Quality Improvement of Product in Plastics Industry using

Six Sigma Approach

by

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ABSTRACT

Six Sigma is a process-focused, data-driven approach aimed at improving the performance of products and processes by finding and eliminating the causes of defects which are critical to customers. A Six Sigma defect is defined as anything that is outside of customer specification. Six Sigma is becoming a new world standard for customer satisfaction and profitability improvement.

The purpose of this research is to study quality related problems in an injection molded plastic product and to improve the quality of the product using Six Sigma methodology in a mid-size XYZ injection molding company. This research paper aims at using a case study approach to show how Six Sigma methodology can be used in order to improve the quality of an injection molded plastics product.

A customer complaint received by the company was studied. Six Sigma statistical tools were used to identify and analyze the warpage defect. Design of Experiment (DOE) was used in order to find the optimum settings of the injection molding process parameters and to reduce the defect. The result proved that the quality of product in a plastic industry can be improved by using Six Sigma approach.

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Chapter I: Introduction

In today's competitive business environment, an organization's success is based on its ability to provide the products and services faster, better, efficient and cheaper than their competitors. Global competition and demand from the customer for high quality and low cost product is forcing the organizations to search for the means to improve their products and processes. Under these circumstances, Six Sigma has gained huge importance for improving quality and productivity.

Six Sigma is a structured and disciplined process, focused on delivering perfect product or services to the customer on a consistent basis. In statistical terms, Six Sigma means 3.4 defects per million opportunities (DPMO). It is a methodology that emphasizes Define, Measure, Analyze, Improve and Control (DMAIC) approach to problem solving.

The aim of Six Sigma methodology is to integrate all operations throughout the processes to make them produce their desired results. It can be implemented in various processes related to manufacturing and services including health care, information technology, distribution operations, warehouse and inventory management, supply chain management and manufacturing.

This study aims at improving the quality of a product in a XYZ plastics injection molding company using Six Sigma DMAIC methodology.

Statement of the Problem

A mid-size XYZ plastics injection molding company received a quality complaint in one of its product from customer. The company was required to improve the quality of the product for its customer satisfaction.

Purpose of the Study

The purpose of this research is to study quality related problems in injection molded plastics products and improve quality of the product using Six Sigma DMAIC methodology.

Objectives of the Study

1. To research and understand injection molding process.
2. To research and identify quality problems in a mid-size plastics company.
3. To identify commonly used Six Sigma tools and techniques.
4. To solve the quality related problem and increase quality of the product using Six Sigma DMAIC methodology.

Assumptions of the Study

1. Data provided by the company are accurate.
2. Data collection process adopted by the company is reliable.
3. Steps used to perform DOE are correct.

Definition of Terms

VOC (Voice of Customer). "The voice of customer is the process for capturing stated, unstated, and anticipated customer requirements, needs, and desires" (Munro, Maio, Nawaz, Ramu & Zrymiak, 2007, p. 18).

CTQ (Critical to Quality). "A characteristic of a product or service that is essential to ensure customer satisfaction" (Munro et al., 2007, p. 414).

Customer Satisfaction. "The result of delivering a product or service that meets customer requirements" (Munro et al., 2007, p. 414).

Brainstorming. A technique teams use to generate ideas on a particular subject. Each person on the team is asked to think creatively and write down as many ideas as possible. The ideas are not discussed or reviewed until after the brainstorming session. (Munro et al., 2007, p. 410)

DPMO (Defects Per Millions Opportunity). "DPMO is the average number of defects per unit observed 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" (S., 2003).

MINITAB. Statistical software.

Chapter II: Literature Review

This chapter is divided into two sections. The first section is focused on discussing about Six Sigma, its benefits, its tools, and methodology. The second section is focused on discussing about injection molding process, its important parameters and different types of defects in injection molded plastic products.

Six Sigma

Six Sigma stands for Six Standard Deviations (Sigma is the Greek letter used to represent standard deviation in statistics) from the mean. It is a process-focused, data-driven approach aimed at improving the bottom line by finding and eliminating the causes of defects in all processes which are critical to customers (Antony, Douglas & Antony, 2007). The Six Sigma methodology goes well beyond the qualitative eradication of customer-perceptible defects and is deeply rooted in statistical engineering techniques (Burton & Sams, 2005). According to Banuelas and Antony (2002) "Six Sigma has been considered as a philosophy that employs a well-structured continuous improvement methodology to reduce process variability and drive out waste within the business processes using statistical tools and techniques" (p. 250). It is a management philosophy developed by Motorola that emphasizes setting extremely high objectives, collecting data, and analyzing results to a fine degree as a way to reduce defects in products and services. In statistical terms, Six Sigma means 3.4 defects per million opportunities (DPMO), where sigma is a term used to represent the variation about the average of a process. In business terms, according to Antony and Coronado (2001), Six Sigma is defined as:

> A business improvement strategy used to improve business profitability, to drive out waste, to reduce costs of poor quality and to improve the effectiveness and efficiency of all operations so as to meet or even exceed customers' needs and expectations. (p. 120)

Although different people have defined Six Sigma in different ways, to define Six Sigma in simple terms is not possible because it includes the methodology of problem solving and focuses on optimization and cultural change (Raisinghani, Ette, Pierce, Cannon & Daripaly, 2005). The central idea of Six Sigma management is that if the defects in a process can be measured then the systematic ways to eliminate those defects can be figured out, to approach a quality level of zero defects (Brue, 2002).

Six Sigma philosophy thus, allows top management to describe the performance of a process in terms of its variability and to compare different processes using a common metric (Raisinghani et al., 2005). This common metric is known as defects per million opportunities. Table 1 shows the sigma levels and the respected defects per million opportunities:

Table 1

Sigma Levels and Defects per Million Opportunities

Sigma Level	Defects/Million Opportunities
6	3.4
5	233
4	6,210
3	66,807
2	308,537
1	690,000

The objective of Six Sigma is to reduce the variation in the processes so that 99.99966 percent of the outputs will fall between the Lower Specification Limit (LSL) and the Upper Specification Limit (USL). In other words, the processes will be producing at most 3.4 DPMO (Brue & Howes, 2006). Variation in the processes is an enemy of quality and Six Sigma approach is committed to dealing with this problem. Any outputs that does not fall within the customer's specifications limits are termed as defects (Snee, 1999). Figure 1 shows the normal distribution curve relating it to Six Sigma. The more of the distribution that fits within the specifications, the higher will be the sigma level.

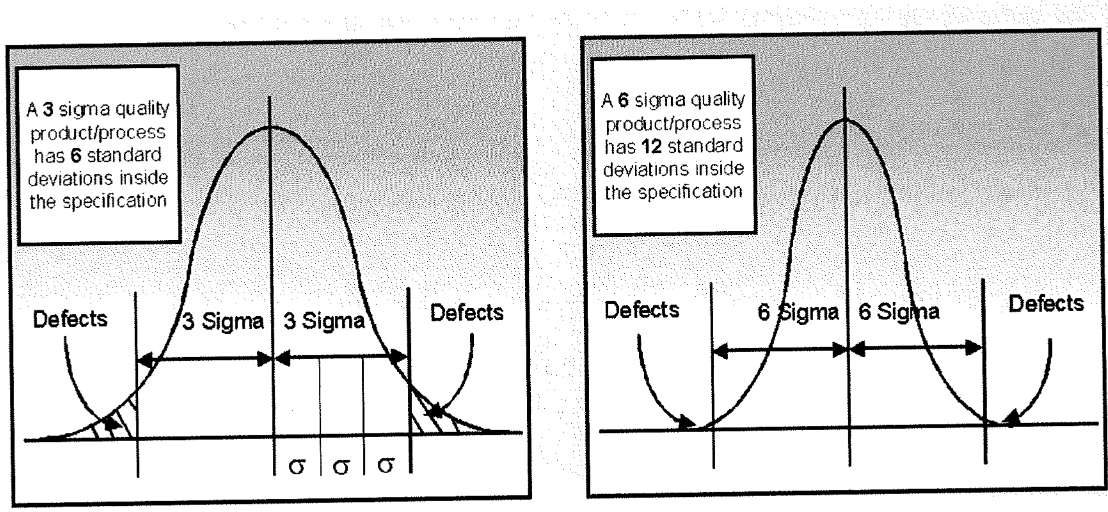

Figure 1. The Technical Meaning of Six Sigma

Source: Lee-Mortimer, 2006, p. 11

The quality level at most companies is at a four sigma level which is equal to 6,210 defects per million opportunities (Brue, 2002). In other words, those companies are working at 99 percent quality level. To illustrate why 99 percent quality level is not acceptable, following facts can be considered (McClusky, 2000):

- At major airports, 99 percent quality means two unsafe plane landings per day;
- In mail processing, 99 percent quality means 16,000 pieces of lost mail every hour;
- In power generation, 99 percent quality will result in 7 hours of no electricity each month;
- In medical surgery, 99 percent quality means 500 incorrect surgical operations per week;
- In credit cards, 99 percent quality will result in 80 million incorrect transactions in UK each year.

