

Review Paper: Quality Improvement through Six Sigma DMAIC Methodology in Plastic Injection Moulding

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ABSTRACT: Injection moulding is a stimulating process for many manufacturers and researchers to produce products meeting customers' requirements at the lowest cost. Its complexity and the huge amount of process parameter manipulation during real time production create a very powerful effort to maintain the process under control Six Sigma is an established effective methodology which is capable of manufacturing the products which are close to customer requirement with improving quality. Six Sigma is a set of techniques and tools for process improvement with DMAIC Methodology.

The Present study shows that the Six Sigma quality improvement of for various defect in Plastic Injection Moulding of components The objectives of this paper is to recognize the problem of various defects, which reduces quality, to suggest measures for the improvement in the Injection Moulding operation using Six-Sigma DMAIC methodology by increasing six sigma level, by analysing various research papers. This reviews paper includes introduction and implementation.

KEY WORDS: Six Sigma, DMAIC, Injection Moulding

I. INTRODUCTION

Injection moulding is an economical production process for producing complex plastic parts in huge quantities. A hot melt of thermoplastic polymer is forced into a mould-cavity at a lower temperature, after that the hot melt solidifies. After solidification, the mould is opened and the product is removed from the mould cavity (Werner Titans et al 2015).

The basic injection process cycle is as follows: Mould closes - injection carriage forward injects plastic - metering - carriage retract - mould open - eject part. In injection moulding moulds are closed shut by hydraulics or electric, and the heated plastic is enforced by the pressure of the injection screw to take the shape of the mould. (Visas Dwvedi et.al 2014).

Plastic Injection Moulding is a high precision tool that is being used to produce plastic parts in mass particularly in industries of consumer and electronics, automotive and medical sector. Though, costly tooling and machinery are required in this type of manufacturing process. Due to the many delicate adjustment required, as it is so much complex processes. The product quality be influenced by on mould design, material selection, and process parameter setting. The main phase of injection moulding process are Plasticization, cooling, packing, injection. (Seaman, C.M et al 1994)

In Plastic injection melding process there are number of process parameter which effect cost quality and productivity. Due to this setting of optimal process parameters is required. This is done by using trial and error method or Taguchi's parameter design method to decide optimal process par meters in plastic injection melding. But this method in now not suitable due to increase in variety of complexity in different large no of parts and its product design and different quality parameters. Due to thisSix Sigma Six Sigma is the strongest professional methodology can be used.

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II RELATED WORK

In this review paper research and development work on Six Sigma methodology and its used in plastic injection moulding is shown in table 1 and table 2 some literature work are explained here.

Six Sigma began in 1986 as a statistically based method to reduce variation in electronic manufacturing processes in Motorola Inc. in the USA. It is developed by Bill Smith at Motorola, later it was adopted by General Electric (GE) and Allied Signals, where it was initiated by Jack Welch (Sunil V. Deshmukh, Ashish Chavan, 2012).

The numerical goal of Six Sigma is in reducing defects to less than 3.4 parts per million (PPM) also known as 'Defects Per Million Opportunities' (DPMO), reducing cycle time and reducing costs dramatically which impact the bottom line (Antony, J. and Banuelas, R. (2002)).

Six Sigma is a data-driven process improvement methodology used to make the process stable, outputs predictable and improve process capability. Six Sigma approach is a continuous improvement strategy that is mainly focused on customer satisfaction (N. Gopalakrishnan 2012).

Six Sigma has two key methodologies, each consisting of five phases: DMAIC (define, measure, analyse, improve, control) and DMADV (define, measure, analyse, design, verify) The first methodology is used for existing processes, while the second is used to design new processes (J.A. De Feo et al 2005)

The DMAIC (Define, Measure, Analyse, Improve and Control) approach of Six Sigma was applied to reduce rejection rate of plastic moulded parts (J. Yadav et al 2014).

III RESEARCH METHODOLOGY

The main purpose of this study is to discover the benefits which Six Sigma with its DMAIC provides to the plastic injection moulding process for improvement of their processes quality and compete with today's globally competitive environment era. This is an attempt to show directions to all plastic injection moulding companies for implementation of Six Sigma and Quality imitative projects. The strategy & methodology used is to collect the various literature (research papers) and case studies where Six Sigma approach was successfully implemented in plastic injection moulding industries.

We have taken total 10 different case study of plastic injection moulding company for critical examination. All the case studies which are selected in this paper are from established publications to show the real research and give impactful path to plastic injection moulding company.

- Overview of Research papers /case studies and publications with author's name.
- Methodology adopted by various plastic injection moulding companies
- Tools and Techniques used in various DMAIC Phases.
- Benefits gained by plastic Injection Companies.
- Critical success factors achieved in various companies.

These all case studies are then compared from different perspective and presented into this review paper.

