AN IMPLEMENTATION EXAMPLE FOR THE IMPROVEMENT OF MANUFACTURING PROCESSES USING SIX SIGMA TOOLS

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Abstract *Six sigma method and its related tools are commonly used in the improvement of manufacturing processes. Using these tools, process map can clearly be developed and non-valuable operations can be identified. Furthermore, design of experiments can be used to diagnose effective factors on the output of the manufacturing process at hand. Using these factors further development can be effectively implemented on the process. In this paper, the application and advantages of six sigma methods together with design of experiments will be shown in a real industrial application. Results of different steps and its advantages will be discussed.*

Keywords *six sigma, design of experiments, manufacturing processes*

1. Introduction

The six sigma method is a project-driven management approach to improve the organization's products, services, and processes by continually reducing defects in the organization (Eckes, G., 2003). It is a business strategy that focuses on improving customer requirements understanding, business systems, productivity, and financial performance. Dating back to the mid 1980s, applications of the six sigma methods allowed many organizations to sustain their competitive advantage by integrating their knowledge of the process with statistics, engineering, and project management (Barney, M. & McCarty, T., 2002). Numerous books and articles provide the basic concepts and benefits of the six sigma method. The challenges and realities in implementing the six sigma method successfully are immense. However, the benefits of applying the six sigma method to technology-driven, project-driven organizations are equally great (Eckes, G., 2003).

Six sigma method has two major perspectives. The origin of six sigma comes from statistics and statisticians. Various authors discuss the six sigma method from a statistical, probabilistic, and quantitative point of view (Breyfogle III, 1999). 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% where sigma is a term used to represent the variation about the process average. If an organization is operating at three sigma level 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 perform at three-sigma level.

On the other hand, design of experiments, DOE, is used in many industrial sectors, for instance, in the development and optimization of manufacturing processes. Typical examples are the production of wafers in the electronics industry, the manufacturing of engines in the car industry, and the synthesis of compounds in the pharmaceutical industry.

Usually, however, an experimenter does not jump directly into an optimization problem; rather initial screening experimental designs are used in order to locate the most fruitful part of the experimental region in question. Other main types of application where DOE is useful is robustness testing and mixture design. The key feature of the latter application type is that all factors sum to 100%.

In this paper, the application and advantages of six sigma methods together with design of experiments will be shown in a real industrial application, namely an automotive part fabrication industry. In the next sections related tools of six sigma and design of experiments will be briefly explained.

2. Six Sigma Tools and Tactics

There are five high-level steps in the application of six sigma tactics, which is called as DMAIC methodologies for short. There are several tools involved in steps of this improvement methodology and they will be listed briefly later in this section. As can be seen from Figure 1, the first step is *Define*. In this crucial step, first the project team is formed, a charter is created, customers, their needs and requirements are determined and verified, and then, a high-level map of the current process is created.

The second step is *Measure*. It is in this second step that the current sigma performance is calculated, sometimes at a more detailed level than occurred at the strategic level of six sigma.

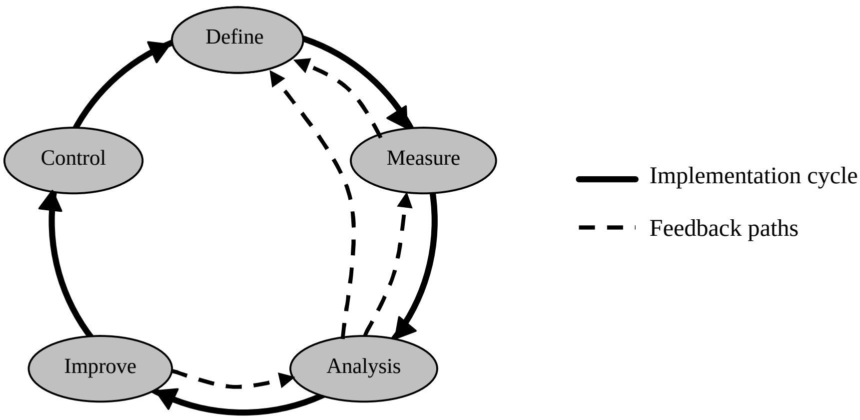

Figure 1. Improvement methodology using six-sigma tools.

The third step in applying six sigma tactics is *Analysis*. During this step, first the team analyzes data and the process itself, which leads to determining the root causes of the poor sigma performance of the process.

The next step in the application of six sigma tactics is *Improve*. In this step, the team generates and selects a set of solutions to improve sigma performance.

And, the fifth and last step is *Control*. Here a set of tools and techniques are applied to the newly improved process so that the improved sigma performance holds up over time (Eckes, 2003).

It can be seen from Figure 1 that there are some feedback loops between the first four steps of the process. These feedback loops are necessary for the validation of the steps involved and improves the effectiveness of the six sigma application at hand.