Benefits of Implementing Six Sigma

By implementing Six Sigma, companies are able to meet the customer expectations and also are able to improve employee relations within the company. One of the positive effects of Six Sigma is that it increases cash flow due to the creation of additional revenue. By using Six Sigma, not only cost decreases but also increased profitability can be seen. The main benefits in implementing Six Sigma initiative are:

1. The search for continued improvement in processes.
2. Achieving customer satisfaction through better comprehension of their requirements.
3. Better understanding of the critical entries in the process necessary to respond to alterations in demands and defined specifications.
4. Improvement in quality.
5. Gains in the flow of processes.
6. Increased productivity.
7. Reduction in cycle times.
8. Increases in production capability and reliability of products.
9. Reduction of defects, cost, and loss.
10. Elimination of activities that do not add value to the process, and
11. Maximization of profits (Arnheiter & Maleyeff, 2005; Blakeslee, 1999; Young, 2001).

Many organizations have reported significant benefits and savings as a result of Six Sigma implementation. General Electric is one of the most successful companies in implementing Six Sigma project. It has reported more than $12 billion in savings due to

Six Sigma initiative (Foster, 2007). Motorola claims to have similar savings. It saved $15 billion over 11 years from six sigma implementation. Home Depot attempted to solve problems by thinning out their workforce and implementing training programs for the remaining employees in order to reduce defects (Antony & Coronado, 2001). Other companies such as AlliedSignal, Citibank and Sony have also succeeded in Six Sigma implementation. Dow Chemical has saved $130 million in two years by applying Six Sigma program to its environmental, health and safety services (Biolos, 2003). Dairy Crest, the UK's premier chilled dairy foods company saved 85,000 pounds per year by implementing Six Sigma at its Crudgington Spreads Business Unit in Shropshire (Lee-Mortimer, 2006). Similarly, a Six Sigma project implemented at Reliance Industries Limited (an India-based global 500 producer of polyester) contributed $4 million per annum in monetary benefits with increased productivity, process capability, and plant yield (Bhatt, Dhingra, Jain, Kale & Vakil, 2006).

Six Sigma Methodology

Six Sigma methodology improves any existing business process by constantly reviewing and re-tuning the process (Summers, 2006). To achieve this objective, Six Sigma uses a five phase methodology known as DMAIC. It is the most common methodology for tackling existing products or processes that are not meeting customer specification or not performing adequately and looking for incremental improvement (Lee-Mortimer, 2006).

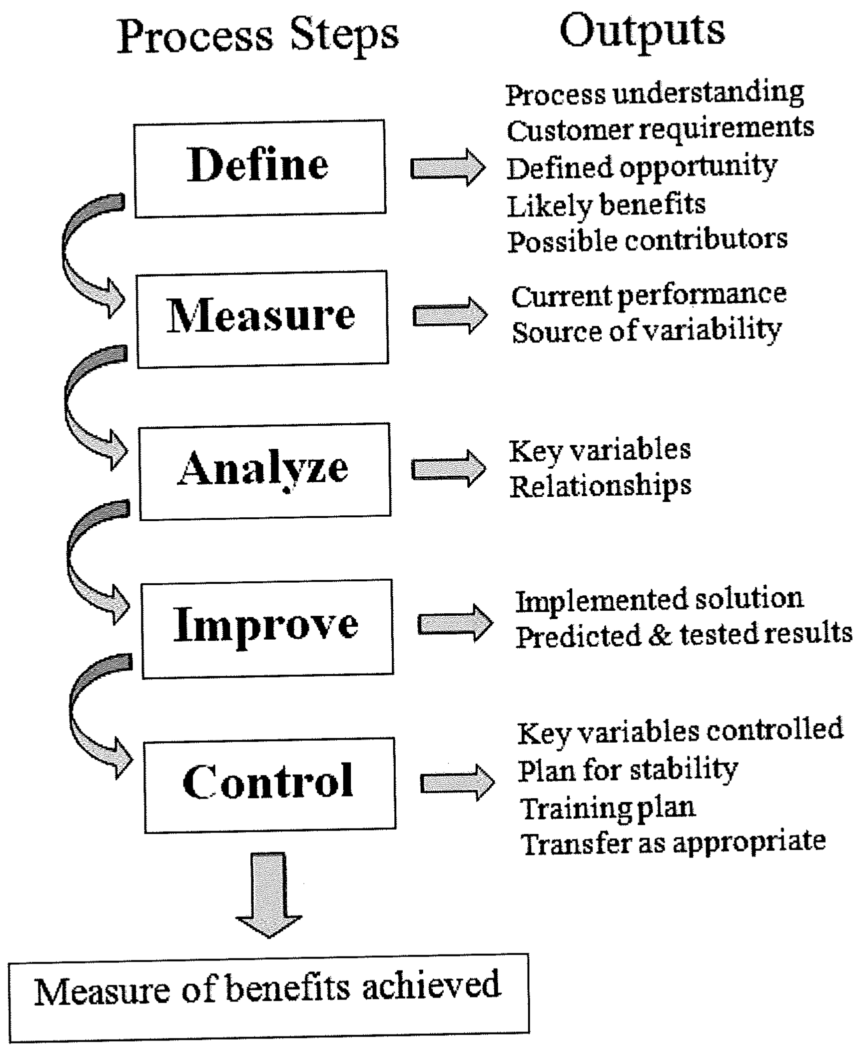

Figure 2. The Six Sigma DMAIC Process and Key Outputs

Source: Knowles, Whicker, Femat & Canales, 2005, p. 57

DMAIC (define opportunities, measure performance, analyze opportunity, improve performance, and control performance) process with key outputs from each of the five phases is shown in figure 2. Each phases of DMAIC methodology is discussed below.

Define. In the define phase, the problem is identified and the requirements of the project and objectives of the project are defined. Customer plays a vital role in this phase

(Brassard, Finn, Ginn & Ritter, 2002). The objectives of the project should focus on critical issues, which are aligned with the customer's requirement and the company's business strategy. During this phase, the customer requirements are identified and quantified in a measurable form and the process output of the product is examined to see whether these requirements are satisfied or not. The factors that are critical to quality, which need to be measured, analyzed, improved and controlled are determined.

Measure. The measure phase starts with data collection plan, executing the plan and verifying whether the data collection is done properly or not. During this phase the characteristics critical to quality are selected (Brassard et al., 2002). These deal with the outputs of the process that are important to the customers. Then the desired outputs are defined and best measurement system is identified. Once the defects have been measured and all critical data are collected, it is important to figure out the root cause of the problems.

Analyze. In the Analyze phase, the data collected in measure phase are analyzed. The causes of the problems that need improvement are determined to eliminate the difference between the existing performance of the process and the desired level of performance (Pyzdek, 2003). This involves discovering why defects are generated by identifying the key variables that are most likely to create process variation (Brassard et al., 2002). In this phase, data are utilized to establish the key process inputs that affect the process outputs. Information gained from the analysis phase can provide insight into the sources of variability and unsatisfactory performance and help improve the processes. Tools like brainstorming, cause-and-effect diagram, hypothesis testing, and regression analysis are used for interpreting the data.

Improve. This phase identifies the improvements to optimize the output and eliminate or reduce defects and variation. It determines which of the available solutions should be used to solve the root causes of the problem. Once the solution is selected, the implementation plans are developed, a pilot run of the changed process are conducted, and the best levels for the process to maintain a consistent output are developed. The results are verified and measured at this point to ensure that the selected solution will work.

Control. The last phase in the DMAIC is the control phase. It is used to establish the required control plan that reflects the finding from the improve phase and to drive controls to sustain the improved performance (Brue & Howes, 2006). This phase documents, monitors, and establishes action plan for sustaining the gains made by the process improvements. This is done by using some proven methods such as statistical process control, mistake proofing, preventative maintenance, accountability audits to ensure that the process stays in a controlled state (Breyfogle III, 1999).

Six Sigma Tools and Techniques

There are several statistical tools that are used in Six Sigma projects. These tools are used in different DMAIC phases to identify the problems, to measure them and analyze them, to improve the process or product by eliminating or reducing the problem, and to sustain the achieved improvements.

Pareto chart. Pareto chart is a bar graph used to break down a problem into the relative contributions of its components, to identify the vital few elements on which one should focus (Brue & Howes, 2006). It is a tool that can be helpful in identifying the source of common causes in a manufacturing process. It uses the famous economist

Vilfredo Pareto's principal of 80:20 which means a large percentage of problems are due to a small percentage of causes (Munro et. al, 2007). An example of Pareto chart is shown in figure 3 below.

