CHAPTER 1
INTRODUCTION

Manufacturing firms have long used structured methods to reduce process variability and standardize outcomes. Quality tools such as statistical process control evolved to analyze behavior and variability of processes and to explore the relationships between inspections, defects, and operating costs. During the 1980s quality control evolved into “named” initiatives or programs, such as Total Quality Management (TQM), Zero Defects, Quality Circles, Continuous Quality Improvement (CQI), Continuous Process Improvement, and many others. While each is perhaps technically different from the others, most involved identifying defects, as they occurred through inspection. It has been suggested that naming these quality initiatives contributed to declination in their popularity and use. For many years, industries focused on quality improvement initiatives such as TQM and CQI. However, these programs lost momentum and popularity due to their lack of data driven analysis, and many managers became disillusioned with the prospects of quality improvement.

In 1987, Motorola launched the concept and practice of Six Sigma [Harry et al. 2000]. Mikel Harry, an engineer and trained statistician, began to study and apply the concepts of process variation developed by W. Edwards Deming in order to find ways to reduce variation and improve performance. The “sigma approach”, named for the standard unit of variation around the mean, caught the attention of Bob Galvin, CEO of Motorola, and soon became the way of doing business at Motorola. With an emphasis on continuous improvement as well as a
continuous aspiration towards perfection, “Motorola adopted a Six Sigma goal in everything they did, roughly equivalent to a process producing only 3.4 defects per million opportunities; near perfection”[Eckes et al. 2001 ].

The practice of Six Sigma addresses and identifies the sources of “common cause variation” as well as variation due to occasional or special causes. Employing a long list of pre-existing statistical, analytical and quality techniques, Six Sigma empowers members of an organization to improve processes and services throughout the organization, using a logical and systematic method, to meet the organization’s financial objectives and mission statements. Although the tools and techniques have been around for quite some time, this method’s layout and infrastructure prescription for the members of an organization, enable Six Sigma to bring sustainable success through changing a company’s culture and the way its business is done.

The claims of phenomenal success using this approach have been repeatedly echoed and validated by bottom-line results reported particularly by Bob Galvin of Motorola, Jack Welch of GE, Larry Bossidy of Honeywell/Allied Signal, and countless others. Decade after the birth of the Six Sigma concept, Motorola saw a “five-fold growth in sales, with profits climbing nearly 20 percent per year; cumulative savings based on Six Sigma efforts pegged at $14 billion, stock price gains compounded to an annual rate of 21.3 percent” [Pande et al. 2000].

Since Six Sigma program focus on data-driven analysis and rigorous methodology to improve quality, it seems to be gaining significant popularity in industrial settings.

Most of the plastic injection moulding firms in India are in unorganized sector, where negligible attention is paid on quality, due to financial constraints and lack of skilled personals. Keeping in mind the importance of injection moulding
process in the current scenario this thesis tries to find out a modified Six Sigma approach which suits the requirements of small and medium scale plastic injection moulding industry.

Injection Moulding (IM) is considered the most prominent process for mass production of plastic parts. More than one third of all plastic products are made by injection moulding, and over half of the world’s polymer processing equipments are used for the injection moulding process [Osswald et al. 2002]. Injection moulding has been a challenging process for many manufacturers and researchers to produce products meeting requirements at the lowest cost. Its complexity and the enormous amount of process parameter manipulation during real time production create a very intense effort to maintain the process under control. Complexity and parameter manipulation may cause serious quality problems and high manufacturing costs [Cabrera et al. 2002].

One of the main goals in injection moulding is the improvement of quality of moulded parts, besides the reduction of cycle time and lower production cost. Solving problems related to quality has a direct effect on the expected profit for injection moulding companies. In many manufacturing processes, meeting required specifications means keeping quality characteristics under control. Quality characteristics in injection moulding are classified as mechanical properties, dimensions or measurable characteristics, and attributes. In general, some of the main causes of quality problems are material related defects like black specks and splay, process related problems, filling related defects such as flash and short shots, packing and cooling related defects like sink marks and voids, and post mould related defects such as warpage, dimensional changes and weight.
Factors that affect the quality of a moulded part can be classified into four categories: part design, mould design, machine performance and processing conditions. The part and mould design are assumed as established and fixed. During production, quality characteristics may deviate due to drifting or shifting of processing conditions caused by machine wear, environmental change or operators' fatigue [Jeyapaul et al. 2005].

Determining optimal process parameter settings critically influences productivity, quality and cost of production in the plastic injection moulding (PIM) industry. Previously, production engineers used either trial-and-error method or Taguchi’s parameter design method to determine optimal process parameter settings for PIM. However, these methods are unsuitable in present PIM because of the increasing complexity of product design and the requirement of multi-response quality characteristics.

