Pakistan Journal of Engineering Technology and Science (PJETS)
Volume 9, No 2, 2021

AN OVERVIEW ON APPLICATION OF SIX SIGMA METHODOLOGY IN PLASTICS INJECTION MOLDING INDUSTRY

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Abstract*- In this research paper, the application of six sigma methodology in plastics injection moulding is reviewed. Every process in industry requires improvements to increase productivity and reduce defect rate and process variation. There are many process improvement techniques are available to indentify the root causes of defects and six-sigma is one of the most famous technique that is widely used to find the real defects causing factors by applying of different tools such as DMAIC. The DMAIC is acronym for Define, Measure, Analysis, Improve and Control method is used in implementing of six-sigma in manufacturing process to improve the quality level of moulded part. Plastics industries face many quality problems due to process variation that increase lead time, loss of money and non-smooth customer's relations. Many complaints are received from customer that the moulded parts have defects include surface marks, colour lines, hard fitting, air bubbles and flow marks. By using six-sigma technique, main aim is to find factors causing process variation and to indentify which factors will resolve the problems in analysis phase. It was identified that by DMAIC, the defects rate can be reduced and process can be improved up to 50%. In the process of six-sigma, the statistical tools such as SIPOC, project charter, cause and effect diagram, brainstorming, Pareto chart, run chart and capability analysis are used to make sure that process is really improved. The sigma level has improved without any vast capital investment. Application of this methodology in manufacturing industries has given rise to a huge economic savings.

Keywords: DMAIC, Six sigma, Injection moulding, Plastics, Manufacturing industry.

I. INTRODUCTION

A. Historical back ground of Six-Sigma

In 1986, Six-sigma was presented by Bill Smith at Motorola as a statically founded way to minimize the defects rate in electronic manufacturing in Motorola Inc. in United State of America (USA). Later on, Allied signals and general electronics adopted this methodology, where it was initiated by Jack Welch [1], [2]. For the evaluation of six sigma, there were two significant contributions from general electronics (GE's) way of application. First, Jack Welch established great pattern of leadership. Second, he backed six-sigma up with a strong recompenses system.

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General electronics altered its incentives compensation plans for the whole company so that 40% of the bonus based on six-sigma results and 60% on financials. This new scheme effectively attracted attentions of GE's employees to six-sigma. Furthermore, the training of six sigma has become requirement for development general electronics (GE's) business hierarchy. Jack Welch asserted that nobody well thought out for administration work without at least green belt training preparing before the end of 1998[3], [4][5]. Moreover, six-sigma has many improvements and changes the progression of time, also its application in manufacturing industries as well as services corporations. Six-sigma methodology is applicable in any fields includes products, school, business, transaction or process [6], [7][8]. It can also be applied in administration, business operation such as research and development, marketing, sales and other areas which directly effects the customer. It comprises on investigation of qualitative facts by using measurable techniques and tools [2], [9], [10]. The variation in manufacturing process can be reduced by six sigma methodology. Profits and advance improvement are connected with it. This methodology has taken consideration from practitioners and academics around the globe [2], [7], [11]. The process variation in moulding process causes defects in moulded parts such as surface marks, colour lines, black dots, flow marks and hard fitting that result of loss of money, lead time and non-smooth customer relation. The main objective of this study is to find out root causes of these defects and remove the defects to improve the quality of plastics product that save time money and time of manufacture.

B. Definition of Six sigma

Six-sigma being systematic, well disciplined, organization wide strategic business, profit driven and customer concentric that assistances to emphasis on the emergent and bringing very close to perfect solution, service and product [5], [12], [13]. Six-sigma, in different ways, is used to reduce the variation in the process that to the quality problems or defects. Six-sigma is an initiative to increase productivity, enhance marketing part and recover customer's gratification with techniques and statistical tools that can chief to innovation significant in product quality. Six-sigma is a methodological and financial element that improve the process and product concurrently [7], [14], [15].

To become globally well matched and to attain business operational excellence industries are apply different quality improvement initiative like ISO certification, lean manufacturing, total quality management and quality circles etc. [16]– [18]. Nevertheless, the results by these wits are not much profitable and are time constrained. So, a methodology is required to be introduced and implemented which can provide significant improvement in short time. Six-sigma is that methodology that can offer significant improvement in short time. So, six-sigma is an important to discover its application for getting important gains and profit in term of quality, customer's satisfaction and market share [19]– [21]. [1], [12], [22], [23].