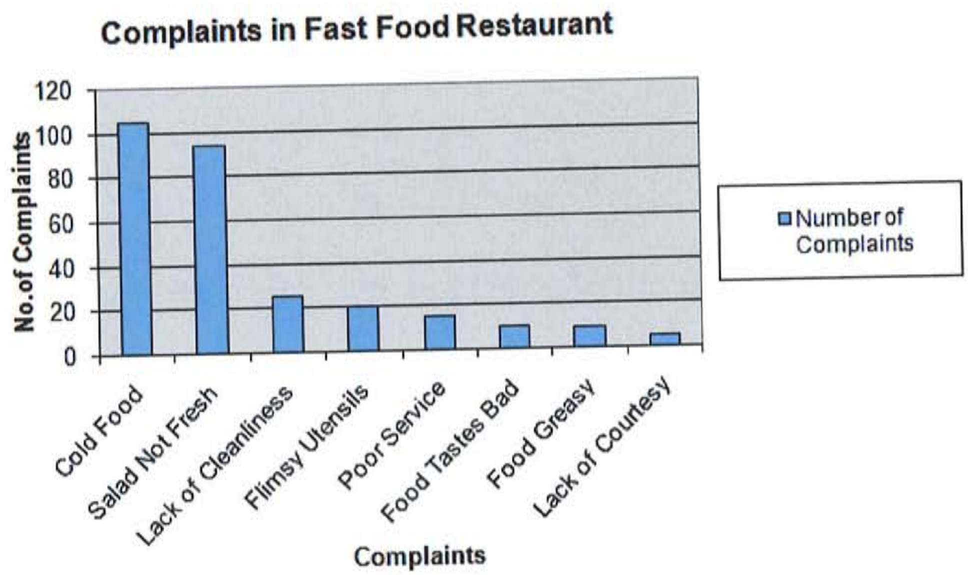

Figure 3: An Example of Pareto Chart

Cause and effect diagram. Cause and effect diagram is also known as fishbone diagram or Ishikawa diagram. It is a graphical analysis tool used to identify and classify causes of a given effect to discover its root cause (Brue & Howes, 2006). This diagram is used to document the final list of causes from the brainstorming session. Once the cause and effect diagram is constructed, the analysis would proceed to find out which of the potential causes are, in fact, contributing to the problem. An example of cause and effect diagram is shown in figure 4.

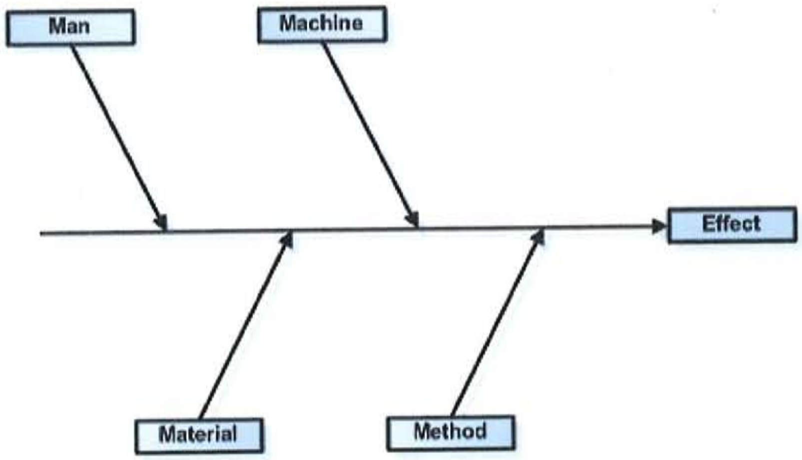

Figure 4: An Example of Cause and Effect Diagram

Control chart. Control chart is a graph used to study how the process changes over time. It is used to monitor the behavior of a process. Control chart display the process variation in real time. This allows the operator to ensure that the process is stable and continuing to operate within the process boundaries that have been established for that process (Munro et al., 2007). These process boundaries are called upper control limit (UCL) and lower control limit (LCL). If something starts to change in the process, the control chart will give the operator an early warning indicator that something needs to be changed or adjusted to bring the process back into the track.

Measurement system analysis (MSA). MSA is a statistical technique which enables the experimenter to determine the amount of variation in measurements that is due to the measuring equipment being used (Ingle & Roe, 2001). It is an area of statistical study that investigates the variation in measurement data due to calibration, stability, repeatability, reproducibility, linearity, and bias (Munro et al., 2007). Before proceeding to optimize the manufacturing process, it is crucial to analyze the ability to measure the characteristics that need to be optimized (Raisighani et al., 2005). Gage repeatability and reproducibility (GR&R) study is conducted to see how much variation is due to the measurement system itself and to verify that the measurement system being used will give the repeatable results with can be reproduced under similar conditions.

Process capability study. Process capability describes the capability or the best a process could currently be expected to work (Breyfogle III, 2003). The objective of the process capability study is to monitor whether a process is in statistical control and the process is capable of meeting customer specification (Munro et al. 2007). There are two calculations done to identify the capability of a process. These two calculations are known as Cp (capability index) and Cpk (process performance). Some examples of common values seen on manufacturing process include:

1. Cp = 2 and Cpk = 1.5 are the values given when a process has achieved Six Sigma quality.
2. Cp, Cpk >= 1.33 shows that the process is capable.
3. A Cp, Cpk value of 1.0 means that the process barely meets the specification. This will produce 0.27 percent defective units.
4. A Cp, Cpk value less than 1.0 means that the process is producing units outside engineering specifications.
5. Abnormally high Cp, Cpk (>3) shows either that the specifications is loose or identifies an opportunity to move to a less expensive process (p. 214).

Design of Experiment (DOE). Design of Experiment is a very powerful and critical tool for improving the performance of a manufacturing process. It is used to optimize the process. A prerequisite for effective DOE is measurement system analysis (Ingle & Roe, 2001). Well designed experiments require less material, time and effort and provide more powerful insights than simple change-one-at-a-time experiments. Instead of changing one process setting at a time, DOE allows the experimenter to estimate the effects of a factor at different levels of other factors. This approach provides information about the interaction of various processing factors. DOE can be used to develop a process that reduces the variability and improves capability (Osswald, Turng & Gramann, 2002).

Independent variables, also known as factors, and dependent variables, also known as responses, are the important elements of DOE. In the injection molding process, the examples of independent variables are time, temperature, and pressure. Dependent variables could be those defined by the customer (Osswald et al., 2002). Following steps show the scientific list of requirements for DOE analysis in the plastics injection molding industry as suggested by Dowlatshahi (2004):

1. Define the objective of the study.
2. Specify the response variables to be measured.
3. Develop and experimental design.
4. Run the experiment, collect and analyze the data.
5. Identify significant and non significant factors.
6. Define the optimum conditions and solutions.
7. Verify the solution (p. 447).

A full factorial design contains all possible combinations of a set of factors. In full factorial designs, experimental runs are performed at every combination of the factor levels. It is the most conservative design approach. There is little scope for ambiguity because all combinations of the factor settings are used. A factorial design is an arrangement in which all levels of each factor are combined with all levels of every other factor.

Factor: A variable or attribute that influences or is suspected of influencing the characteristic being investigated. For example, temperature, pressure, time etc.

Level: The values of a factor being examined in an experiment.

Treatment: A single level assigned to a single factor during the experimental run.

Response: The output that needs to be improved.

Injection Molding

Injection molding is the most widely used method in the manufacturing of plastics products. According to the Society of Plastics Industry (SPI), the plastics industry is the third largest manufacturing industry in the United States which represents a multibillion dollar annual business. More than one third of all plastics, by weight, are injection molded (Rosato & Rosato, 1986). Injection molding process is one of the most economical methods and is used for manufacturing a variety of parts, from the simplest component to the complex shapes that require precise dimensions (Osswald et al., 2002).

A schematic of an injection molding machine is shown in figure 5. In the injection molding process, plastic resins are fed through the hopper into the barrel. Plastic is melted under high temperature inside the barrel using heater bands and by mechanical shear between barrel and rotating screw. The rotating screw moves back as plastic moves forward to form a shot. As soon as there is enough supply of melt for one shot, the screw stops rotating and moves forward to pump the melt into a colder mold cavity under pressure through the gate. In the cavity, the plastic melt cools and solidifies to take the shape of the mold cavity. The mold opens up and ejector pins move forward to eject the part from the mold (Rosato & Rosato, 1986).

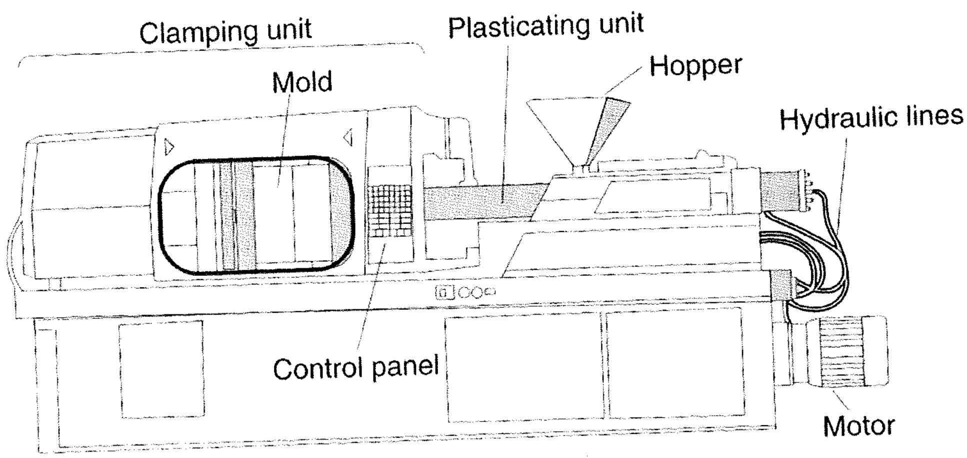

Figure 5. Schematic of an Injection Molding Machine

Source: Osswald et al., 2002, p. 8

Machine, mold and material are three important elements in the injection molding process (Johannaber, 1994). The most important component of the injection molding machine is the mold. The mold distributes plastics melt into and throughout the cavities, shapes the part, cools the melt, and ejects the finished product (Osswald et al., 2002). Generally, the mold consists of two halves, the core and the cavity. The hollow portion of the cavity space is called cavity. The matching, often raised or convex portion is called the core (Rees, 2001). The mold may consist of a single cavity or a number of similar or dissimilar cavities, each connected to flow channels that direct the flow of the melted plastic to the individual cavities.