IV. OVERVIEW OF CASE STUDIES AND PUBLICATIONS

Various case studies of different research papers are arranged in a systematic manner as shown in table 1. It indicates preferred name for different research papers (case studies) Title of research papers, information about publications (journal etc.) with year of publication, Name of the authors and details of the case study in plastic injection moulding process. To study recent trends in plastic injection moulding companies all case studies are taken from year 2006 to year 2016.

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Table-1 Over view of Case studies

Sr No	Title Of Paper	Authors	Journal/publishers AND Year/Thesis	Case study/
A	Six Sigma; As Applied in Quality Improvement for Injection Moulding Process	Vikash Dwivedi and Mohd. Anas, Mohd. Siraj	International Review of Applied Engineering Research. Volume 4, Number 4 (2014), pp. 317-324	Case Study of identify to Find out Black specks in plastic products during Injection Moulding Process.
B	Application Of Six Sigma In Injection Moulding Process	Jogender Singh Yadav, Dr. Prabhakar Kaushik	International Journal Of R&D In Engineering, Science And Management Vol.1, Issue I, Aug 2014	Case study was carried out on a injection moulding unit which manufacture latch i.e. child part of automobile door lock system in Small Firm
C	Six Sigma Approach for Quality Management in Plastic Injection Moulding Process: A Case Study and Review	P.K. Bharti M.I. Khan ² and Harvinder Singh	International Journal of Applied Engineering Research Volume 6, Number 3 (2011) pp. 303–314	Case study to improve the quality of nylon-6 bush (KAMANI BUSH) produced by plastic injection moulding process manufactured by the Targor Corporation.
D	Improvement In Production Rate By Reducing The Defects Of Injection Moulding	Vikas Tayal , Jitender Kumar	International Journal of Computer Science and Communication Engineering IJCSCE Special issue on “Emerging Trends in Engineering” ICETIE 2012	The present case study deals with reduction of rejection due to moulding defects in a moulding industry.
E	Plastic Injection Quality Controlling Using the Lean Six Sigma and FMEA Method	A Mansur, Mu’alim, and Sunaryo	IOP Conf. Series: Materials Science and Engineering 105 (2006) ICET4SD IOP Publishing	Case study of PT. Yogya Presisi Teknikatama Industry (PT. YPTI) plastic injection maker company. For bush product
F	Quality Improvement Using Six Sigma Concepts In Injection Moulding Manufacturing	Suresh S/O Vasu	Thesis submitted to University Teknikal Malaysia, Melaka April 2008	quality improvement of major defect injection moulding assembly line in the ALPS MALYSIA Sdn.Bhd
G	Quality Improvement of Product in Plastics Industry using Six Sigma Approach	Sumnima Bhandari	Paper submitted to The Graduate School University of Wisconsin-Stout May, 2009 Menomonie, WI	A XYZ company located in western Wisconsin will be chosen for the case study and a customer complaint in one of its product will be studied

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H	Scrap Reduction at EFD	David J. Byler, Nathan W. Griggs, and Caitlin E. Macko	A Major qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfilment of the requirements for the Degree of Bachelor of Science David J. Byler, Nathan W. Griggs, and Caitlin E. Macko 3/6/2009	Case study of injection moulding Department of Electron Fusion Devices, or EFD
I	Applying Six Sigma Techniques in Plastic Injection Molding Industry	Tarek Safwat, Aziz Ezzat	Proceedings of the IEEM 2008 IEEE	Using a case study of NATPACK Co. a plastic packaging company in Al Obour City, Cairo, Egypt
J	Evaluation of inking quality in plastics molding by Six Sigma method	Marcela Pavlůčková and Gabriela Bogdanovská	17th International Carpathian Control Conference (ICCC) IEEE 2016	Case study of Six Sigma method to evaluate the moulding inking quality in company producing plastic automotive Supplies.

V. METHODOLOGY ADOPTED BY CASE INDUSTRIES

As **discussed earlier** in Six Sigma concept that there are mainly two methodologies for the Six Sigma, but most of research papers shows that starting of their projects with DMAIC approach to improve quality and productivity in existing processes, because DFSS approach is used for new processes or products. Table 2 showing the methodology with their goal (objective) which have been adopted by different plastic moulding industries explained in various research papers. It is clear from the table 2 that all the case industries are using DMAIC methodology.