There are two approaches of six sigma methodology;

I. DMAIC (D-define, M-measure, A-analysis, I-improve, C-control)
II. DMADV (D-define, M-measure, A-analysis, D-design, V-verify)

DMAIC practice is applicable on current process or products that need be improved while the DMADV is applied on new process or product which are intended and applied in such a way that it can deliver a six-sigma recital

DMAIC Cycle

According to Deming cycle, the DMAIC method is based upon improvement process. It can be used in different area of enterprises or manufacturing industries.

The goal and requirements of this process are as following:

- It defines responsibilities and needs
- It defines organizational structure to gain the goal.
- Identify the settings and essential element to find estimated date of end of project.
- Gaining support from higher authority.

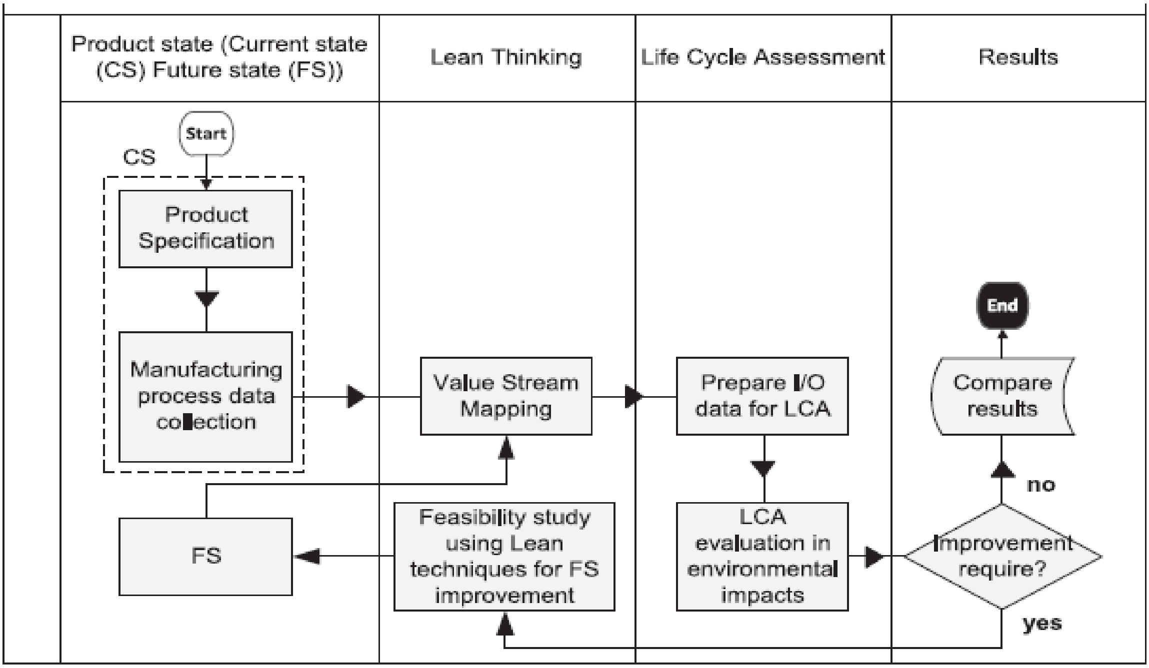

Figure 1 The map to proposed method of incorporating lean thinking in manufacturing environment[10].

The main purpose of this stage is to confirm the necessary actions to resolve the quality problems in manufacturing process. This method has different phases or steps through which a product or process can be improved.

This method starts by finding the problems that desire a solution and close with considerate these and clear indication of organisation management. An improvement has many ways to resolve a problem. It is necessary to focus on external factors that produce cost for association and remove the defects and then resolve internal problems of cost.

The following steps can be adopted to account the existing procedure:

- Identification of existing efficiency and performance.
- Examination if there are adequate facts to quantity
- Documentation of reliable and valid system of measurement

- Execution relative examinations.

