that run normalized to one million. Defects per Million Opportunities, synonymous with PPM. To calculate DPU to DPMO, the calculation step is actually DPU/ (opportunities/unit) * 1,000,000.

TABLE:-I SIX SIGMA TABLE

SIGMA LEVEL	SHORT TERM (PROCESS NOT SHIFTED)		LONG TERM (PROCESS SHIFTED 1.5 SIGMA)	
	Yield(OK) %	Reject ppm	Yield(OK) %	Reject ppm
1	68.27	317,000	30.23	697,700
2	95.45	45,500	69.13	308,700
3	99.73	2,700	93.32	66,810
4	99.9937	63	99.3790	6,210
5	99.999943	0.53	99.97670	233
6	99.9999998	0.002	99.999660	3.4

(Source: **-** http://www.shmula.com/lean-startup-conference-2014-review/16163/Date 24/4/2017 5.12 pm)

II. DMAIC METHODOLOGY

The main objective of the Six Sigma methodology is the implementation of a measurement-based approach that mainly focuses and emphases on process improvement to improve quality. The other main objective is deviation and nonconformity reduction with the help of the application of Six Sigma improvement projects or programs. This is achieved and complete through the use of two Six Sigma sub-methodologies: DMAIC and DMADV. The Six Sigma DMAIC process has five different step like define, measure, analyze, improve, control. It is an improved system for present existing processes dropping below specification and observing for incremental improvement. The Six Sigma DMADV process also have five steps like define, measure, analyze, design, verify It is also an improvement system used to develop new processes or products at Six Sigma quality levels. It can also be employed if a current process wants more better or huge improvements Above two methods of Six Sigma processes are implemented and completed by Six Sigma Green Belts and Six Sigma Black Belts and are overseen by Six Sigma Master Black Belts**.**(Pyzdek, 2014).In Six Sigma DMAIC is an iterative process that provides organization help and guidance to improve processes .It also improves productivity and quality in the workplace or in the industry. Project managers and Six Sigma consultants or experts apply the DMAIC steps and appropriate analysis tools are used under each step, to analyze and improve key metrics of a business. Metrics are recognized, variation is studied and reduced and processes are improved and optimized. The result is improved performance, fewer errors and increased efficiency and productivity and performance.

A. He Dmaic Steps Are The

Step 1**.**DEFINE the problem and choice the work determination of the project team. The description of the problem should include the problem faced by the customer and/or business as well as how long the issue has existed. Hence, identify the customer(s), the project goals, and timeframe for completing the important points that have to be taken into account are

1) The appropriateness of the selected project to your capability and opportunity
2) Creating a higher quality level and the high possibility of cost reduction.
3) Defining problems clearly and as much possible as numerical.

Process maps or Deployment maps can also be useful in identifying non-value added steps and can be important in determining process measures.

Step2. MEASURE the current process or performance. Identify coalition of data and its source, and develop a plan for it. Collect the data and summarize it describe the problem. This usually includes an application of graphical tools. In the measurement stage, measurement work of the failures that cause the problem is made. In terms of the measurement work, number and ratio of failures are defined and possible consequences are evaluated.

Step3. ANALYZE the current performance to separate and identify the problem. The analysis is done through statistical and qualitatively techniques and it is beginning to frame and test hypotheses about the root cause of the problem. In the analysis stage, the causes of defects that yields to poor quality are scrutinized and relevant factors scanned in details for improvement.

Step4. IMPROVE the problem by selecting appropriate solution. Based on the recognized root cause(s) in the prior step, directly address the cause with an improvement. Brainstorm and discuss potential solutions, arrange them based on customer requirements, make a selection, and take the trial to see if the solution resolves the problem. In the improvement stage, essential works are done in order to eliminate the causes of defects that yields to poor quality.

Step5. CONTROL the developed process or product performance to ensure the target(s) are met as per requirements. After achieving solution of the problem, the improvements must be standardized and sustained over time. Control work is made to eliminate the causes of defects that yields to poor quality and to maintain the continuity in process improvement in this stage the reduced defects in the first four stages are defined and it is decided that by which methods are used to control it.

Various major tools generally used by various researchers in different Phase of DMAIC are shown in table-II.