As discussed above there are several tools involved in steps of the six sigma application. While these tools are generally technical in nature, they are relatively easy to learn and apply for specific projects. These technical tools can be listed as follows (Harry & Schroeder, 1999):

- ***The Critical to Quality (CTQ) Tree***: Used in define step and to brainstorm and validate the needs and requirements of the customer of the process selected for improvement.
- ***The Process Map***: Used in define step and is a picture of the current steps in the process.
- ***The Histogram***: Used in the analysis step and to identify variations in the process.
- ***The Pareto Chart***: Used in the analysis step and to identify variations in the process. Used with discrete data.

- ***The Process Summary Worksheet***: Used in the analysis step and indicates steps that add value in the process.
- ***The Cause-Effect Diagram***: Used in the analysis step and to identify root causation.
- ***The Scatter Diagram***: Used in the analysis step by taking ideas one by one about root causation and by tracking corresponding data.
- ***The Affinity Diagram***: Used in the improve step and to help sort and categorize a large number of ideas into major themes or categories.
- ***The Run Chart***: Used in the improve step and to see some measurement over time.
- ***The Control Chart***: Used in the control step and helps to identify when the process is no longer consistent, predictable, and repeatable, i.e. "out of control".

3. Design of Experiments

In a similar context, design of experiments (DOE) and data analysis is used to find the cause-and-effect relationship between the output and experimental factors in a process (Yang & El-Haik, 2003). DOE is a statistical procedure for tightening tolerances to reduce variation. It is equivalent to the "Tolerance Design" portion of "Robust Engineering".

In any DOE project, experimental factors are deliberately changed and their effects are observed on the output. The data obtained in the experiments are used to fit empirical models relating output (y) with experimental factors (x).

Generally a DOE project has many steps involved. These steps can be listed as follows:

i. Project definition.
ii. Selection of response variable, i.e. output.
iii. Choice of factors, levels, and ranges.
iv. Select an experimental design.
v. Perform the experiment.
vi. Analysis of DOE data.
vii. Conclusions and recommendations.

It should be noted that, the main DOE data analysis tools include analysis of variance (ANOVA), empirical model building, and main-effects and interaction charts. From this brief information it can be deduced that, in fact, six sigma tools and design of experiments are closely related. Specifically speaking, although design of experiments is not intended to optimize the physics of the function, it does generate statistics that are vital for six sigma's DMAIC methodologies. In addition, using statistics-based DOE allows one to use a common methodology for both product and process improvement.

In the next section the tools described in sections 2 and 3 will be applied on a real life example and its results will be discussed.

4. Implementation Example

For implementation purposes a simple part that is used in cars has been chosen for this paper. The part is used in some regions of the car. The purpose of the project is to minimize and stabilize the working range of the part.

Related important factors for this part are given as:

- Y: Response (Working range of the part)
- X1: First dimension of the part under a certain force
- X2: Second dimension of the part
- X3: Third dimension of the part

For this part, first the factors, levels and ranges have been identified. Then the experimental design was set up. During the implementation phase the most critical step was the identification of the factors. This was mainly because of the low possibility of measuring all the related dimensions and the forces effecting the process and thus the part.

Figure 2 and 3 gives the related main effect and interaction graphs of the DOE procedure. Here, 'Design' indicates the improved results of the previous runs.

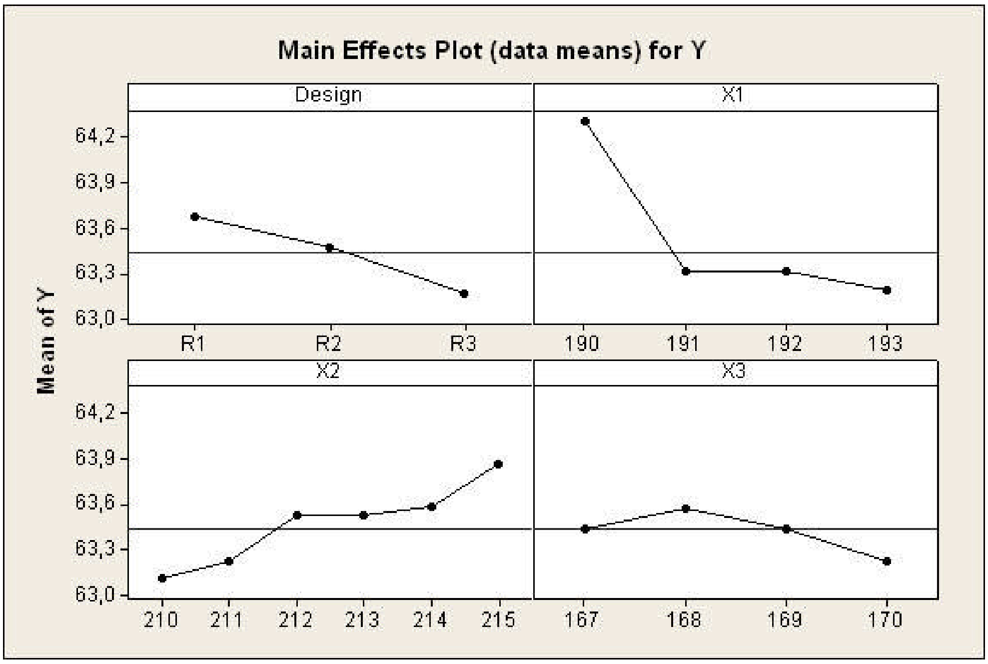

Figure 2. Main effects graph.