Optimization of process parameters is routinely performed in the manufacturing industry, particularly while setting the final optimal process parameters. Final optimal process parameters’ setting is recognized as one of the most important steps in injection moulding for improving the quality of moulded products [Mok and Kwong, 2002]. Previously, the engineers used trial-and-error methods, which depended on the engineers’ experience and intuition to determine initial process parameter settings. However, the trial-and-error process is costly and time consuming; therefore it is not suitable for complex manufacturing processes. Also because of the enormous competition, using the trial-and-error approach to determine the process parameters for injection moulding is no longer good enough.
Quite a few researchers have attempted various approaches for the determination of process parameters for injection moulding, in order to reduce the time to market and obtain consistent quality of moulded parts.

The most widely used approach to determine the process settings is to optimize performance measures as functions of the input variables. This is done by using a model to relate the behavior of the performance measures to the controllable variables and then optimizing these models. Two types of models can be used. The first type is: a model that is based on the physical laws that govern the phenomenon of interest. When the physics of a system are not completely understood or become very complicated, it is more convenient to use the second type of model that is called a metamodel. A metamodel is an empirical expression that is fit to mimic an initial data set that can be obtained from a physics based model or the physical system itself. The advantage of the metamodel is that once it is created, it can yield large amounts of predictions quite fast. Two types of metamodels have been considered in this project: linear regression models, and artificial neural networks. The use of artificial neural network to model polymer processes is a relatively new area for research. These metamodels are used to represent the behavior of a single parameter as a function of the input variables. It is common practice to optimize these models one at a time.

However, difficulties arise when trying to optimize more than one performance measures simultaneously because they often show conflicting behaviors. For example part warping and cycle time, both of these performance measures are greatly affected by the temperature at which the part is ejected. Allowing the part to cool to a lower ejection temperature would favorably decrease the part
warping. However, this would eventually increase the cycle time, which means that fewer parts would be produced. Therefore, to effectively optimize an IM process, a compromise must be found between all the parameters of interest. The problem of considering several parameters simultaneously is referred to as a multiple criteria optimization.

Most of the plastic injection moulding firms in India are in unorganized sector, where negligible attention is paid on quality, due to financial constraints and lack of skilled personals. Unfortunately, there is no research work available on six sigma specifically focusing on SMEs. There is, therefore, a need to perform primary research in the area of six sigma applications in SMEs especially focused on plastic injection moulding industry.

Having arisen in large corporations, six sigma is surely one of the most comprehensive approaches for company’s development and the performance improvement of the products and processes. Nevertheless, it appears that the majority of small and medium sized enterprises (SMEs) either do not know the six sigma approach, or find its organization not suitable to meet their specific requirements. In the SME environment, there is little spare resource; every employee has a key role and usually several. The challenges of smaller companies are “funding and logistics”, a “limited talent pool”, “multi-hat roles”, and “less exposure to management innovations in other industries”.

Keeping in mind the above points a modified Six Sigma cycle based on Taguchi method, Regression analysis and Artificial Neural Network has been demonstrated in this work which suits the small industries, especially plastic injection moulding enterprises. Its feasibility was studied with the help of a case study. The method has been employed for the improvement in two quality
characteristics (hardness and over shrinkage) of injection-moulded nylon-6 kamani bush produced in a small enterprise.

The main objective of this study has been to improve the quality of injection-moulded nylon-6 bush (KAMANI BUSH) with the implementation of a modified six sigma cycle called DAURR (Diagnose, Analyze, Upgrade, Regulate and Review) and to check its usefulness for small scale plastic injection moulding industries.

In the case study first, critical-to-quality factors (CTQ) have been determined based on the customer’s requirement for quality. Then the causal factors for the bush properties are identified within the processing window being tested. For the analysis procedures, the Taguchi design-of-experiment method (DOE) has been employed for screening pertinent process parameters in the injection process. With the help of S/N (signal to noise) ratio for twenty seven experiments, obtained from Taguchi design-of-experiment method (DOE), four important processing parameters have been selected. Multiple regression analysis of second order has been carried out taking these four parameters as input which provides a good prediction model for two important quality characteristics hardness and bulging with r square value of nearly 0.97, to further validate this model a prediction model based on Artificial Neural Network (ANN) was developed. After completing the procedures, confirmation experiments have been conducted with selected combinations of factors and levels. The experimental results show substantial improvement for the profile accuracy and hardness of moulded nylon-6 bush. As a result of the present study, the upper process capability index CPU for hardness of nylon-6 bush has improved from 0.56 to 1.16, process mean increased from 69.79 to 83.44 , while the lower
process capability index CPL for over shrinkage of nylon-6 bush has improved from 0.24 to 1.225, and the process mean decreased from 0.1015 to 0.0615. The process quality characteristics have improved from 3.19σ standard to 4.99σ standard for hardness while it improved from 2.38σ standard to 5.18σ standard for over shrinkage. This work shows that the process improved closer to six sigma standard by changing the processing conditions only without any change in the part design, mold design, and machine performance. This work demonstrates a process for finding the best compromises between several performance measures for one case of IM. Through finding the efficient compromises between performance measures, one can trace back the corresponding levels of the controllable variables. The present work also offers advantage in choosing the best tools that fit the SMEs as well as it can be used for achieving Six Sigma standard in plastic injection moulding companies having limited resources and expertise.