Table-II DMAIC Tools Used In Various Phase

DEFINE	MEASURE	ANALYSE	IMPROVE	CONTROL
Project charter	SIPOC	Ishikawa Diagram	Design of Experiments (DOE)	Control Plan and Chart
Project Plans	Process mapping	Cause and Effect Matrix	Affinity Diagram	Failure Mode and Effect Analysis(FMEA)
Pareto Chart	Lead time/cycle efficiency	ANOVA	5S(Sort, Straighten, Shine, Standardize, Sustain)	Audit Plan
SIPOC	Pareto charts	Regression Analysis	Poka Yoke (Mistake Proofing)	New Process Capability
Voice of Customer	Cause-and-effect matrix	Hypothecs testing		Total Preventive Maintenance(TPM)
Kano Analysis	Failure modes and effects analysis (FMEA	Failure Mode and Effect Analysis(FMEA)	Failure Mode and Effect Analysis(FMEA	Plan-Do-Check-Act Cycle
Survey Design	Brainstorming	Simulation Software	Implementing TPM	Process Control
Cost of Poor Quality	MultI voting	Gauge Repeatability & Reproducibility (GR&R)	Virtual Management	Project-Commissioning
Critical Matrix	Check sheets	Basic Statistical tools Control Charts	Simulation	
Functional Development Diagram	Measurement accuracy (gage R&R)	Pareto Charts	Benchmarking	
Surveys	Run charts/control charts	ANOVA	Kanban	
Value Stream Map	Histogram and Box Plot		Poka-Yoke	

(Major Source:-Lean six sigma for services George M. L McGraw-Hill 2003)

III. CRITICAL SUCCESS FACTOR

In current tough competitive era companies are focusing on quality implementation with the help of their strong R&D departments for product development and continuous improvements. Among these tools, Six Sigma is an emerging strong quality tool for all worldwide organizations, industries and service sector also. Today all major corporate of software and manufacturing companies

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are acclimating to improve product quality and improve customer satisfaction and to keep more world-class corporations as their customers, especially in the field of and production and services. Depending on the type of the organization, products, and services the enterprises adopting new quality change process where they must need to identify the key success factors for easy implementation of Six Sigma. Brother ton and Shaw (1996) define CSFs as the essential things that must be attained by the company to identify which areas will produce the greatest "competitive leverages for success. This highlight that CSFs are not major objectives, but are the actions and processes that can be controlled by the management to achieve the organization's goals in best possible way. Critical success factors (CSFs) are those factors which are critical to the success of any organization, in the logic that, if objectives associated with the factors are not achieved, the organization will fail, catastrophically (Rockart, 1979).In every organization's formation and creation of a Six Sigma infrastructure is unique, however, there are success factors common to every success story (Breyfogle et al., 2001). Importance of the project selection process as a CSF has been researched by many authors like Kelly (2002), Anthony and Banuelas (2002), Snee and Rodenbaugh (2002), Park (2003).Finally, on the basis of the literature survey following are the major critical success factor

A. Choice of right Project & Project Champion and Project team
B. Serious to education and training of workforce all team members
C. A good measurement assurance system;
D. A creative problem-solving approach
E. Application of the right tool mix at right plac
F. Development of cross-functional teams in organization.
G. Linking Six Sigma to suppliers; long-term supplier collaboration linked with Six Sigma goals;
H. Supplier capability assessment and enhancement;
I. Proper documentation of CTQ special processes and characteristics
J. Level of top management commitment and support at all leve
K. Quality of six sigma project leadership;
L. Development of right work culture;
M. An integrated work and process flow and management system for information and communication
N. Recognizing and developing appropriate metrics and deliverables;
O. Relating Six Sigma to corporate business strategy and goals;
P. Innovation management and design capability of the firm; process mapping and re-engineering;
Q. Availability of infrastructure and resources
R. Motivating the workforce and all team members
S. Linking Six Sigma to customers; and employees.

IV. RESEARCH METHODOLOGY

We have taken total 19 different case study of Casting Foundry Company for critical examination. All the case studies which are selected in this paper are from established publications to show the real research The main aim of this study is to find out the benefits which Six Sigma with its DMAIC tools and for improvement in six sigma level and compete with today's globally competitive environment era and give impactful path to Foundry industry.
Overview of Research papers With publications authors name, and case study. (Table-III)
Methodology adopted by various casting foundry with benefitsAchieved and critical success factor (Table IV)
ools and Techniques used in various DMAIC Phases, (Table-V)
Here in this review paper Table III describes overview of research paper, Table IV shows methodology adopted by various casting foundry. It also shows the benefits achieved and critical success factor observed in different 19 case study as explained in table III Table V show various tools and techniques used in various phases of DMAIC and improvement in Sigma level in various 19 case study.