The sequence of events during the injection molding of a plastic part, as shown in figure 6, is called the injection molding cycle. The injection molding cycle consists of the following stages: plasticizing, injection, cooling, and ejection.

Plasticizing. It is a conversion of the plastics resin from its normal, hard granular form, to the liquid form necessary for injection at its appropriate melt temperature.

Injection. It is the stage during which the melted plastic is forced, under pressure, into a mold to completely fill a cavity.

Cooling. It is the process in which heat is removed from the melt to convert it from a liquid state back to its original rigid state.

Ejection. It is the removal of the solidified molded part from the mold cavity. Ejector pins are used to eject the part from the mold.

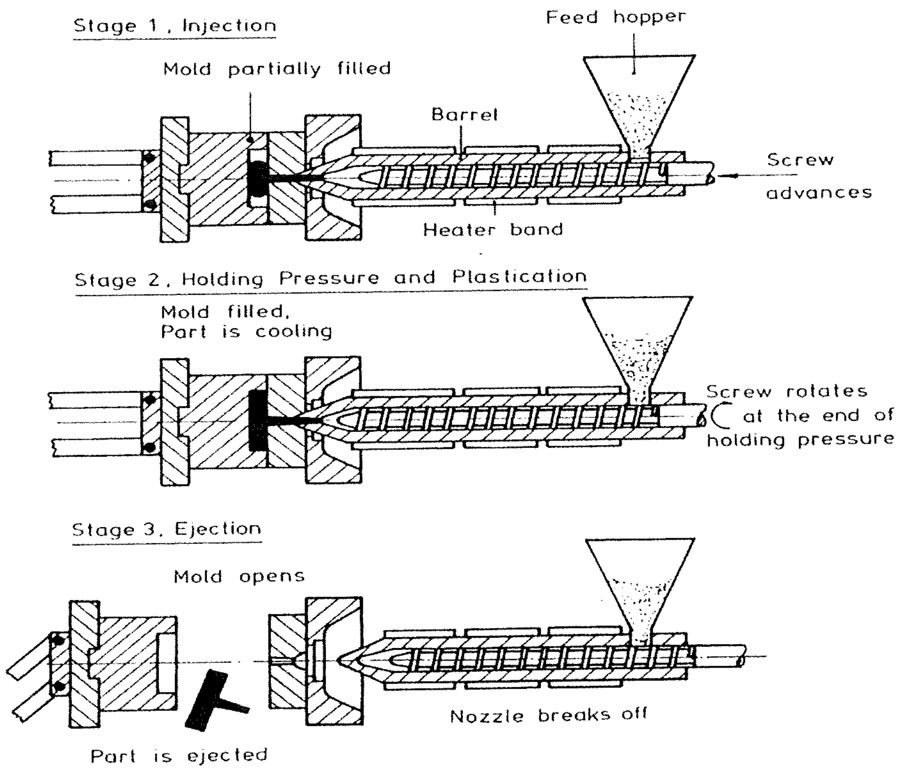

Figure 6. The Three Stages of Injection Molding: Injection, Plastication, Ejection

Source: Johannaber, 1994, p. 9

Injection Molding Process Parameters

Injection molding machines have many adjustable parameters that affect the quality of finished plastic products. Products quality is directly correlated with these process variables and will affect the functional, dimensional, and aesthetic requirements of the product (Johannaber, 1994). Time, temperature, pressure and injection speed are the four critical variables in this process. Cavity pressure, plastic temperature, plastic flow rate, cooling rate, and mold temperature are primary factors that affect part characteristics (Osswald et al., 2002).

The temperature of the cavity wall or the mold temperature is of major importance for part quality, economy of the process, exact dimensions, and accurate duplication (Johannaber, 1994). It is the temperature which determines the cooling time. Hold pressure is another important process parameter. The magnitude and duration of the hold pressure are of major importance for dimensional accuracy and cosmetic quality of a part. Once the cavity is filled, a hold pressure is maintained to compensate for material shrinkage.

Defects in Injection Molded Plastic Product

There are different types of defects found in injection molded plastic parts. These defects result in bad quality of plastic products. Some of the defects in injection molded plastic parts are discussed below:

Contamination. Contamination in an injection molded parts is large areas of discoloration from foreign matter or foreign material embedded in the surface of a part. Some of the causes of contamination are particles on the tool surface, contaminated material or foreign debris in the barrel, and too much shear heat burning the material prior to injection.

Gate Blush. It is the dullness on the surface, often seen as rings or half circles near the gate area caused by the plastic flow during molding.

Flash. Flash is an excess plastic at parting line or mating surface of the mold. Flash are normally very thin and flat projection of plastic along an edge of a part. Sometimes it appears as a very thin string or thread of plastic away from the edge of a part known as string flash. Possible causes of flash are tool damage, parting line mismatch, dirt and contaminants around tooling surfaces, too much injection speed, and too low clamping force.

Scratch. Scratches are any surface imperfection due to abrasion that removes small amount of material. Depth of scratch is not measurable.

Shorts. Shorts, also known as short shots, are missing plastic due to incomplete filling of the mold cavity. Parts are not completely formed. It can usually be identified by smooth, shiny and rounded surfaces. Low injection rate, low injection pressure, barrel worn or broken, trapped gas are some of the possible causes of shorts.

Splay. Splay is off colored streaking usually appears silver-like. It is usually caused by moisture in the material, unmelt, dirt, cold slug, thermal degradation of the resin during processing etc.

Warp. Warp or warpage is dimensional distortions in a part. It is a result of retained compressive, tensile, orientation and or crystalline stresses (Osswald et al., 2002). Warpage causes a part to bend or twist out of shape and alters dimensions as well as the contours and angles of the part. Some of the possible causes of warpage are dissimilar wall sections, gating in a thin section of a part, too short cooling, material too hot, incorrect water temperatures etc. Asymmetric cooling across the part thickness from the cavity and core is one of the most common causes of warpage. If the temperature on both half of the tool is not uniform, the parts bow inwards towards the hot side of the tool. Examples of warpage are shown in figure 7a and 7b below.

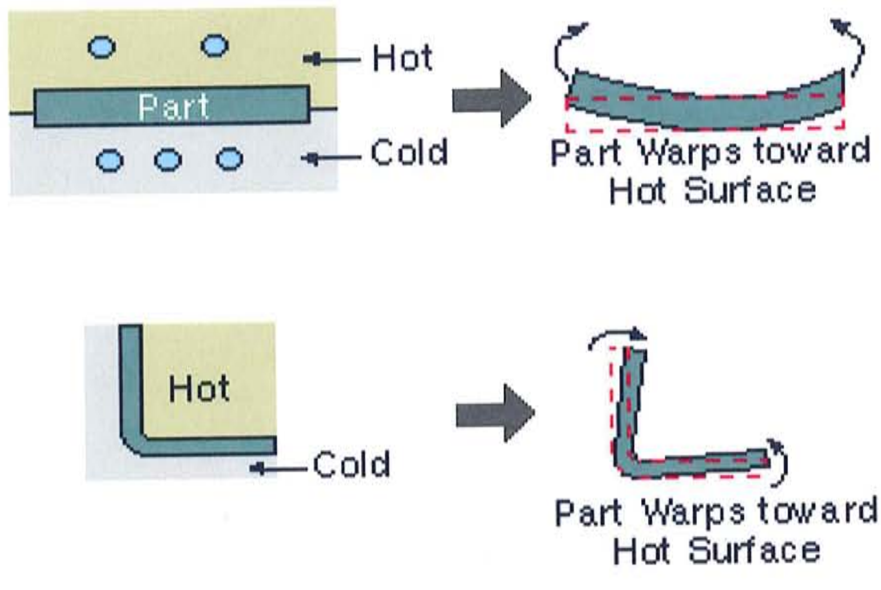

Figure 7a. The Effect of Mold Temperature over Warpage

Source: "Warpage," 2008.