Table 2 Methodology adopted and goal / objective of various case study

Refereed No	Methodology	Objective/ goal
A	DMAIC	Focus on Quality improvement in Plastic Injection Moulding Process reducing defects
B	DMAIC	The main objective is to reduce rejection rate in latch manufacturing process showing high rejection rate, which was 3.5 percent causing big annual losses to firm. It. The study was taken to identify the key factors of rejection using the six sigma approach and how the process can be improved.
C	DMAIC	Main Objective is determining optimal process parameter settings critically influences productivity, quality, and cost of production in the plastic injection moulding (PIM) industry.
D	DMAIC	In the present paper, an attempt has been made to apply DMAIC (Define, Measure, analysis, improve, control) approach. The emphasis was laid down towards reduction in

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		the defects (Blush ,Burn ,cold flows ,cold slug , contamination ,peeling ,gloss) occurred in the injection moulding by controlling the parameters with DMAIC technique.
E	DMAIC	The objectives of this research are minimizing the defective goods and reducing the waste using Lean Six Sigma and FMEA approaches, especially for Bush product. From the analysis result, defective types on Bush product can be classified into bubble, speckle, short shoot, sunken, sink mark, over-cut, flashing, and discolour.
F	DMAIC	To utilize six sigma methodology in performing the study. To study the “black dot” rejects utilizing QC tools at the identified assembly lines.
G	DMAIC	The objective of this study is to research commonly used Six Sigma tools and techniques, research and understand injection moulding process, research the quality related problems in injection moulded parts and improve quality of the product using Six Sigma DMAIC methodology. A case study approach will be used in this research paper to show how Six Sigma methodology can be used in order to increase quality of an injection moulded plastics product.
H	DMAIC	The goal of this project was to provide EFD with the groundwork and recommendations to reduce costs resulting from waste produced within their injection moulding department, including moulding scrap and machine downtime. They focused on overall scrap reduction in line with six sigma ideals.
I	DMAIC	This paper presents an approach to implement a six sigma technique to decrease the scrap rate in a plastic injection moulding plant In this case study they compare the average scrap rate for the “Before” study period with the average scrap rate of the “After” study period.
J	DMAIC	Main aim is to improve and evaluation of inking quality in plastics moulding by Six Sigma method.

VI. PHASE WISE USE OF TOOLS AND TECHNIQUES

There is an existence of so many tools and techniques which are normally used in different phases of DMAIC approach according to ISO 13053-1 standard (Vasileios Ismyrlis et al 2013)

Table 3 showing the various tools and techniques used by different case industries in plastic injection moulding companies General tools and technique which are used in different phases are shown below

Table-3 Different Tool used in Different Phases of DMAIC

Phase Wise Use of Tools and Techniques (where, D=Define, M=Measure, A=Analyse, I=Improve and C=Control)

Different Tools and Techniques used	Different Review Papers									
	A	B	C	D	E	F	G	H	I	J
Project Charter/Statement of work-SOW								D	D	
Voice of Customer(VOC)			D							
SIPOC diagram	D	D			D	D		D	D	D
Process Flow Diagram/Chart		D			I	D		D		M
Gauge repeatability and reproducibility(Gauge R and R		M						M		
CTQ tree/OR Factors	C		A D		M		M		D M	
High level Process map		C		D		M			M	

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GANTT chart										
DPMO Calculation/cpk	M C		M				M			
Pareto diagram					M	D	D	D,M	M I	
Brainstorming	C		D			D				
Fish bone Diagram						D	M			
Why/Why Analysis							A			
Cause-effect diagram/Root Cause analysis/ <i>Ishikawa Diagram</i>	A	A I	A I	A I			A	A	M	M
MSA									M	
Histogram			M I							
Hypothesis tests			A						MI	
Regression analysis			A							
Process capability analysis		A			M					
ANOVA			I							
DoE (Design of Experiments)		A C								
	A	B	C	D	E	F	G	H	I	
Taguchi Method			A							
FMEA(Failure Mode and Effect Analysis)					A I				M I	A I
Two sample T-test		A,I								
Control chart		C							I C	
Various Software Like Minitab		C							C	C
Monitoring System/Control Plan			C	D	C				C	C

VII. BENEFITS GAINED BY CASE INDUSTRIES

The main objective of various plastic moulding companies is to earn more profit in today's globally competitive market. This can be achieved by in plastic injection moulding companies by improving and increasing their business performance, in terms of quality productivity and reducing cost. In any plastic injection moulding company quality and productivity can be increased by reduction in scrape or wastage while manufacturing of compacted part and reducing cycle time, idle time rejection, and rework with effective use of Six Sigma concept with DMAIC Methodology.