Table-III General Overview of Case Industries (Foundries) Using DMAIC Six Sigma Methodology –

Sr no	Name	Author	Journal name	Case study
1	Relevance of Six Sigma Line of	Prabhakar Kaushik	Journal of	The methodology has been

	Attack in SMEs: A Case Study of a Die Casting Manufacturing Unit		Engineering and Technology | Jul-Dec 2011 | Vol 1 | Issue 2	applied to Reduce the rejection rate of the engine mounting bracket (EMB) by reducing defects inherent in the processes.
2	Reducing Rejection/Rework In Pressure Die Casting Process By Application Of DMAIC Methodology Of Six Sigma	JavedhusenMalek Darshak Desai	International Journal for Quality Research 9(4) 577–604	Reducing the rejection/rework of Artos Body by the pressure die casting process.
3	Application of Six Sigma Method to Reduce Defects in Green Sand Casting Process: A Case Study	Suraj Dhondiram Patil, M MGanganallimath, Roopa B Math, YamanappaKarigar	International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE) Volume: 2 Issue: 6 June 2015	For minimize the defectsin the Transmission Case.
4	Utilization of six sigma(DMAIC) Approach for Reducing Casting Defects	VirenderVerma, Amit Sharma, Deepak Juneja	International Journal of Engineering Research and General Science Volume 2, Issue 6, October-November, 2014.	The present study is done at Shree Balaji Casting Samalkha, Panipat. The Main Component Of Shree Balaji Casting Samalkha, PANIPAT was Upper gear, Lower gear, Key, Roller sporting arm, Worm gear.
5	Assessing The Success Of Six Sigma: An Empirical Study	S. K. Tiwari, R. K. Singh, S. C. Srivastava	ELK Asia Pacific Journals – Special Issue	A case study has been carried out in a leading ferrous casting unit of southern India XYZ company Ltd. XYZ has since been a significant and diligent participant in the ferrous casting industry,
6	Systematic Approach On Reducing Scrap Level Using Six Sigma In Indian Foundries	S.Saravanakumar,	International Journal of Emerging Researchers in Engineering Science and Technology, Volume 2, Issue 12, December '15	The casting manufacturing process
7	Optimization of Foundry Parameters for Reducing Casting Defects.	Sandhya.M.S, Dr.H.Ramakrishna Y. SundaraRajalu	IJSRD - international Journal for Scientific Research & Development| Vol. 3, Issue 03, 2015	Case study of casting rejections in Foundry produced
8	Defect Analysis On Cast Wheel By Six Sigma Methodology To Reduce Defects And Improve The Productivity In Wheel Production Plant	C.Manohar, A.Balakrishna	International Research Journal of Engineering and Technology (IRJET Volume: 02 Issue: 03 | June-2015	Six Sigma project, undertaken by the company for the production of wheels.

9	Reduction of Reworks in Green Sand Casting Process: A Six Sigma Perspective	Sanjiv Kumar Tiwari, Ritesh Kumar Singh Sharad Chandra Srivastava	International Journal of Applied Engineering Research Volume 11, Number 5 (2016) pp 3141-3150	A case study has been carried out in a leading ferrous casting unit of southern India
10	Application of DMAIC for Process Industry: A Case Study	Vikas Kumar, Pradeep Kumar RussiKamboj,	International Journal of Scientific & Engineering Research, Volume 6, Issue 5, May-2015	Thestudy was done at Swastik Industries Kaithal, Haryana on application of Six Sigma methodology and Selection of tools and techniques for problem-solving,
11	Molding a Solution	By Prasun Das,	How Six Sigma Enhanced product performance at an Indian foundry Case study six sigma forum magazine I August 2012	Case study of Casting Process casting process of gearboxes used as parts of mechanical power transmission units.
12	Six Sigma–DMAIC Approach for Improving Induction Furnace Efficiency and Output at an Iron Foundry Plant	Chen Kwang Fong	St. Cloud State University the Repository at St. Cloud State Culminating Projects in Mechanical and Manufacturing Engineering 2016	This project was conducted in a local foundry plant specialized in producing ductile and gray iron castings for automotive, truck and other heavy equipment applications. In this project, the author worked with six other employees in the plant to study and improve the induction melting process in the Melt Department
13	Reduction Of Reducing Rate Using Six Sigma	Deepak, Dr. RohitGarg, SomvirArya	International Journal of Exploring Emerging Trends in Engineering (IJEETE) Vol. 02, Issue 04, JUL-AUG, 2015 Pg. 202-209	Case study carried out at company Sapphire foundry unit in north India manufactures the different casting products: Here product JCB Bed Plate Core is taken for study.
14	Six Sigma in Manufacturing of Ingot Moulds in Foundry and Pattern Shop by Improving Sand Quality	AbhishekPandey, Dr. K. K. Jain.	American Journal of Engineering Research (AJER) e-ISSN: 2320-0847 p-ISSN: 2320-0936 Volume-5, Issue-4, pp-209-217	A study performed in foundry andpattern shop of a steel industry explains various challenges that cause defects in casting
15	Implementation Six Sigma And Data Mining To Improve Die Casting Production Process At	Rina FItriana, Johnson Saragih, SittaSarasaty	Proceeding 7th International Seminar on Industrial	Case study was carried out at production per month which has the largest percentage