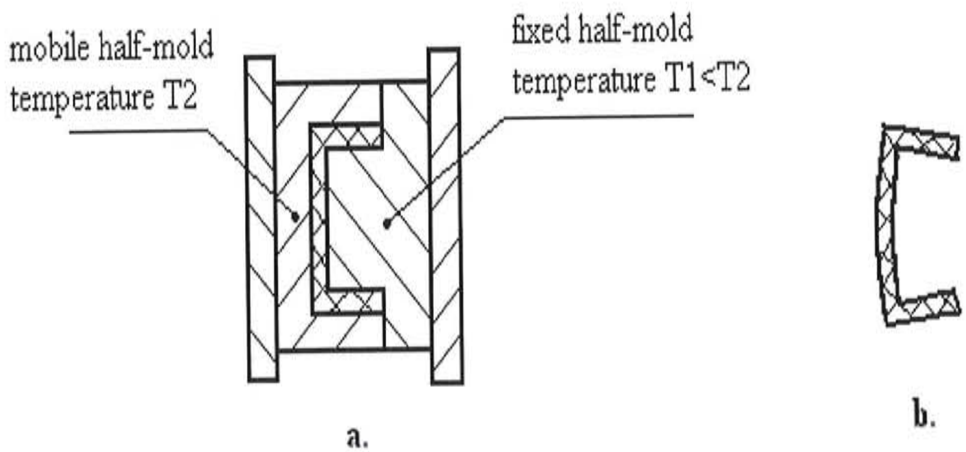

Figure 7a. The Influence of Mold Temperature over Warpage.

a. Closed mold b. Warped part

Source: Chira & Mihaila, 2005, p.291

Chapter III: Methodology

The objective of this study is to research commonly used Six Sigma tools and techniques, research and understand injection molding process, research the quality related problems in injection molded 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 a injection molded plastics product. 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. Subsequently, Six Sigma DMAIC methodology will be implemented in order to reduce or eliminate the defect and increase the quality of the product.

Subject Selection and Description

A case study from XYZ Company has been used in this research paper to explain how Six Sigma and its tools can be used in a manufacturing process in order to improve quality of a product. XYZ Company recently received customer complaints for the warp found in one of its injection molded plastic parts. The part was a flat rectangular shaped plate which was a sub-component of an assembled product. Flatness of this part was crucial to the customer because twisted or distorted part would not fit with its parent assembly properly. The customer was sending the parts with warp back to the company because of non-conformance. The warp in the product increased the customer's dissatisfaction and XYZ Company's bottom line was impacted by this.

Instrumentation

A Six Sigma DMAIC methodology will be used in this research paper in order to reduce the defective products due to warp and improve the quality of a plastic product.

Define. In the define phase, a problem which causes decreased customer satisfaction will be identified. A team will be formed to brainstorm the causes of the problem and to create a cause and effect diagram to illustrate the various causes affecting the customer satisfaction.

Measure. Data will be collected from the process to measure the defects. Response variable will be determined to measure the defects. Gage R&R study will be conducted on measurement system to make sure that the measurement system is adequate to measure the response variable. Further, process capability study will be performed on the current process to determine whether the process is capable of producing the parts within customer specification.

Analyze. The collected data and the process will be studied using different statistical tools to identify the possible root cause of the problem.

Improve. The solution to the root causes that was identified in the analysis phase will be developed. A designed experiment will be conducted to optimize the process.

Control. The process will be monitored in order to sustain the gains.

Data Collection Procedures

Data were collected from quality and production departments. The data were gathered from IQMS (ERP software) system for two months in order to find the defects and to sort out the defect that is causing higher scrap. Also, data were collected from the injection molding process.

Data Analysis

The collected data were analyzed using Minitab version 15. Six Sigma DMAIC methodology was used to define and determine the root cause of the problem. Tools such as cause and effect diagram, brainstorming, Pareto diagram, process capability study, and DOE were used to analyze the data.

Limitations

1. The XYZ company has not made corporate-wise decision to implement Six Sigma methodology in each and every process. The DMAIC methodology will be used in this specific case-study only.
2. Not all employees and participants of this project are formally trained on Six Sigma methodology.
3. No formal titles such as sponsor, champion, stakeholder etc will be defined to implement Six Sigma DMAIC methodology for this case-study. The inputs and suggestions of manufacturing engineer, process engineer, sample tech, production supervisor and quality manager will be taken to implement this case-study.

Summary

A Six Sigma DMAIC methodology will be used in this research paper to analyze and to reduce the quality defect in an injection molded plastic product. A XYZ company that has received a customer complaint because of quality defects on one of its product will be chosen for a case study. Data will be collected from IQMS (ERP software) and injection molding process. Various statistical tools will be used to analyze the data. The result and discussion of the case study are explained in next chapter.

Chapter IV: Results

The purpose of this chapter is to study and analyze the warpage defect using Six Sigma approach. Each of the steps of DMAIC methodology is discussed below in detail.

Define

The lots of product rejected by the customer in past two month's period was studied. The results of investigations on the types of defects on the plastic part that contributed to the customer rejection or complaints are shown in table 2.

Table 2

Part Shipped versus Rejected by Customer due to Defects in the Month of January and February

Description	January	February
Total Quantity Shipped	280,000	310,000
Rejected due to warpage	37,000	35,000
Rejected due to contamination	4,500	6,650
Rejected due to scratches	3,900	3,560
Rejected due to splay	3,200	2,690
Rejected due to gate blush	2,600	1,700

Pareto charts plotted based upon the above data are shown in Figure 8 and 9 below. Both Pareto charts of January and February of 2009 revealed that warpage or the distortion of the part was the number one defect. The data of both months showed that the warpage only was responsible for above 70% of the rejection. The defects due to contamination, scratches and splay were considered to be minor. Therefore it becomes obvious that focus should first be given to the warpage defect.

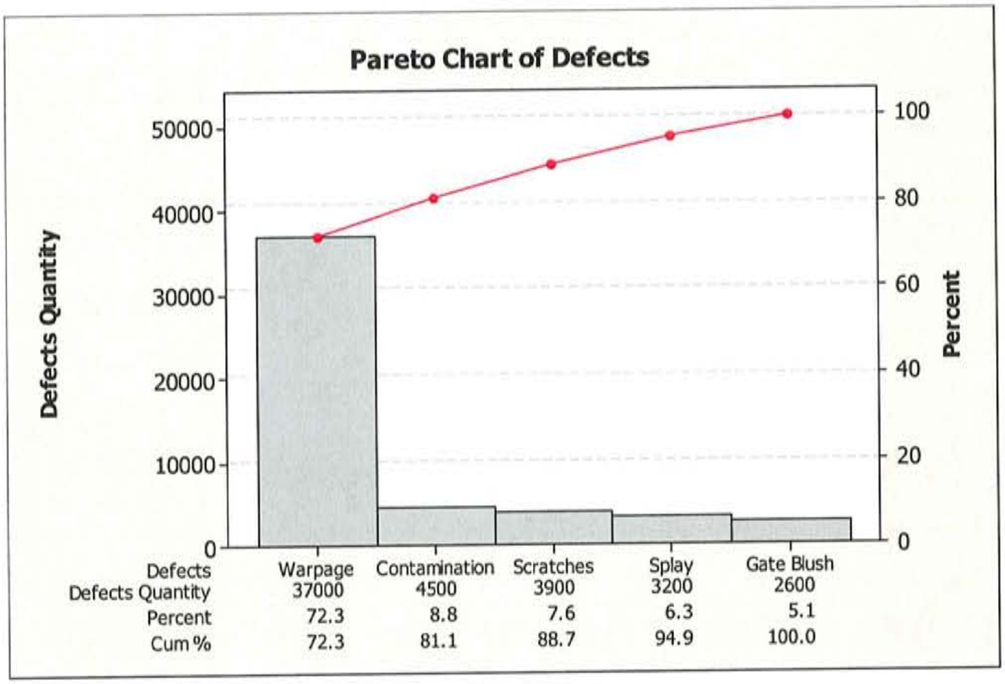

Figure 8: Customer Rejects during Month of January 2009

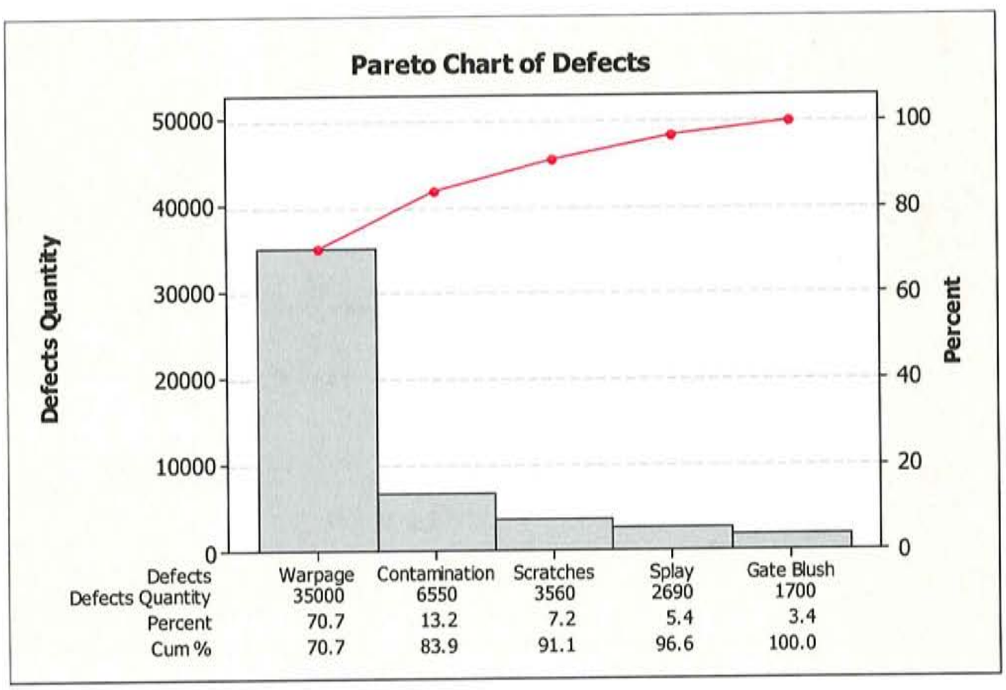

Figure 9: Customer Rejects during Month of February 2009

Measure

The flatness of the part was determined as a response variable. Flatness is the best factor to measure the warpage in the part or in other words the part will be considered to be warped if it is not perfectly flat. As per customer's specification, the part with flatness between 0.000 and 0.020 inches was not considered as warped or distorted part. Coordinate Measuring Machine (CMM) was programmed and used as a gauge to measure the flatness of the part.