Table-4 Benefits Achieved and status of Six Sigma level if any

Name Of Paper	Benefits Achieved	Six Sigma Level If Any/Decrease In Rejection Rate
A	Root Causes of Defect of Black specs are identified In Injection Moulding Process	The highest rejection rate was identified in the month February (2012). Thus lowest sigma level i.e. 4.2356 was recorded for the month of February whereas the highest being 4.331 for May
B	This increase in sigma level will give saving of Rs. 0.708 million per annum to the industry which is a good figure for such industry	Six Sigma implementation increase the process sigma level from 1.80 to 5.46 by reduction in Latch hole diameter variation.
C	After implementation of the proposed method the lower	Process improved from 2.38σ standard to

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	process capability index CPL for over shrinkage of nylon-6 bush has improved from 0.24 to 1.225, process mean decreased from 0.1015 to 0.0615. This study has two advantages. First is to choose the best tools that fit that type of industry. Second is to encourage similar companies to apply the same methodology	5.18 σ standard.
D	Main benefits is in the injection moulding by controlling the parameters with DMAIC technique. improvements in its processes, products and services is achieved This approach is here used for reducing defects in the organization	The overall result of present work is clearly shows that by applying DMAIC approach the rejection has reduced from 7.44% to 2.75 %.
E	The recommendations for improvement that can be given from this research are making checklist for maintenance and production monitoring, enhancing work supervision and inspection, as well as improving the environment and work stations.	Based on the total number of defects that is used as the attribute for the calculation of the whole products in 2014, the DPMO score is 988.42 or 4.6 sigma level, which means that the company is still producing defective products for 5213 pieces per one million products,
F	The root cause for the black dot defect had been successfully determined. Corrective action to overcome this quality problem has been suggested. The implementation of the proposed corrective action needs commitment from the management of the company. The findings from this project can be used as a guide to improve other quality problems. It is hoped that the company can take up the suggestion given in this study to be implemented.	Study shows that the sigma level from the month May to October ranging from 4.2420 to 4.2686. This shows the average sigma level for the whole process is 4.2452.
G	Six Sigma DMAIC methodology can be used to improve the quality of the product in plastics industry With the help of DOE with optimum setting of an injection moulding machine parameters are possible to reduce warpage defect on plastic product	Not specified .optimum sting of injection moulding parameters.
H	In EFD their injection moulding department, reduce costs resulting from waste produced including moulding scrap and machine downtime	Out of the 2,442 lbs of virgin materials entering the job, 861.97 lbs went back to regrind, 1529.93 lbs toward finished goods, and 50 lbs toward floor/QA/prior to first piece submitted scrap. The 35% of materials entering this job will eventually be reused, resold, or scrapped.
I	Using the financial department of Natpack Company to calculate the hard savings in Egyptian Pounds, the result was 123000 L.E/Yr. This value equals to a cost saving of 3% of the total cost of goods sold.	This study has created a decrease in the scrap rate from an average of 5.2% to 2.6%.

VIII. CRITICAL SUCCESS FACTOR OBSERVED IN VARIOUS RESEARCH PAPER

Critical success factor (CSF) is a management term for an element that is required for an organization or project like six sigma to achieve its mission or goals. It is a critical factor or activity required for confirming the success of a company or an organization. (Rockart, John F et al 1979)For the successful implementation of Six Sigma for achieving required

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results, organizations should focus on the key elements or elements which can lead them towards their goals or objective with big success.

The main success of a Six Sigma implementation work cannot be taken for granted. Many a times the failures in Six Sigma implementation by companies are due to improper and impractical approach without proper foundation and planning. Table 5 shows the critical success factors observed in Plastic injection moulding company due to implementation of six sigma DMAIC concept.

Table-5 Critical Success Factor observed

Critical Success Factors	A	B	C	D	E	F	G	H	I	J
Top management involvement and participation	√	√	√	√	√	√	√	√	√	√
Awarding the success to financial benefits		√			√	√	√	√	√	
Training and education of the staff and workers								√	√	
Linking Six Sigma to business strategy				√				√	√	
Adequate resources for implementation									√	
Setting measurable goals and objectives				√					√	√
Easy availability of Data		√		√	√				√	√
Proper Selection of team all members				√				√	√	√
Proper Utilization of the tools/techniques	√	√	√		√	√	√	√	√	Y
Focus on customer requirement and satisfaction							√	√	√	√
Proper documentation			√	√	√		√			
Encourage similar companies to apply the same methodology			√							
Quality Improvement	√	√	√	√	√	√	√	√	√	√
Establishing Project Driven Management				√	√			√	√	√

IX. CONCLUSION

From the study of plastic injection moulding companies case study it is found that Six Sigma as an innovative approach supports organizations to detect and remove defects and improve their business performance considerably. It also shows that Six Sigma's expanding influence on industry as Because of the remarkable benefits the Six Sigma approach has demonstrated in various plastic injection moulding companies, This study also reviewed the effect of six sigma tools in various Phases of DMAIC and its benefits achieved in form reduction in rejection rate and increasing quality level by increasing six sigma value The result of this study proved that the quality of product in a plastic industry can be improved by using Six Sigma approach. Adapting Six Sigma as a part of business strategy certainly helps the organizations to accomplish sustainable growth.

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