	Pt. Ab		Engineering and Management	of defects in PT. AB PT. AB is well known as a manufacturing industry which operates in motorcycle industry of Indonesia.
16	Winning Customer Loyalty in an Automotive Company through Six Sigma: a Case Study	Maneesh Kumar, Jiju Antony, FernieJiju Antony1 and Christian N. Madu	Quality And Reliability Engineering International Qual. Reliab. Engng. Int. 2007; 23:849–866 Published online 7 November 2006 in Wiley Intd science	This case study deals with the reduction of casting defects in an automotive engine
17	Taguchi-Based Six Sigma Defect Reduction of Green Sand Casting Process: An Industrial Case Study	Joseph C. Chena &Abhilash Reddy Buddaram Brahmaa	Journal of Enterprise Transformation 4:172–188, 2014 15 December 2014	The study is performed in a metal casting industry that has incurred heavy losses from the scrapping of products because of casting defects
18	Data mining driven DMAIC framework for improving foundry quality – a case study	SushovanGhosh& J. Maiti	Production Planning & Control: The Management of Operations05 October 2014, At: 12:27 Publisher: Taylor & Francis	A case study is performed in an iron foundry that produces the majority of the cast products of an automobile company in India. The focus of this study is eliminating casting defects of a critical six-cylinder engine head.
19	Implementing the Lean Sigma framework in an Indian SME: a case study	M. Kumar, J. Antony, R. K. Singh M. K. Tiwari& D. Perry	Production Planning & Control Production Planning & Control, Vol. 17, No. 4, June 2006, 407–423 Publisher: Taylor & Francis	The die-casting unit under study was established in 1978 with 150 employees, which comes under the category of SME as per the classification is given by Indian Trade Industry.

Table-IV Methodology Used, Benefits achieved and Critical Success factor status

Sir No	Methodology used	Other Benefits or improvement in Sigma level achieved	Critical success factors achieved /Status of various case study
1	Define, Measure, Analyze, Improve, and Control.	Due to application of Six Sigma project recommendation carried the process sigma level to 5.24 from 1.64 by reduction in EMB hole diameter variation in the process of machining after die casting This increase in the sigma level is equivalent to a monitory saving of Rs. 0.260 million per annum	As small companies are more agile, it is much stress-free to buy in management support and commitment, as opposed to large organizations The success of the Six Sigma application in this case study can positively encourage the other manufacturing units to use Six Sigma as a quality tool to reduce the losses in their processes and gain amusing benefits from

			it.
2	DMAIC methodology	Sigma level was improved from 3.1σ to 3.7σ. Financial savings of this project were due to two improvements. One improvement is the reduction of rejection/rework from 15.50% to 4.47% which results in financial savings of INR 12,72,242 per annum.	This project creates awareness for an industry to look into the requirement of quality consciousness and improve the performance of processes (die casting process in this case study) Six Sigma is applied to reduce setup time as well as the lead time of different products to improve the customer satisfaction by on-time delivery without delay The Six Sigma application in SMEs is a new paradigm for improving quality which is experienced by many experts.
3	DMAIC (Define–Measure–Analyze–Improve–Control) methodology along with Taguchi method	A higher product yield is possible because prior to the application of the Taguchi and ANOVA, the casting defects of the molding process were 9.58 % of the Transmission Case castings produced, and, after the application of Taguchi and ANOVA, the casting defects of the molding process declined to 5.6 %	Six Sigma DMAIC approach can be successful in identifying the problem, improving the process, and controlling the defects. Standardization and documentation of the improved process. Improvement in project in terms of customer requirements ,needs and satisfaction.
4	DMAIC (Define–Measure–Analyze–Improve–Control) methodology along with Taguchi method	The DMAIC approach has been successfully applied. The overall result of present work clearly shows that by applying DMAIC approach the rejection has reduced from 6.98% to 3.10% and saving of cost Rs 2.35 lac Rs. approximately	This methodology is customer-focused program where cross-functional teams work on project aimed at improving customer satisfaction.
5	The DMAIC (Define-Measure-Analyze-Improve-Control) approach of six sigma	The research findings show that the rejection rate of casting has been reduced to 3.36% from 4.51%. As a result, the cost associated with rejection, repair, scrap, and re-inspection can be reduced and the company is realized an annual saving of about US$ 0.45 million	Complete organizational involvement, timely training of the employees and updating regarding the new technologies are observed. incentive schemes for the Successful teams.
6	DMAIC approach	The results indicated that the calculated yield was 87.65%, from this yield, the sigma level was calculated and found to be 2.7 corresponding to DPMO of. 123,548.0.Using the company's target of 2% waste, the target sigma level was calculated to be 3.55 leading to DPMO of 20,000 and per design yield of 98% as mentioned earlier.	Management involvement and commitment. • Culture change. • Communications. • Organization infrastructure. • Training as a parallel learning structure
7	DMAIC methodology	It is concluded from the analysis that, the quality can be improved by Six Sigma i.e.	Efficiency and performance level of the casting process can be improved by