C. Six-Sigma methodology application in manufacturing industry

Six-Sigma methodology is a statistical technique to investigation for excellence organisation. Hence, the DMAIC methodology is applied to improve the product quality in injection moulding process [11] [24]. Six-sigma has following phases in figure1;

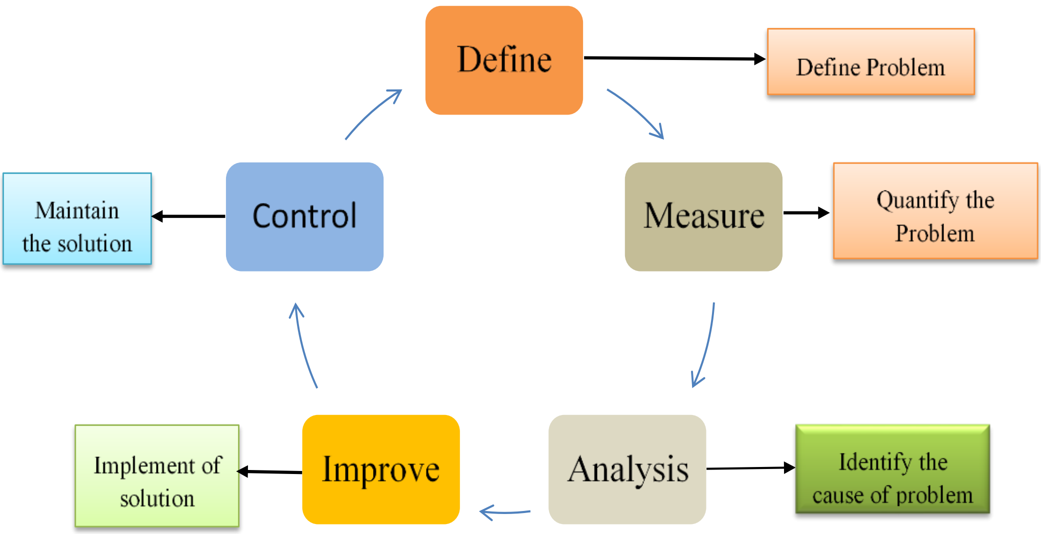

Figure 2 Six sigma methodology flow chart

A. Define Phase

The define phase is first phase of six-sigma methodology. In this phase project is selected, targets and initial goals are set. Moreover, the problem is also defined and grow a project statement or charter of exertion is being processed. The quality cost is calculated associated with existing process. Critical to quality (CTQ) and SIPOC (supplier, input, process, output, customer) analysis are recorded. Improvement goals and targets are set in term of cost associated and sigma level[25][3][26]. The define phase is also includes defining quality features and identification of root cause of defects.

In this phase project, problem and its objective are defined. Relevant statistical are also defined in this step that are used in this process improve the quality of process and find the root of defects or problems.

Supplier	Input	Process	Output	Customer
Polymer line Company	PVC pellets		Fittings products	Thermosole Company
Interplast Company	Master batch		Runner + sprue	Al Ashrafiya Company
Al Watanis Company			Cycle information sheet	
Volta Dies and Mould Company	• Melting temperature • Screw speed • Injection speed • Injection pressure • Packing pressure • Packing time • Mould time • Cooling time			

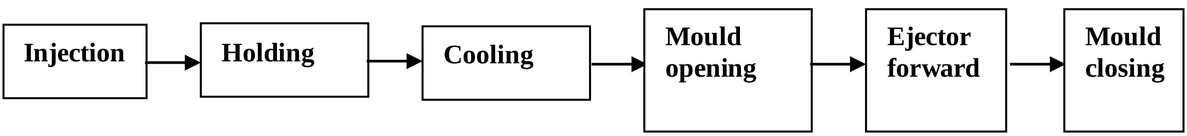

FIGURE 3 SIPOC DIAGRAM FOR INJECTION MOULDING PROCESS [11].

A. Measure Phase

The 2nd phase of six-sigma methodology is measure phase. Through this phase, observation as well as collection of data is approved and created on process capability analysis or DPMA (defect per million opportunity) is estimated on basis of the characteristics of data[13][9]

B. Analysis phase

Analysis phase is third phase of this methodology. By this phase, possible reasons through which defects or variation are happening that are existing the process output is recognised. The very important stage in analysis phase is cause-and-affect diagram[28]. Six sigma researchers find possible causes which may create from material, source, machine, such as man, environment and methods. In this system, researchers adopt another technique called why-why analysis[21] [15].They find at least five possible reasons that have influence of specific causes, so that root cause of defects could be identified. Each suggestion may need clarification in order to make every participant know about effect of specific cause. Statistical tools and existing or new data is used to validate the causes such as analysis of *variance(ANOVA), scatter plots, regression, design of experiment (DOE) and hypothesis testing. Implementation of wastage of resources and ineffective improvement can be prevented by validating the root causes[18][29][30].*

