CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

Implementation of Six Sigma in the sand casting foundry to improve the customer satisfaction includes product quality and timely delivery of the product. Green sand casting process, in general, involves a large number of parameters affecting the various casting quality features of the product. Some of the parameters are controllable while some are uncontrollable. Generally, the molding procedures of sand casting processes are the same even though the materials used in the processes are different. A large number of experimental investigations for the effect of green sand casting parameters with casting quality have been carried out by the researchers and foundry engineers over the past few decades. The purpose of the process development is to improve the performance characteristics of the process related to customer needs and expectations. The process development can be achieved through experimentation and the aim is to reduce and control variation of a process. Subsequently, decisions must be made concerning which parameter affects the performance of the process. The loss function quantifies the design factor which influences the average and variation of performance of the process. By properly adjusting the factors, the variations of the process are reduced thereby the losses can be minimized. Several new statistical tools and concepts of quality improvement depend heavily on the statistical theory of experimental design. Implementation of Six Sigma DMAIC methodology emphasizes an intelligent blending of the wisdom of an
organization, with proven statistical tools, to improve both the efficiency and
effectiveness of the organization for the whole-hearted satisfaction of the
customer and profitability by improving the quality of products and services.
The success of Six Sigma program hinges on the sequence of many Six Sigma
elements of a model for implementation and aims at reducing the defect levels
in products and processes to a level of less than 3.4 defects per million
processes, product or service opportunities (DPMO). The human side of Six
Sigma implementation is an important area because it contributes to the
science and practice of the implementation to reduce the waste and create
value. The empirical study of job satisfaction upon implementing Six Sigma
determines the satisfaction level of employee’s commitment. Analysis of
various critical process parameters and the interactions among them is carried
out with the help of Taguchi’s method of experimental design. Further, to
improve the results obtained and make the analysis more precise and cost
effective, RSM is also incorporated. Eventually, the optimized parameters
obtained using Taguchi method and RSM, are tested in a foundry to validate
the recommended method and its process parameters with help of process
window approach based on theory of inventive problem solving. When a
company is deeply committed to changing its functions and improving its
processes, employees willingly go along and give their best effort. The
customers are increasingly emphasizing flawless delivery, that is, very short-
cycle, on-time delivery, and responsiveness to the customer’s changing needs.
In today’s highly competitive business environment, only innovative product
manufacturers can provide customized and innovative products and in the
process, they also achieve innovative performance dimensions. The present
study aims at implementing the DMAIC based Six Sigma approach in order to
reduce the incidence of defects to achieve product quality, increase the sigma
level of the sand casting process, on-time delivery and customer satisfaction
at the least cost. Job satisfaction, base stock level inventory system and
overall equipment efficiency are also determined and analyzed.
1.2 IMPLEMENTATION OF SIX SIGMA – AIM AND PURPOSE WITH OBJECTIVE

Six Sigma is a quality improvement program that aims to reduce the number of defects to as low as 3.4 parts per million. It uses the normal distribution and strong relationship between product nonconformities, or defects, and product yield, reliability, cycle time, inventory, schedule, etc. Six Sigma emphasizes an intelligent blending of the wisdom of an organization with proven statistical tools to improve both the efficiency and effectiveness of the organization when it comes to meeting customer needs. The ultimate goal is not simply improvement for improvement’s sake, but rather the creation of economic wealth for the customer and provider alike. This does not imply that Six Sigma replaces existing and ongoing quality initiatives in an organization rather that senior management focuses on those processes identified as critical-to-quality in the eyes of customers. Creating a successful Six Sigma infrastructure is an ongoing process whose aim is to infuse an awareness of quality into the way all employees approach their everyday work. However, implementation of strategies like Six Sigma may demand an investment, dedication of the best resources, training to employees, etc. which many companies may not be able to afford. Yet, there still exists a need for the industrial sector to look for this breakthrough business improvement strategy for survival and growth. In the present study, an investigation on Six Sigma DMAIC methodology implementation in sand casting process foundry is reported. Earlier studies are focused on implementation of Six Sigma with considering human and technical factors separately without covering of inventory system and PWA based TRIZ concepts in the sand casting process, whereas the present study objective is focusing on implementing Six Sigma DMAIC methodology for sand casting process management with considering human and technical factors jointly including the importance of optimal inventory system and PWA based TRIZ concepts to improve customer
satisfaction. In this work, the effectiveness of the Six Sigma implementation is also evaluated by OEE measure.