		(DMAIC) approach of parameters at the lowest possible cost and sigma level is increased after optimization of various parameters	adopting a Six Sigma approach.
8	DMAIC	As a result of the project, the rejection level of Ingates and Cracks after the six sigma methodology has been reduced to 1.45% from 1.64% for Ingates and 0.69% from 0.77% for Cracks.	The Six Sigma Approach is customer-driven. The Six Sigma Approach attentions on Customer needs, Data-driven improvements & the inputs of the process. Processes and products consistently meet our and customer requirements.
9	DMAIC methodology	The research findings show that the rejection rate of casting has been reduced to 7.97% from 10.69%. As a result, the cost associated with rejection, repair, scrap, and re-inspection can be reduced and the company is realized an annual saving of about US$ 0.45 million.	Due to global competitiveness manufacturing industries are facing a tough challenge to produce high quality and customized products at low cost to meet the uprising market demand. Six Sigma was evolved as one of the powerful methodologies in order to tackle these situations.
10	DMAIC approach	Upper housing whose rejection cost due to defects before application of DMAIC was Rs.67230.which has been reducing to Rs. 26082 after implementation of DMAIC.The motor pulley pervious rejection cost in Rs 35720 which has been reduced to Rs.9785 and for mini chaff cutter has been reduced from 87864 to 31080 by implementation of DMAIC	Application of DMAIC for minimization of sand casting defects in a process industry. Six Sigmais not simply a quantitative statistical measure of processes; it holds every aspect and phase of work, using a disciplined, fact-based approach of problem-solving.
11	DMAIC	The deviations in the process, if minimized and controlled, could lead to about 10-15% fewer defective parts shipped to the customer that wouldn't have been typically caught by inspection	Quality consciousness became top of mind with management at the foundry because of increased competition in foundry also.
12	DMAIC	The actual cost savings were estimated at $211,271 per year, while the predicted cost savings were estimated at $165,644 per year	Six Sigma DMAIC(Define-Measure-Analyze-Improve-Control) methodology to improve the processes in both departments to reduce overtime labor cost and high production wastes and rework
13	DMAIC Methodology	The rate of rejection was about 23% before applying this approach. The rate of rejection of the JCB Bed Plate is reduced to 10% from 23% using six sigma approaches	Six Sigma is ruthless, persistent pursuit of the reduction of variation in all critical processes to achieve a continuous and breakthrough improvement through the elimination of waste. rework, scrap, non-value added effort, defects, and opportunities for defects from process by controlling process parameters
14	DMAIC Approach	This work controls the sand quality which improves the casting and reduces the defects. This work also attempt the improvement in	Six Sigma is controlled philosophy for reducing the defect and improves the quality. DMAIC based Six Sigma