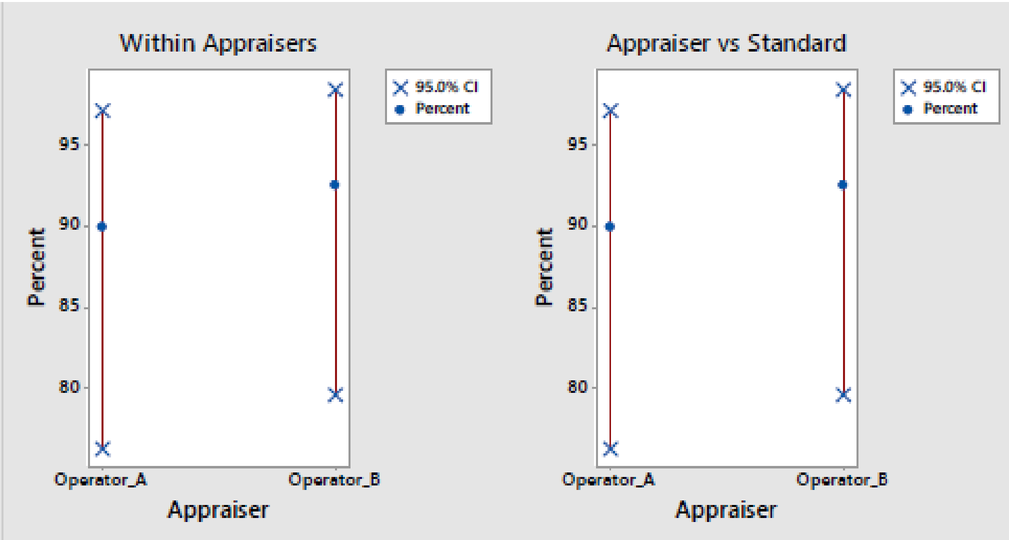

Figure 4 Characteristic arrangement analysis [11]

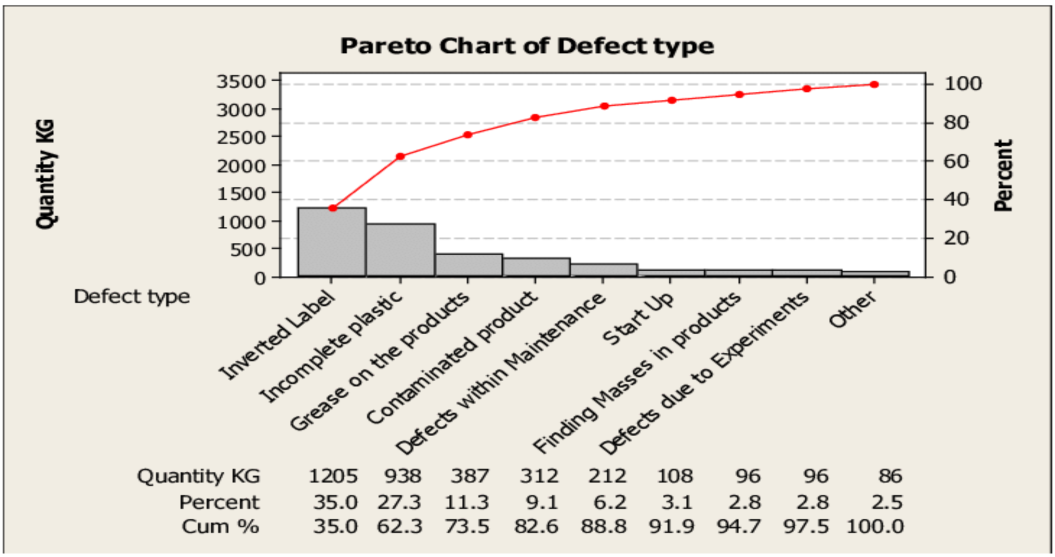

Figure 3 Pareto chart of the types of defects and defectives [2]

B. Improve Phase

The improve phase is forth phase of six sigma methodology. After analysis of collected data, the defects or variation is reduced that is critical for customer satisfaction. To reduce the defect rate, countermeasures are recorded that could be applied to improve the process in this phase. Ideas and solutions of issues are presented by using affinity diagram[24]. On the bases of probability of success, the list should be lessened to one or two potential improvements, time execution, cost and impact on resources[31][27]. On the basis of solutions and ideas, a pilot project is carried out for the application and data collection is carried out. The researcher team should continue full scale implementation, if small scale implementation offers severe success[2][13][19].
In order to attain improvement, it was proposed to:

- Collect tools and parts at spot
- Remove interior operations
- Simplify set-up to decrease alterations
- Replace only essential fragments and make all others as world-wide as possible
- measure time.