Measurement System Analysis was conducted of the CMM to ensure its adequacy to measure the flatness of the part. For the study, ten random samples were selected from the manufacturing process. Two operators were chosen to participate in the study. Each part was measured two times by each operator. The output of the GR&R study is shown in figure 10.

Gage R&R Study - ANOVA

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000000	0.30
Repeatability	0.0000000	0.30
Reproducibility	0.0000000	0.00
Operators	0.0000000	0.00
Part-To-Part	0.0000001	99.70
Total Variation	0.0000001	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0.0000158	0.0000949	5.47
Repeatability	0.0000158	0.0000949	5.47
Reproducibility	0.0000000	0.0000000	0.00
Operators	0.0000000	0.0000000	0.00
Part-To-Part	0.0002884	0.0017303	99.85
Total Variation	0.0002888	0.0017329	100.00

Figure 10: Result of GR&R Study of CMM using MINITAB

The result indicates that the CMM program was an acceptable measurement method to accurately measure the flatness of the part, because less than 10% of the total measured variance is from repeatability and reproducibility of the gage.

Next, it was important to find out whether the flatness of the parts coming out of current process was within the customer's specification or not. The process capability study was performed in order to determine whether the current process has the capability to meet established customer specifications. In order to find out whether the process was capable or not, samples from the process were collected and the flatness of the part was studied. Thirty pieces were pulled from the current process in a definite interval for this study. The result of the study is shown in figure 11.

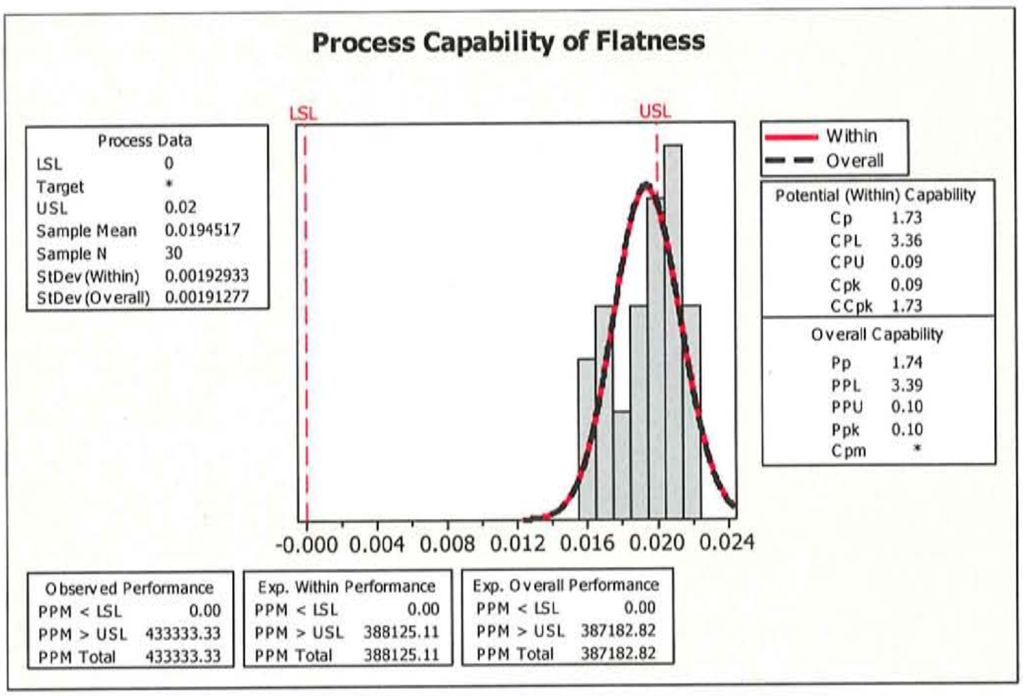

Figure 11: Process Capability Study of Flatness of the Rectangular Part of XYZ Company.

The result showed that the current process was operating at higher end and above the upper specification limit. The Cpk value of 0.09 revealed that the current process is not centered towards the mean and was not capable of producing the part well within the customer specification.

Analyze

The investigation of manufacturing process problem required the understanding of different process parameters that influenced quality of the part (Lin & Chananda, 2003). To better understand the injection molding process, various process parameters and their effect on quality of the molded parts, the researcher went through two days of injection molding certification training program in the company.

Then a team was formed to investigate and solve the warpage defect in the part. The team was comprised of a process engineer, a quality engineer, a sample technician, and the researcher. The team went through a brainstorming session to identify the most likely sources of the warpage defect. The outcome was summarized in a cause-and-effect diagram in figure 12. The root cause for warpage defect was classified into six major categories, which are man, material, mold, product design, process, and machine.

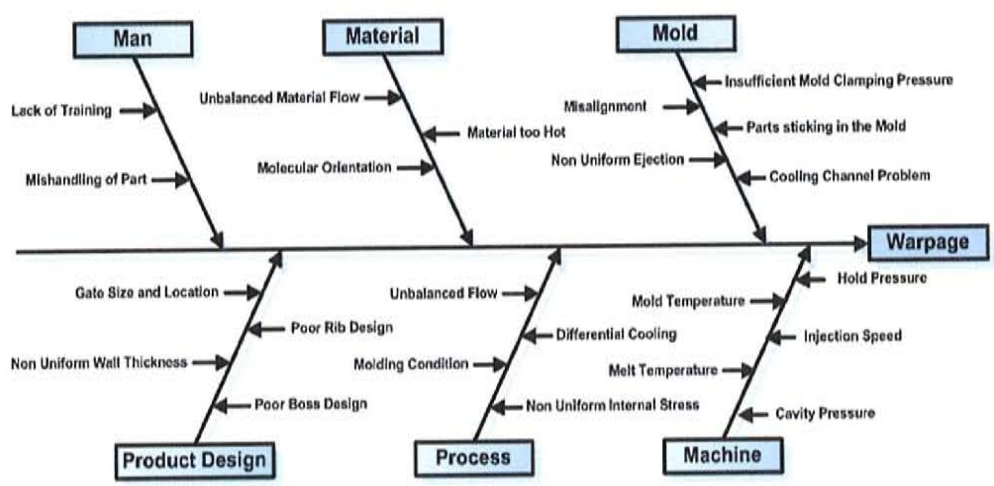

Figure 12: Cause-and-Effect Diagram for Warpage

For the man category, the problem could be due to operator's lack of experience and practice. Defect might occur when job is carried out without following work instructions or methods. The number of defects could increase due to improper handling of the part after ejection from the mold.

From the material side, imbalanced material flow could cause the warpage. This may result in solidifying of melted plastics non-uniformly where the molecules could be left to shrink at different rates and warpage could occur. When a material is contaminated with other foreign materials, it will affect the properties of the part and could lead to the warped part.

Injection molding machine itself could contribute to the warpage defect.

Mold is one of the major causes of the problem. Part could be warped if ejection of the part is not uniform. Misalignment of the mold in the machine could cause parts to stick in the mold which could cause warping of the part. Besides this, if the cooling channel has problem, parts could not be cooled uniformly resulting in warped part.

Warpage is greatly influenced by wall thickness, design of ribs and bosses. Gate size and its location could also cause the warpage.

The difference of temperature between the fixed half-mold and the mobile half-mold could produce warpage.

Improve

Part redesign and mold reconstruction were not considered to be cost effective in the initial phase. Hence, it was decided to work on process parameters to deal with the warpage defect. DOE was chosen as an improvement tool to reduce the warpage problem by finding optimum process parameter settings. It was used to determine the most influential process parameters and/or their interaction(s) which cause parts to be warped. Steps taken to complete the DOE are discussed below.

Step 1: Define the goal/objective of the experiment

The goal of the experiment was to determine the most significant factors affecting the quality of the product and subsequently reducing or eliminating the warpage defect.

Step 2: Specify the input parameters and output response to be measured.

Based on the suggestion from process engineer, literature reviews, and other experienced sample technicians, it was decided to select mold temperature of core (A half), mold temperature of cavity (B half), and hold pressure as input variables. The flatness of the part was determined to be the output response. The range of part with flatness between 0.000 and 0.020 inches does not considered as warped or distorted part.