1.3 TWO PERSPECTIVES OF SIX SIGMA

1.3.1 Statistical Viewpoint

Six Sigma has two major perspectives. The origin of Six Sigma comes from statistics and statisticians. Montgomery (2001) has discussed the Six Sigma method from a statistical, probabilistic, and quantitative point of view. From the statistical point of view, the term Six Sigma is defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997% in which sigma is a term used to represent the variation about the process average (Antony and Banuelas 2002). If an organization is operating at three sigma levels for quality control, this is interpreted as achieving a success rate of 93% or 66,800 defects per million opportunities. Therefore, the Six Sigma method is a very rigorous quality control concept where many organizations still performs at three sigma level as reported by McClusky (2000).

1.3.2 Business Viewpoint

In the business world, Six Sigma is defined as a ‘business strategy used to improve business profitability, to improve the effectiveness and efficiency of all operations to meet or exceed customer’s needs and expectations’ (Antony and Banuelas 2002). The Six Sigma approach is first applied in manufacturing operations and rapidly expanded to different functional areas such as marketing, engineering, purchasing, servicing, and administrative support, once organizations realized the benefits. Particularly, the widespread applications of Six Sigma are possible due to the fact that organizations are able to articulate the benefits of Six Sigma presented in financial returns by linking process improvement with cost savings.
1.4 DEFINING SIX SIGMA

Based on different perceptions of the Six Sigma approach nature, the business management approach is proposed and it is defined as:

The Six Sigma is a managerial approach, directed towards the improvement of all types of processes within a business - by their control and improvement on all levels, by losses reduction, by decreasing of invested resources, and by increasing customer’s satisfaction - leading to a level of organization and management guaranteeing the achievement of the main objective of the company.

1.5 PROCESS IMPROVEMENT

The purpose of process improvement is to eliminate the root causes of performance deficiencies in processes that already exist in the organization. These performance deficiencies may be causing real problems for the organization, or may be preventing it from working as efficiently and effectively as it could. To eliminate these deficiencies a DMAIC five-step approach is used. In Six Sigma, DMAIC methodology involves the defining improvement goals, measuring the existing standards at baseline for future reference and analyzing the relationship between defects and their causes. This Six Sigma methodology also entails improving processes to deliver consistent goal achievement in accordance with company strategy and consistent with customer demand. The analysis process of this Six Sigma methodology sets the stage for midway course correction, called improvement.

1.6 IMPLEMENTATION OF SIX SIGMA – BENEFITS

When the principles and methodologies of Six Sigma are properly applied to virtually any key business process, they return positive bottom-line
results. Regardless of the company’s type of work and mission, the following can be expected:

- Improved overall customer satisfaction.
  Closing the gap between “quality of the product for the customer” and the “quality of the product for the company”.

- Increased productivity and added value
  Increasing the “value of the product for the customer” and decreasing the “value of the product for the company”.

- Improved capacity and productivity;

- Reduced total defects and cycle time;

- Increased product and service reliability;

- Improved process parameters;

- Improved process flow;

- Return of investments for the implementation of the Six Sigma.

1.7 DEFINITION OF TERMS

1.7.1 Voice of Customer (VOC)

The voice of customer is the process of capturing stated, unstated, and anticipated customer requirements, needs, and desires.

1.7.2 Critical to Quality (CTQ)

A characteristic of a product or service that is essential to ensure customer satisfaction.
1.7.3  Casting Defects

Casting defects may be defined as those characteristics that create a deficiency or imperfection contrary to the quality specifications imposed by the design and the service requirements. The defects may be attributed to:

Unsuitable or unsatisfactory raw materials used in molding, core making or casting, the application of unsatisfactory molding or casting practice by the individual worker or incorrect advice by the supervisor, the use of improper tools, equipment, appliances, or patterns, unprofessional management policies relating to the fixing of incentive plans and setting up of production procedures, faulty organization and poor work discipline, or lack of training.

1.7.4  Customer Satisfaction

Customer satisfaction should be preceded from the inside to the outside. The mutual relations between internal customers and external customers are inseparable for businesses to reach the goal of total customer satisfaction. While the company takes the needs of external customers into consideration, it is necessary to manage the needs of internal customers as well. Customers would feel satisfied if they feel the real performance equal to or better than prior expectations otherwise they would feel dissatisfied if the performance worse than prior expectations.

1.7.5  Defects per Millions Opportunity (DPMO)

It 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.
1.7.6 Cost of Poor Quality (COPQ)

Cost of 'not doing it right the first time.' The time, materials, and resources expended in nonproductive, non value-added products and services, such as fixing a problem for a customer after the product has been delivered.

VOC is translated to critical to quality, as described below.