		sand quality for Ingot mold in Foundry and pattern shop of steel industry where such innovative task has not been performed for achieving the Six Sigma by using the optimization techniques like ANOVA and Taguchi for controlling process parameters by available soft tool platform MINITAB in research society.	approach implemented to optimize the processes parameters and performance level of the casting process. It can be improved by using ANOVA and Taguchi method of experimental design is used.
15	Six Sigma, DMAIC	Based on the research, processing, and analysis, it can be concluded that the DPMO the value generated prior to implementation that is equal to 15 357 and the sigma level of 3.66. Results of observation and analysis, it was given a proposal to reduce the defects caused by the use of decision tree flow line	Six Sigma is a comprehensive and flexible system for achieving, sustaining and maximizing business success. Six Sigma is uniquely driven by a strong understanding of customer needs.
16	DMAIC	The application of DMAIC has resulted in a significant financial impact (over U.S. $110 000 per annum) on the bottom-line of the company.	Creating and maintaining customer loyalty were the key challenges for the organization as the management. The company's management has-been convinced of the benefits of adopting the Six Sigma problem-solving methodology and it has been linked directly to the strategic goals.
17	DMAIC;	The optimal parameter setting reduced the defect percentage from 31 to 4% in the confirmation run.	Six Sigma DMAIC approach was successful in identifying the problem, improving the process, and controlling the defects. A counteraction plan included training and certifying operators and employees, establishing a periodical maintenance plan, inspecting incoming material; revising the operation-standard operating procedure (SOP); is prepared.
18	DMAIC; data mining	Gas defect percentage has been reduced from 15% to 3% and the total defect rate has been reduced to below 10%.Bring down the total defect rate to the target level of below 5%	The proposed approach has practicalviability and can be effectively applied in the constrainedsituations where experimental design is not feasible option for finding out the most importantvariables impacting the process and their optimalsettings.
19	Six Sigma (DMAIC)	The implementation of the Lean Sigma strategy has resulted in savings of around $140 000 per year. The optimal settings of the process parameters have improved the casting density of the die casting Process by over 12%.	Lean and Six Sigma are two widely accepted business process improvement strategies available to organizations today for achieving dramatic results in cost, quality and time by focusing on process performance.

Table V Different tools used in Different phase of DMAIC in various review papers and increase in sigma level

The Following table shows various tools used in different phase of DMAIC by various researchers shown in table-1

Sr No.	Define	Measure	Analyze	Improve	Control
1	SIOPC, Flow Diagram for Engine mounted bracket, High-level process map for EMB rejection	Measurement system analysis (MSA) is conducted which includes the gauge repeatability and reproducibility (Gauge R&R) studies	Process capability analysis of EMB hole Diameter Data Sheet for Current Six Sigma and DPMO	Design of Experiments (DOE)	X bar/R control chart was drawn to visualize the presence of an assignable cause of variation A 100-sample size was taken for drawing the X bar/R Chart.
2	Problem statement Goals CTQ and SIPOC on the pressure die casting process	Gauge repeatability and reproducibility (R&R) Visual Inspection	Cause &Effect diagram Cause &EeffectMatrix	Cleaning-Lubrication-Inspection-Tightening (CLIT) preventive maintenance And Design of Experiment.	P Chart Control Plan
3	Voice of Customer, Decide project Goals and Prepare project charter	Pareto analysis And DPMO Calculation	Fish Bone Diagram	Experimental Design and orthogonal array ANOVA and Minitab	A process flowchart was displayed at the working section With details of process specification. Check sheets
4	Problem Formulation	Data Collection Sheet	Cause-and-Effect analysis tool: Ishikawa Diagram	Improvement in blow holes defects	Controlling the Process Parameters
5	Project charter, SIPOC Diagram	Defect data and Calculation of DPMO	Control chart (X bar and S chart) before improvement	Taguchi's DOE, Experimental Design MINITAB® 15. Anova	A Control Chart of the existing process (i.e., after improvement)
6	SIPOC Diagram	Process Mapping Data Collection Sigma level calculations (4) Down Time Measurements	Pareto chart Analytical Hierarchy Process (AHP Fishbone Diagram	Monthly waste monitoring and reporting to beImplemented for the purpose of keeping the waste below 2 %as per design specifications.	Controlling the process
7	Voice of Customer and the voice of business,	Critical to Quality (CTQs) Pareto Charts	Cause and Effect Diagram	Root cause validation GEMBA analysis Control Charts	Critical process parameters are continuously monitored and documented to update
8	Deliverables to customers	CTQ (Critical to Quality):	Pareto Analysis Binomial	Binomial Capability Analysis Cause and Effect diagram,	Control Plan and Monitoring