Main effects graph, Figure 2, indicates that X1 factor has the highest effect on the process, and X3 has the lowest effect. Related numerical results obtained using Minitab can be seen in Table 1.

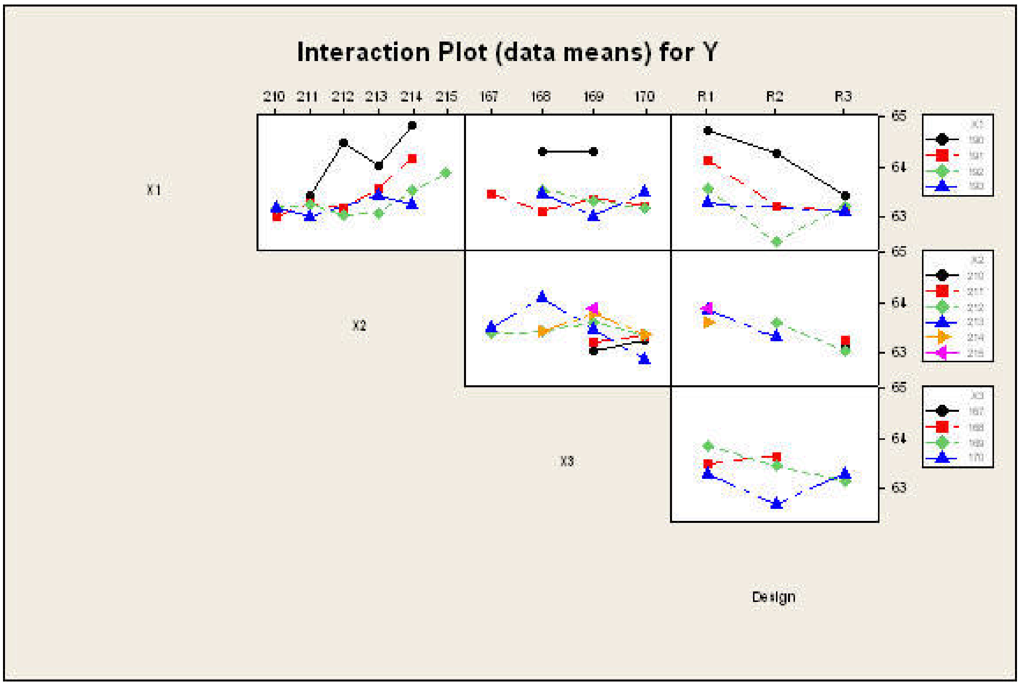

Figure 3. Interaction graph.

Table 1. Results of ANOVA.

Analysis of Variance for D1, using Adjusted SS for Tests

Source	Model DF	Reduced DF	Seq SS
X1	3	3	11,53087
X2	5	5	2,42848
X3	3	3	0,04515
Rapor1	2	2	2,82154
X1*X2	15	9+	3,47202
X1*X3	9	5+	0,83104
X1*Rapor1	6	2+	0,00755
X2*X3	15	7+	2,36368
X2*Rapor1	10	0+	0,00000
X3*Rapor1	6	1+	0,14440
X1*X2*X3	45	2+	0,91041
X1*X2*Rapor1	30	0+	0,00000
X1*X3*Rapor1	18	0+	0,00000
X2*X3*Rapor1	30	0+	0,00000
X1*X2*X3*Rapor1	90	0+	0,00000
Error	-198	50	7,47431
Total	89	89	32,02945

+ Rank deficiency due to empty cells, unbalanced nesting, collinearity, or an undeclared covariate. No storage of results or further analysis will be done.

S = 0,386634   R-Sq = 76,66%   R-Sq(adj) = 58,46%

5. Conclusions

Successful implementation of six sigma method has been on the rise in the last few years. It is rapidly becoming a major driving force for many technology-driven or project-driven organizations. Understanding the key features, obstacles, and shortcomings of six sigma provide opportunities to the industry for better implementation of six sigma projects. It should be noted that, various approaches to six sigma can be applied to increase the overall performance of different sectors.

In this paper, the advantages and application procedures of six sigma methods together with design of experiments is explained and applied on a real industrial application. According to the results, using six sigma tools, a parameter of a car part has been analyzed and improved in terms of dimension. During the implementation route it is observed that there are too many factors in the process and for better analysis these factors should be reduced. Future work will be focused on the verification of the methodology using data from more extensive trials with fewer factors, so that accuracy and reliability of the results can be improved.

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