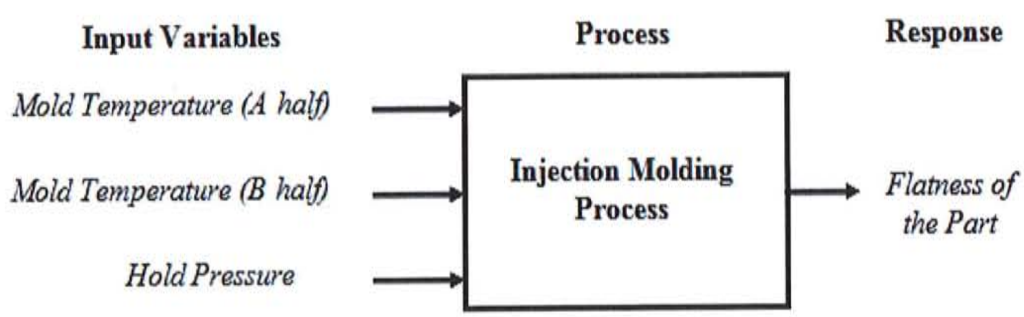

Figure 13: Process Diagram for Full Factorial Design of Warpage

Before conducting the experiment, several (dry) cycles were run to determine the best working range for input parameters. Table 3 shows the test range for the input parameter setting in the injection molded process. Based on the test runs, the following levels for each factor were selected (See Table 4).

Table 3

Test Range for Input Parameters Setting

Factors	Test Range (Min / Max)
Mold Temperature (A half)	115 – 165°F
Mold Temperature (B half)	115 – 165°F
Hold Pressure	290 – 720 psi

Table 4

Factors and Corresponding Level of Input Parameters

Factors	Low Level	High Level
Mold Temperature (A half)	120°F	160°F
Mold Temperature (B half)	120°F	160°F
Hold Pressure	300 psi	700 psi

Step 5: Develop and run the experiment

The choice of experimental design has an impact on the success of an industrial experiment because it depends on various factors such as the nature of the problem, the number of factors to be studied, resources available for the experiment, time needed to complete the experiment and the resolution of the design (Antony, n.d.). Considering time, resources, and cost that will be involved in the experiment, simple three factors, two- level full factorial design was used for the experiment (See figure 14).

Full Factorial Design

```
Factors:  3   Base Design:         3, 8
Runs:     8   Replicates:             1
Blocks:   1   Center pts (total):     0

All terms are free from aliasing.

Design Table (randomized)

Run  A  B  C
  1  -  -  +
  2  +  +  -
  3  +  -  -
  4  -  +  +
  5  -  +  -
  6  +  -  +
  7  +  +  +
  8  -  -  -
```

Figure 14: Full Factorial Experimental Design from Minitab

Experimental design matrix was constructed, so that, when the experiment was conducted, the response values could be recorded on the matrix. Figure 15 shows the experimental design matrix and the recorded output response values of flatness.

StdOrder	RunOrder	CenterPt	Blocks	MoldTemp A	Mold Temp B	Hold Pressure	Flatness
5	1	1	1	120	120	700	0.02335
4	2	1	1	160	160	300	-0.01690
2	3	1	1	160	120	300	0.01475
7	4	1	1	120	160	700	-0.01115
3	5	1	1	120	160	300	-0.01615
6	6	1	1	160	120	700	0.04215
8	7	1	1	160	160	700	-0.00575
1	8	1	1	120	120	300	0.00720

Figure 15: Design Matrix with Flatness Value Obtained from Minitab

For this experiment, several cycles were run to stabilize the machine at each setting. Once the machine was stabilized, ten consecutive parts were pulled for measurement. Since this was an experiment with multiple measurements, the response variable used for the analysis was the average of the flatness measurements.

Step 6: Collect and analyze the experimental data

The experimental data was analyzed using MINITAB Version 15. Figure 16 shows the result of the analysis. The P value from this analysis indicates that mold temperature of B half has a high degree of statistical significance and the other factors are not significant. Factor whose P value is less than the alpha ($\alpha = 0.05$) value is considered to be statistically significant.

Factorial Fit: Flatness versus MoldTemp A, Mold Temp B, Hold Pressure

Estimated Effects and Coefficients for Flatness (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		0.00469	0.000637	7.35	0.086
MoldTemp A	0.00775	0.00387	0.000637	6.08	0.104
Mold Temp B	-0.03435	-0.01717	0.000637	-26.94	0.024
Hold Pressure	0.01493	0.00746	0.000637	11.71	0.054
MoldTemp A*Mold Temp B	-0.00543	-0.00271	0.000637	-4.25	0.147
MoldTemp A*Hold Pressure	0.00435	0.00217	0.000637	3.41	0.182
Mold Temp B*Hold Pressure	-0.00685	-0.00343	0.000637	-5.37	0.117

Figure 16: Minitab Result of the Analysis

Step 5: Identify significant and non significant factors.

Probability plot of the effect is shown in figure 17. By examining the plot, it can be concluded that the important effects from the analysis is the main effect of Mold Temperature of B half.

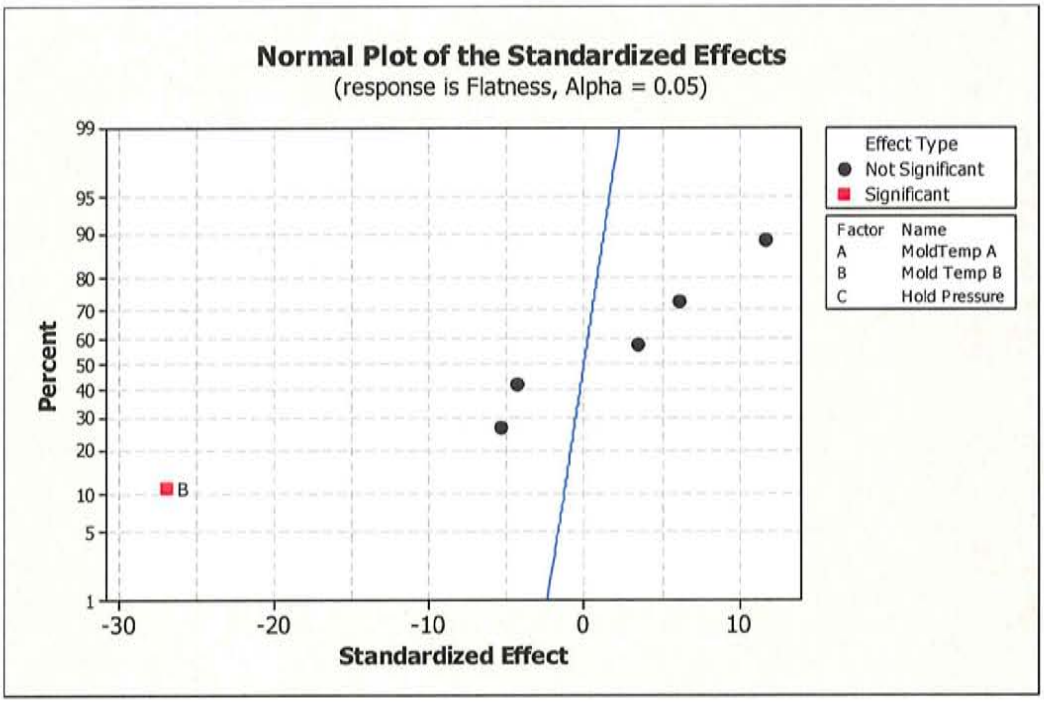

Figure 17: Normal Probability Plot of the Effects

The Pareto chart is shown in figure 18, with an alpha (α) = 0.05 decision line. When the magnitude of an effect is beyond this line, the factor is considered to be statistically significant (Breyfogle III, 2003). From this chart it is seen that mold temperature of B half has greatest effect on the flatness of the part.

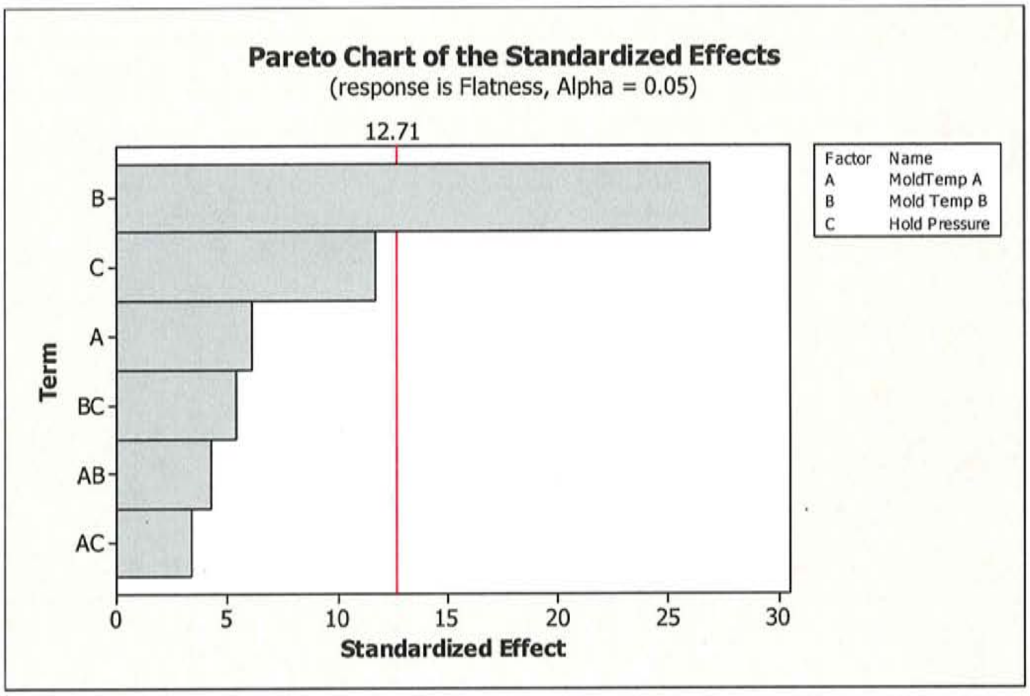

Figure 18: Pareto Chart of the Effects

The main effects Mold temperature A half (Core), Mold temperature B half (Cavity), and Hold Pressure are plotted in figure 19. This plot shows that low mold temperature of both halves and low hold pressure would produce more flat part, which means parts with minimum warpage.