			Capability Analysis		
9	SIPOC	Defects per million opportunities (DPMO	X bar-S chart	The surface methodology has been used for the design and modeling of the experiment	Experimental Design
10	Blowhole in Casting found as Critical to Quality	Data Collection sheet and Rejection Rate Sheet	Brainstorming Sessions,	Cause-and-Effect analysis, Fishbone, diagram. Process Mapping	After the study of Blow holes in Foundry unit the following recommendation is made to control the reduction of Blowholes defects of submersible pumps parts. 1.Control the permeability of Moulding Sand. 2. Control the moisture content of Moulding sand.
11	Process Map	Baseline Sigma level, Pareto chart	Cause and Effect Diagram Process variables and their significance	Improvement plans, ImprovedDPMO	Standard Operating Practices (SOP) were prepared
12	SIPOC TQ requirements, identify potential KPOVs.	identifying the potential KPIV Pareto Chart Analysis	Cause and Effect Analysis, Data Analysis, Root Cause Analysis	Root Causes Analysis Microsoft Access, Microsoft Excel's Pivot	P chart Control plan
13	Graph Charts etc.	Kaizen Sheet, MSA of Attribute Data	Cause and Effect Matrix	Tables Charts	Statistical Process Control (SPC) technique
14	Histogram	Cause and Effect Diagram Pareto Chart	WHY WHYAnalysis	Taguchi-based experimental design Analysis of Variance (ANOVA)	Control Plan
15	Project Charter, Diagram SIPOC	CTQ (Critical To Quality)	FMEA, Decision Tree Ishikawa Diagram	WEKA Software	Control Maps p and u
16	Project Charting	Process Mapping, Cause and Effect Analysis	Regression Analysis	Design of Experiment	Run Charts
17	Pareto Chart	Statistical Analysis Cause-and-Effect Analysis	Fishbone Diagram Orthogonal Array Design	Analysis of Variance (ANOVA Taguchi-based experimental design	Statistical Process Control (SPC)
18	Critical to Quality(CTQ)	Cost of Poor Quality (COPQ)	Decision-tree-based Analysis	Decision-Tree Analysis Data Mining Analysis	Long-term Control Plan

		Analysis Cause-effect diagram (Ishikawa/ Fishbone diagram)	Tree-based Algorithms, CART decision tree CHAID nonbinaryDecision Tree QUEST		
19	Critical to Quality (CTQ) characteristics based on the Voice of Customer (VOC)	A Gauge repeatability and reproducibility (R&R) study	Pareto chart, Cause and Effect Diagram	Design of Experiment, 5S system	Mistake proofing exercise, Total Productive Maintenance (TPM). Control Chart for casting density

V. OUTCOMES OF CRITICAL ANALYSIS

The main aim of this paper is the critical analysis of various attempt for improving quality and productivity of the foundry by applying the Six Sigma – DMAIC methodology. The implementation of it resulted in understanding the problems from all sides, qualitatively as well as quantitatively, and setting out the improvements through effective analysis of the roots causes of the problem. Six Sigma has already developed as one of the most effective business strategies in the large organizations worldwide now can be used in small-scale foundry also. This paper is an attempt to provide roadmap application of Six Sigma in the Small-Scale foundry which is normally accepted to be in the section of large industries. The Six Sigma application in the various foundry is a new paradigm for improving quality which is practiced by many researchers. This quality improvement program can be used to improve product performance, and Six Sigma completed that with castings at the foundry. The monthly vendor evaluation report received by management from the foundry's customers showed a noticeable improvement in the quality of foundry products. This papers also creates awareness for the industry to look into the requirement of quality consciousness and improve the performance of processes in the various foundry. One of the critical success factors of the Six Sigma that is top management interest and promise was recognized in various research papers because every time whenever there are requirement resources and funds, top management support is required up to their extent which creates this project to be implemented successfully in the foundry. The various research paper is an attempt to justify the highly useful role of management techniques like Six Sigma for small-scale foundry which is normally presumed to be in the domain of large foundry industries.

Six Sigma is applied to critical processes with correct tools & techniques in each phase of DMAIC methodology then Six Sigma has an ability to improve the process and give the considerable improvement in the performance of the process in foundry industries. DMAIC methodology is a business approach used to improve business profitability and efficiency of all operation to meet customer needs and prospects

The Six Sigma methodology has been gradually accepted worldwide in the foundry sector in order to enhance productivity and quality performance and to make the process robust to quality variations. the quality and productivity improvement in a foundry through with an application of Six Sigma DMAIC (Define-Measure-Analyze-Improve-Control) methodology which provides a framework to identify, quantify and eliminate sources of variation in an foundry process in question, to optimize the operation parameters improve and sustain performance viz. process yield with well implemented control plans to reduce defect and improve sigma level.