VOC is that the massive defect rate and not meeting the customer delivery is unacceptable as it is leading to dissatisfaction of customer at the casting of flywheel product. It is due to that there is no systematic or optimization procedure in the casting process and product delivery and hence the CTQ is translated as reduction of quality ( rework and repair ) and timely delivery of product problems related to customer satisfaction in sand casting foundries (Pande et al 2000).

1.8 PROCESS CAPABILITY ($C_p$)

Six Sigma implementation starts with process capability study, which reveals the status of the process with regard to the number of rejections. Process capability refers to the ability of the process to meet technological or other requirements, to fulfill the demands put on it (Syrkos 2002). It provides a quantified value of the process variability with respect to the product requirements or specifications. This process variability indicates a measure of the uniformity of output (Montgomery 2001), and the variability in the process output can happen due to the inherent variability of the process or some special causes. For a repeated process where the output data is assumed to follow normal distribution, process capability is obtained for one quality characteristic of the product at a time, and is expressed in terms of Process Capability Ratio (PCR), Mathematically,

$$C_p = (USL - LSL) / 6\sigma$$  (1.1)
A sigma, \( \sigma \) (Greek letter), represents the process standard deviation which is a measure of the spread in the output data (population) collected from the process, and the term \( 6\sigma \) is called process spread. The plotted data takes a form of bell shaped curve as shown in Figure 1.1. Graphically, one standard deviation is the horizontal distance between the process mean \( \mu \), and the point on the curve where it turns from convex to concave.

![Figure 1.1 Bell shaped curve obtained when the output data from a repeated process are plotted (Montgomery 2001)](image)

The process capability ratio, \( Cp \) in Equation (1.1) can be used to assess the process capability where the customer has specified both \( USL \) and \( LSL \). There are situations where only one sided specification is given, either \( USL \) or \( LSL \). In such cases, the \( Cp \) value, called the one-sided PCR, can be obtained using the relations (Montgomery 2004):

\[
Cpu = (USL - \mu) / 3\sigma \quad \text{(when USL only is given)} \tag{1.2}
\]
\[
Cpl = (\mu - LSL) / 3\sigma \quad \text{(when LSL only is given)} \tag{1.3}
\]

Ideally, the process mean \( \mu \) should be on the target specified by the customer. If that is the case, the process is said to be a centered process. However, in actual processes, the mean will always be off, by some extent, from the target. Such processes are said to be off-centered processes. The process capability ratio \( Cp \) in Equation (1.1) does not take into account where the process mean is located with respect to the specification limits. Thus, for
an off-centered process, the process capability is given by another term Process Capability Index ($Cpk$), is given in Equation (1.4):

$$Cpk = \text{minimum of } (Cpu, Cpl)$$  \hspace{1cm} (1.4)

Thus, $Cpk$ is simply the one-sided PCR for the specification limit nearest to the process mean $\mu$. For a centered process where the process mean and the customer target are the same, $Cp = Cpk$. If $Cpk < Cp$, the process is considered to be off-center (Montgomery, 2005). It is the responsibility of the process owners to bring the values of $Cp$ and $Cpk$ as close as possible and maintains a narrow process spread in order to reduce the rejection rate. This calls for reducing the value of ‘$\sigma$’ as low as possible in Equations (1.1), (1.2), and (1.3). A Six Sigma process means the spread of the process is $\pm 6\sigma$ on either side of the process mean and it outputs 99.9999998% of defect free products (Montgomery 2001), as shown in Figure 1.2. However, processes vary and drift over many cycles of manufacturing. This variation typically falls between $1.4\sigma$ and $1.6\sigma$ (Schroeder et al 2008). Thus, an adjustment is required to the process mean by offsetting normal distribution by $1.5\sigma$ on either side of the target. This shift of $\pm 1.5\sigma$ of process mean from the target, would account for 99.9997% of good products, or put other way, only 3.4 defects per million opportunities (DPMO).

![Figure 1.2](image)

Figure 1.2  The 12$\sigma$ spread of the normal curve for a repeated process controlled between $-6\sigma$ to $+6\sigma$ (Montgomery 2001)
1.9 **CALCULATION OF DPMO**

Calculation of sigma = 0.8406 + \( \sqrt{29.37 - 2.221 \times \ln(DPMO)} \)

Defects per Opportunities (DPO) = Total number of defective components / Total number of production \( \times \) Number of types of defects

\[
DPMO = DPO \times 1000000
\]

1.10 **DISADVANTAGES OF SIX SIGMA**

Six sigma has been argued that it is a simple tool for continuous improvement as practiced by Toyota. It of leads to the outsourcing of improvement projects which leads to a lack of accountability. Many people argue that quality standards should be set according to the specific task or process they are related to and that setting 3.4 defects per million as a standard yardstick could actually lead to more time spent in less profitable areas.