It was suggested to develop and complete the external set-up checklist to define the needed tools, materials and gauges and their storage location.

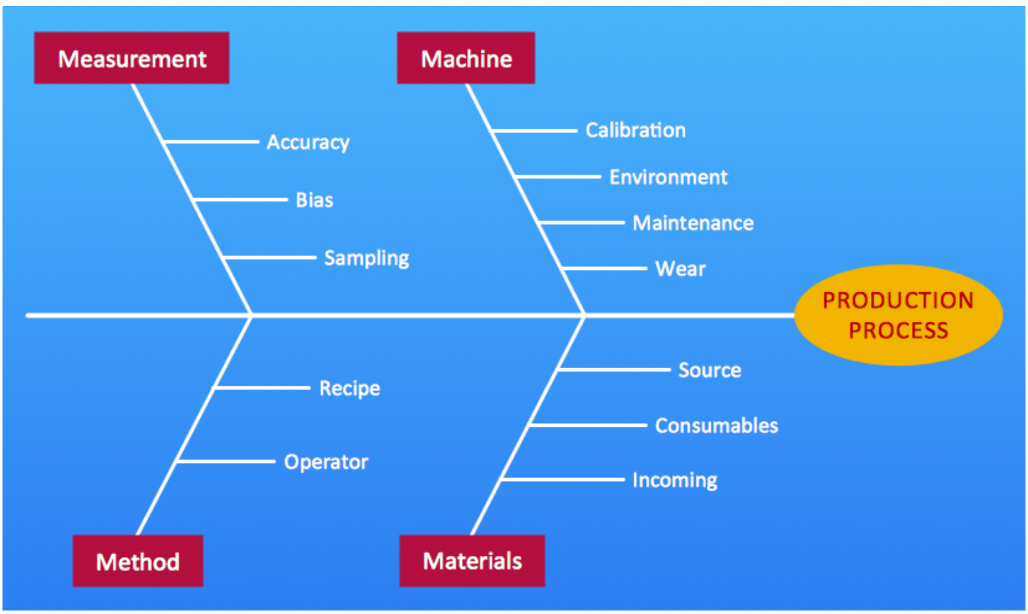

FIGURE 6 FISHBONE DIAGRAM

In figure 6, fishbone or Ishikawa diagram is shown. This diagram is used to find out the actual defects or problems in process. Different sections that are related to the process are included in fishbone diagram to analysis the root cause of defects in any process. This diagram is not specifying any process, rather than, it can be used in any operation, process, transaction that need to improve their quality. In this diagram, main components of operations and their relevant equipment are included so that actual process to be analysed. Every process and its involved equipment like machine or its parts, material and operator are considered. This diagram is constructed over that sections that involve in this whole process. For example, un-trained machine operator could not handle the machine and moulded product properly to avoid from problems. In this way, delay in maintenance or improper maintenance is also a major factor that causes the defects. Improper maintenance of machine may causes leakage of oil, burning of material and flow marks in moulded parts. Environment is also having big contribution in defect rate and process variation such as moisture, overheating and dust particles which cause contamination in material.

The measurements in process are also having major role in process variation. Inspection and testing of material and its moulded parts require special care. Negligence and inappropriate techniques affect the quality of products. The measurements require accuracy during process running. The incoming material refers to raw material that received from client for manufacturing. Contamination in material or mixing of different materials leads to colour lines, burn marks and spots on the surface. The manufacturing of material and its delivery is referred to material source also accounted for improvement of quality of moulded parts.