Due to global competitiveness and rising prices foundry industries are facing a tough challenge to produce high quality and customized products at low cost to meet the increasing market demand. Six Sigma was evolved as one of the powerful methodologies in order to tackle these situations. Six Sigma is a project-driven management approach that is pertinent to all the areas of a foundry. It improves the process efficiency by identifying and eliminating the defects to increase quality DMAIC based Six Sigma approach is implemented to optimize the process parameters of the foundry. Due to this, the stability of the casting process is also increased. Before the use of Taguchi and ANOVA, the parameters of the casting process in foundry were more random and difficult to control and hence the product quality suffered instability problems. Taguchi and ANOVA yielded optimized control factors. Application of Six Sigma in foundry has the large scope, but due to lack of knowledge and awareness on latest quality tools and statistical techniques among the management, its implementation is very limited. In this situation, application of Six Sigma methodology on one of the best method for quality improvement and reduce customer complaints etc. Foundry industries are facing many problems for quality so attempts are made by various researchers so an attempt is made to implement six sigma methodology to the various system to considerably improve quality, productivity, and profitability. Various literature also said that very large financial benefits due to six sigma in the large foundry so an attempt can be made to replicate it in small scale foundry also. Lean Sigma framework can be used in foundry and die casting industries to reduce the defect occurring in the final product (automobile accessories) manufactured by a die-casting process. The proposed framework integrates Lean tools (current state map, 5S System, and Total Productive Maintenance (TPM)) within Six Sigma DMAIC methodology to enhance the bottom-line results and win customer faith fullness. Failure mode and effect analysis (FMEA), in-house scrap and rework data, inspection data, and analysis of customer complaints were used to pinpoint potential problems that could be resolved by mistake proofing DMAIC framework, compelled by data mining techniques for defect diagnosis and quality improvement in the foundry where historical and online process data can be effectively utilized. Decision tree algorithms namely, Classification and Regression Tree and Chi-squared Automatic Interaction Detection can be used for developing the proposed framework.

VI. CONCLUSION

In foundry Define 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 compositionfor six sigma implementation in this Phase the project charter is prepared including business case, problem statement, project goal and CTQ tree. SIPOC (Supplier-Input-Process-Output-Customer) analysis to provide the better understanding of the casting process in a foundry to all the team members. The main objective of the Measure phase is to completely understand the current performance and gather adequate baseline data so that once improvements are made the impact can be verified. In Measure Phase Cause and effect diagram, Ishikawa diagram, Gauge repeatability, and reproducibility (R&R) studies, Measurement system analysis with MINITAB Software, and Pareto Chart etc tool are used. Current six sigma level and DPMO is also calculated to know the present status of Six Sigma for the foundry. The main aim of the measured phase is to understand and establish the baseline performance of the process in terms of process capability or sigma rating in the foundry for further improvement. Measure phase also includes process mapping and data collection for foundry defects and casting process. Cost of Poor Quality (COPQ) analysis is an effective tool that straightly links the improvements of the process performance to the business profitability. In Analyze phase the main purpose of this phase is to the identification of the root causes of the problem or the causes having maximum impact on the CTQs. for six sigma improvement in the foundry, a brainstorming session was carried to identify the probable causes of the problem. Cause & effect matrix and diagram, cause validation plan, Regression Analysis, ANOVA, Failure mode and effect analysis (FMEA) Hypothesis testing etc. tools are used. Various simulation software can also use in this phase.The fourth phase of the DMAIC procedure of Six Sigma is Improved phase in which the project team will choose the improvement steps based on final validated root causes in analyses phase. No of different tools like 5S, FMEA, ANOVA, Taguchi method is used in this phase The last phase of the DMAIC methodology of Six Sigma is control phase in which the project team will take the activities in the way of sustaining the improvements which are achieved in improve phase in foundry for sustain six sigma level improvement. in foundry industry. Six Sigma is a project-driven management approach that is pertinent to all the arenas starting from manufacturing to service industries. It enhances the process efficiency by identifying and eliminating the defects. The step-by-step application of the Six Sigma DMAIC methodology for reducing the rejection rate of casting in a various sand casting foundry. From a review of the different paper, it can be said that the efficiency and performance level of the casting process can be improved by implementing a Six Sigma approach. It is decided from the various analysis that, the quality can be improved by Six Sigma i.e. (DMAIC) approach with lowest possible cost. And the successful implementation of DMAIC approach. DMAIC has been considered as an innovative method to product and process quality improvement in the foundry. Six Sigma approach in Indian foundry industry to reduce scrap/waste from the operations, thus greatly improving the production efficiency. Six Sigma project in the foundry is to get benefit from this strategy in a ‘project-based' approach rather than planning, training or investing here and there for accumulating various resources required for Six Sigma implementation.

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