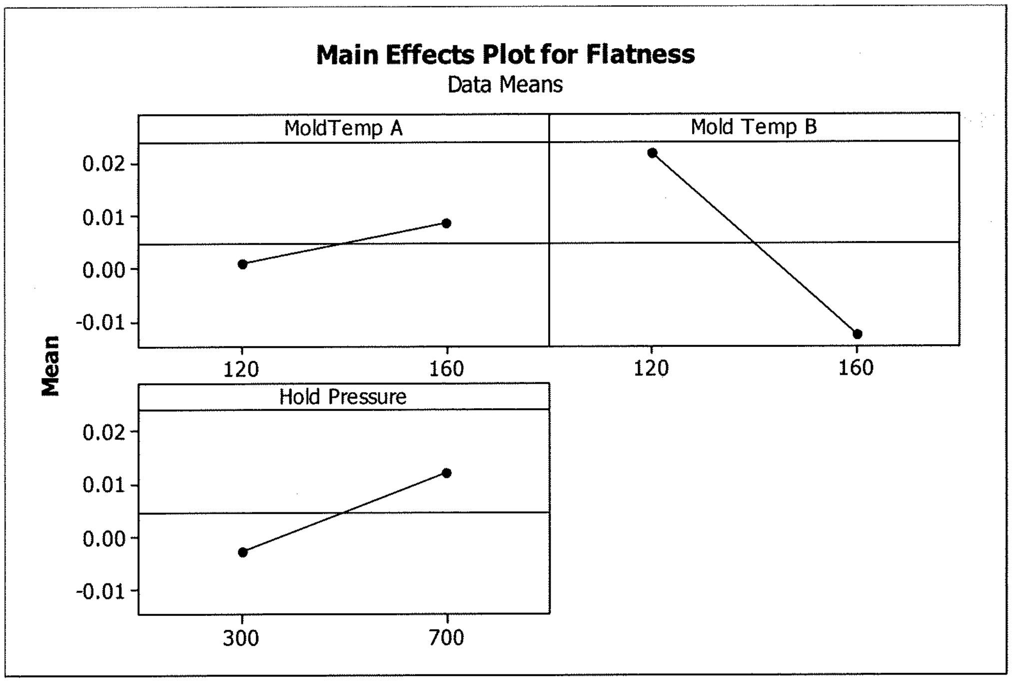

Figure 19: Main Effects Plot for Average Flatness

Step 6: Define the optimum conditions and solutions.

Based on the analysis, the production run should set the mold temperature of A half and the B at low level (120°F), and hold pressure at low level (300 psi) in order to reduce the warpage in the part.

Step 7: Verification of the solution

Before switching the entire manufacturing operation to the above determined settings and producing a high volume of parts, it was necessary to run some verification runs. Verification runs are required to check the reproducibility and predictability of the result. For this experiment, twenty consecutive samples parts were pulled after the machine was stabilized at determined settings and flatness of the parts were measured. The flatness measured of those twenty samples is tabulated in table 5. Table 6 shows the process parameters setting and the average flatness of twenty sample parts.

Table 5

Flatness of Twenty Samples Pulled from Verification Run

Sample	Flatness (Inches)
1	0.0076
2	0.0071
3	0.0079
4	0.0085
5	0.0089
6	0.0069
7	0.0095
8	0.0080
9	0.0091
10	0.0113
11	0.0088
12	0.0075
13	0.0101
14	0.0077
15	0.0067
16	0.0085
17	0.0073
18	0.0071
19	0.0070
20	0.0110

Table 6

Process Parameters Setting and Average Flatness of the Part Measured for Verification Run

Setting	Mold Temperature (A half)	Mold Temperature (B half)	Hold Pressure	Average Flatness
1	120°F	120°F	300 psi	0.0083 inches

The result showed that parts with minimum warpage could be produced when the mold temperature of A half and B half is set to 120°F, and hold pressure is set to 300 psi. The average flatness of the part at those settings was 0.0083 inches which was well within the customer specification between 0.000 to 0.020 inches.

Control

Control must be implemented to ensure that over time the optimum setting determined does not get lost. Following steps were taken to sustain the gain obtained:

- Master cycle sheet will be maintained so that parameter settings will be in place.
- In-process inspection will be performed to measure the flatness of the part to make sure part is not warped.
- Control chart will be plotted of the flatness data to monitor the improved process.

Chapter Summary

A warpage problem in one of its flat product of XYZ company was studied and Six Sigma DMAIC methodology was used to improve the quality of the injection molded part. Tools such as Cause-and-Effect diagram, Pareto Diagram, Measurement System Analysis (GR&R), and Design of Experiment (DOE) were used in order to reduce the warpage defect. Pareto chart was used to identify, organize, and prioritize the defects found in the part from highest to lowest order. GR&R study was performed to verify that a sound measurement system exists and gives consistent result each time. Cause-and Effect diagram helped on finding the causes of the warpage defect. Although there were several causes for warpage, it was decided to first deal with process parameters to overcome the warpage defect. A simple yet very powerful two-level full factorial experimental design was used to identify the most influential process parameters that impact the injection molding process and the quality of the part. The verification runs showed that the warpage defect could be reduced under properly controlled environment. Hence, the combination of Six Sigma DMAIC methodology and the knowledge of injection molding process can be used to solve defects in injection molding process and improve the quality of plastics products.

Chapter V: Discussion

A mid-size XYZ plastics injection molding company received a quality complaint in one of its product from the customer. The company was required to improve the quality of the product for its customer satisfaction.

The purpose of this research is to study quality related problems in injection molded plastics products and to improve quality of the product using Six Sigma DMAIC methodology. The objectives of this study are to:

1. Research and understand injection molding process.
2. Research and identify quality problems in a mid-size plastics company.
3. Identify commonly used Six Sigma tools and techniques.
4. Solve the quality related problem and increase quality of the product using Six Sigma DMAIC methodology.

In order to show that Six Sigma DMAIC methodology can be used to improve the quality of an injection molded plastic product, a mid size plastic injection molding company in western Wisconsin was chosen. The injection molding process and defects in injection molded plastics products were studied. A customer complaint in one of a flat product was chosen as a case study. The majority of the rejection was due to the warpage defect. The data collected was utilized to conduct root cause analysis of the problem and several statistical tools were used to study the data. The Six Sigma DMAIC (Define, Measure, Analyze, Improve and Control) methodology was used to identify and reduce the warpage defect and to improve the quality of the plastic part. DOE was conducted in order to find the optimum setting of the injection molding process parameters and this resulted in improved quality of the product. Twenty parts pulled out from the verification run with the optimum setting showed that all of the parts were within the flatness specification of 0.000 to 0.020 inches.

Major Findings

1. Six Sigma DMAIC methodology can be used to improve a quality of an injection molded plastic product.
2. Six Sigma tools such as Pareto chart, cause and effect diagram, measurement system analysis, process capability study, design of experiment are very useful on improving the quality of injection molded plastics product.
3. Design of Experiment is a very useful tool to find the optimum setting of an injection molding machine parameters to reduce warpage defect on plastic product.
4. The combination of Six Sigma DMAIC methodology and knowledge of injection molding process can be used to solve defects in injection molding process.

Limitations

1. The result of the study is limited to XYZ company.
2. The research is limited to only one product manufactured in XYZ company.
3. Only warpage defect on the plastic part was studied.
4. The analysis and results are based upon the researcher's knowledge and experience.

Conclusions

Six Sigma DMAIC methodology can be used to improve the quality of the product in plastics industry. 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 definitely helps the organizations to achieve sustainable growth.

Recommendations Related to the Case Study

The XYZ company is recommended to prepare a cycle sheet of the molding process parameters obtained from DOE. The cycle technicians are recommended to set the process parameter as per the cycle sheet so as to obtain the flatness of the part within customer specification. This will result in minimum warped parts.

The XYZ company was visually inspecting the part for the warpage and shipping it to the customer. It is recommended that the flatness of the part be inspected using CMM program during their in-process inspection. This will reduce the chances of shipping bad parts to the customer that will result in reduced customer complaints.

Recommendations for Future Study

Six Sigma DMAIC methodology can also be used to solve other types of molding defects besides warpage. It is recommended to use the DMAIC methodology and Six Sigma tools for quality improvement in not just injection molding companies but in other types of manufacturing and service industries as well.

Six Sigma combined with lean manufacturing, continuous improvement, total quality management methods can be used in different industries to improve quality of products and services and reduce the cost with improved customer satisfaction.

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