	Inportance to customer (1-10)	6	3	5	10				
	Output Variables (Ys) →	Weight	Cycle Time	Thichness	Number of Defects				
Process step	Input Variables (Xs) ↓					Weighted score (X)	%	Order	Status (Critical or Eliminated)
Injection Molding Process	Injection Speed	9	9	9	9	216	23.7	1	critical
	Injection Pressure	9	3	9	9	198	21.7	3	critical
	screw Speed	3	9	3	3	90	9.9	4	eliminated
	Packing Pressure	3	1	1	3	56	6.1	6	eliminated
	Packing Time	3	3	1	1	42	4.6	7	eliminated
	Cooling Time	3	3	1	3	62	6.8	5	critical
	Meting Temperature	9	9	9	9	216	23.7	2	eliminated
	Clamping Force	0	1	0	0	3	0.3	9	eliminated
	Contamination of Material	0	0	0	3	30	3.3	8	eliminated
	Weighted Score (Y)	**39**	**38**	**33**	**40**	**913**			

Figure 4 cause and effect matrix[11]

Sigma level can be computed by using following formula

Over-all rejection = R

Total mass-produced parts = P

Total CTQ = O

Defect per unit (DPU) = R/P

DPO = DPU/CTQ

DPMO =DPO×106

Sigma level =0.8406+√ {29.37-2.221ln (DPMO)}

A. Control Phase

The last and fifth phase of six sigma methodology is control phase. Control of improved implementation is done in this phase. Indication should be displayed by early signal, if process is going towards out of control[14][32]. Team may develop devices which use lights, no go designs, logic program, sound, indicators to control a process[33]–[35]. The main purpose of this step is to control the inputs and monitoring the outputs to reduce the variation. The actual encounter of six sigma application is not in making improvement in the operations but supporting attained results[21], [22][36].

Figure 3 shows major steps which are taken during in manufacturing process. This chart also explains SIPOC (Supplier, Inputs, Process, Output and Customer).

This chart relates the whole cycles starting from supplier to customer voice. In this, all process and critical inputs and output as well as customer requirement are considered. This chart also explains how and when a process can be started.

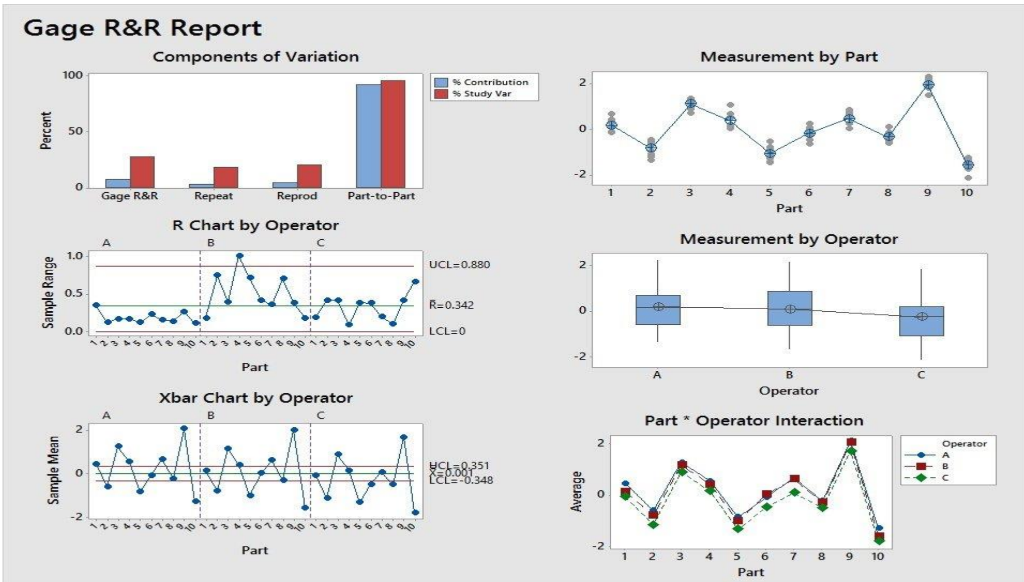

Figure 8 Gage R & R (Repeatability and Reproducibility) [37]