The standardization of Six Sigma may inhibit new and creative processes and may actually stifle company growth if Sig Sigma enthusiasts are given free reign.

1.11 **PROBLEM FORMULATION**

Today, it is necessary to achieve the global quality and hence many foundries follow the defect prevention concepts like Six Sigma. Currently the concept of the Six Sigma is proposed as a management tool for achieving process improvement, reduced cost, reduced wastage, increased customer satisfaction and above all, increased profitability. All processes need not operate at the Six Sigma level. The appropriate level will depend on the strategic importance of the process and the cost of the improvement relative to
the benefit. If a process is at the two or three sigma level, it will be relatively easy and cost effective to reach the four sigma level. However, to reach five or Six Sigma will require much more effort from employees and more sophisticated statistical tools. The effort and difficulty increases exponentially as the process sigma increases. Ultimately, the return on investment for the improvement effort and the strategic importance of the process will determine whether the process should be improved and the appropriate sigma level should be targeted. Despite the massive amount of literature on Six Sigma, its impact on employees is almost completely neglected. Six Sigma consists of both process and people aspects but, until today, only few studies focused on understanding the human factor. Six Sigma is action oriented and focuses on processes used in customer service and defect reduction through variation, reduction and improvement goals, but it requires the employee satisfaction.

This study is conducted in a Southern Indian foundry. The company manufactures gate valves, flywheel outer casings, and flywheels etc, by using sand casting techniques. Earlier there is no strategy to control production defects, and therefore, defects occurred per production are stochastic. Mainly defects occurred due to poor design, lack of knowledge in the usage of resources, ignorance of operational instructions, poor material handling, and improper planning of managing activities, lack of training and especially poor employee commitment towards work. The company production is made on contract and production depended, upon the availability of resources. The company under study could not meet the customers demand fully. There is no optimized model to meet the stochastic demand and on-time delivery. There is no strategy to evaluate the equipment efficiency to identify the idleness and effectiveness of the resources. Due to this reason, the turnover of the resource is not efficient. Generally, the company’s daily production depends on both people and technical processes.
Until now little research on Six Sigma applications on process management have been carried out, so far only some human factors have been studied while research on implementation of Six Sigma DMAIC methodology customer satisfaction model in foundries has not been undertaken. Considering the above, it is decided to study both people and technical processes of Six Sigma implementation is tried by the research team to improve the customer satisfaction and overall performance of the casting process in the foundry.

1.12 OVERVIEW OF THE THESIS

The thesis is organized as 11 chapters. The overall introductory part of this study, in which the underlying concept of six sigma, necessity of Six Sigma implementation, advantages and disadvantages of Six Sigma implementation, sand casting process, sand casting defects, problem definition and main objectives of the present investigations, are explained in Chapter 1.

Chapter 2 deals with the literature review, in which the survey (Six Sigma with DMAIC, job satisfaction, sand casting process with DOE and RSM, base stock level inventory system, PWA based TRIZ, TPM with OEE measure and performance indicators) of implementing Six Sigma DMAIC methodology in the sand casting foundries, are explained in detail.

In chapter 3, the detailed studies on the Six Sigma implementation experimental procedures and methodology are explained. A pilot study is carried out to investigate the job satisfaction level of employees and sigma level of the company is determined. The possible technical corrections also made and explained in chapter 4.
An optimization technique for process parameters of green sand casting of a cast iron flywheel, based on the Taguchi parameter design approach, is determined in chapter 5.

The evaluation of the most critical process parameters identified by the Taguchi analysis is taken and the significant parameter experimental results are statistically analyzed through RSM in chapter 6.

Chapter 7 focuses on the innovative PWA based on TRIZ to validate the Taguchi and RSM optimized process parameters of sand casting process and the results are discussed in detail.

Chapter 8 deals with the study, to implement of inventory base stock level system in a stochastic environment and it is carried out in a foundry towards achieving on-time delivery and customer satisfaction at the least cost are studied in detail.

The investigations and observations are undertaken and then additional tangible and intangible performance indicators are introduced in order to identify the effectiveness and efficiency of the system. The effectiveness of the approach is subsequently evaluated and the benefits the host organization received through this new approach by measuring OEE in the Six Sigma environment are analyzed in Chapter 9.

Chapter 10 deals with the results of the Six Sigma implementation model elements calculations and analysis are discussed in detail.

Chapter 11 is the concluding chapter in which the major contributions of research study are highlighted. Scope for further research of the thesis is also included in this chapter.