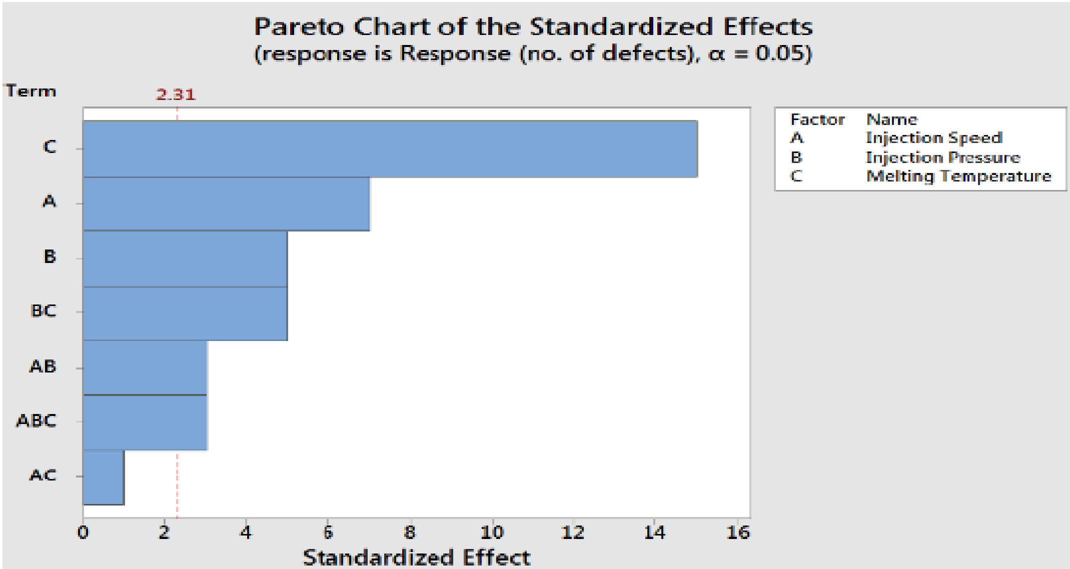

Figure 9 Pareto chart for the standardized effects [11]

RPN	Failure mode	Action Plan
560	Dryness of material	✓ Use a drying machine
294	Contamination of material	✓ Reduce the recycled material and distribute it evenly among the batches of PVC
270	Occupational health issues	✓ Provide a first aid kit ✓ Provide frequent breaks
160	Behavior of operator	✓ Assign rewarding and recognition programs ✓ Assign penalties
140	Cleanness of mold	✓ Make a schedule to clean the mold
84	Insufficient amount of material inserted	✓ Make a schedule to check the amount of material in the hopper

RPN

FIGURE 10 ACTION PLAN FOR MANUFACTURING PROCESS

A short tool kit and six sigma improvements are shown in below table 1[38] [39]:

Table 1 Six sigma improvements and statistical tools

Define Phase	**Measure Phase**	**Analysis Phase**	**Improve Phase**	**Control Phase**
Customer needs	========	Control charts	=======	Preventive activity
Benchmark	Seven Q.C tools	Cause & Effect diagram	Design of Experiment (DOE)	Control charts
Charter	Data collection forms, plan, logistics	Decision & risk analysis	Tolerancing	Procedural adherence
Quality function deployment	=========	Capability	========	===========
Kano model	Sampling techniques	Statistical inference	Robust design	Performance management
Baseline	Defect metrics	(FMEA)	Modelling	Time seriesmethods
Process flow map	=========	Reliability analysis	==========	=========
Management by fact	=========	Systems thinking	==========	=========
Project management	==========	Root cause analysis	=========	========

VI. CONCLUSION AND FUTURE RESEARCH DIRECTION

The implementation of six-sigma in injection moulding industry brought a significant improvement in quality of moulded parts. Six-sigma DMAIC is an easy way to find root cause of defects that responsible for process and remove them. This technique really helped to reduce variation up to 50% in injection process. Real causing factor is found in analyze phase that made it clear that the root causes of process variation is due to un-trained machine operator, material handling and improper maintenance of machine. In improvement phase, the process improved by applying statistical tools in six-sigma DMAIC methodology. Maintenance check sheet has been made and handed to industry management to maintain process improvement. Six-sigma does not depend upon material. It is just process improvement technique to improve the quality of process and remove the process variations. Moreover, Six-sigma can applicable due remarkable improvements in different fields or sector that want to improve their work or business and operating excellence. Through six sigma methodology, productivity, profitability and quantum attain in quality can be achieved.

Some Recommendations for change of material from plastics to rubber

- Rubber material requires more pressure as compared to plastics material per square inch of cavity surface in moulding. So, high injection pressure machine is required.
- The cavity of mould for rubber is different from plastics mould that requires more cooling time for solidifies of material. Conformal cooling channel are required is mould cooling.

Avoid from regrinding material or recycled material put into resin for rubber manufacturing.

ACKNOWLEDGMENT

This paper is published by students of University of Engineering and Technology, Lahore Pakistan. This an overview of six sigma to improve the quality of plastics products in injection moulding industry.

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