INTEGRATION OF "SIX SIGMA" INTO THE UNDERGRADUATE ENGINEERING CURRICULUM

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Abstract

Quality Management using the "Six Sigma" approach is a fact based, decision making tool for many operations to improve quality, reliability and productivity in an organization. Six Sigma ensures that quality functions meet customers' needs and that the chosen operation reduces waste and defects, while improving product, processes and services and increasing customer satisfaction. Six Sigma has become one of the most powerful emerging management tool used by the Fortune 500 companies today. In this paper we outline the basic tools and methodology used in Six Sigma. We discuss the development of an introductory Six Sigma course for sophomore/junior engineering/ technology students. We also discuss strategies to integrate Six Sigma into the engineering design courses.

I. Introduction

"Six Sigma" is a data-driven, fact based, decision making management tool used to improve the profitability of a business enterprise by reducing the waste and defects while improving product, processes and services and increasing the customer satisfaction. Six Sigma is widely used in industry to improve the efficiency of product design and development, manufacturing and marketing.

The Greek letter б (sigma) in the context of mathematical statistics represents standard deviation. However, in industry, б is used as a measure of performance variation. Industry's performance is measured by the sigma level of their business performance. Traditionally industry operates on three sigma (3б) which translates into 670,000 defects per million opportunities. Six Sigma (6б) means 3.45 defects per million opportunities, which is near error free business performance.

Six Sigma has become one of the most powerful emerging management tool used by the Fortune 1000 companies today. Six Sigma continuous quality improvement concepts were pioneered by Motorola in the early 1980's. Due to the profound success of Six Sigma by companies such as Allied Signal, Dow Chemicals, General Electric, Honda, Motorola, Caterpillar, Sony, Texas Instruments and others in recent years, increasing number of Fortune 500 companies are considering to adopt it. Globalization of business practices continues to intensify market competition worldwide. Since Six Sigma has proven to increase profitability, it is fair to assume that the application of Six Sigma will increase dramatically worldwide over the next few decades.

The increasing use of Six Sigma by industry creates a challenge for the academic community to educate engineering/technology students with the necessary knowledge, understanding, and skills to interact and provide leadership in implementing this breakthrough management tool of Six Sigma.

The purpose of this paper is to discuss the integration of Six Sigma into the undergraduate engineering/technology curriculum.

2. Six Sigma Tools and Methodology

The fundamental objective of the "Six Sigma" methodology is the implementation of a measurement based strategy that focuses on quality improvement of process, products and services by reducing the waste and variation through the use of statistical tools [1]. The following statistical tools and techniques are essential for implementation of Six Sigma [1,2].

- Process Maps
- Cause and Effect Diagrams (Fishbone Diagram)
- Quality Function Deployment (QFD)
- Failure Modes and Effects Analysis (FMEA)
- Statistical Process Control (SPC)
- Analysis of Variance (ANOVA)
- Design of Experiments (DOE)
- Process Capability Analysis (PCA)
- Measurement Systems Analysis
- Multi-Variant Studies
- Control Plans
- Pugh Matrix (Criteria Matrix), etc.

A brief description of some of the above tools are given below [1,2]:
Cause and Effect Diagrams: Developed by Dr. Kaoru Ishikawa, these diagrams explain the factors causing a problem and how those factors are result in a single effect . It deals with everything related to a particular problem. These diagrams are arranged in four main categories. For manufacturing generally, 4Ms (Machinery, Manpower, Methods, Materials) are used. Once the causes are known one can work upon the ones within ones control and modify them so as to meet the organizational goals and objectives.

Pareto Analysis: This is a Six Sigma tool used to examine quality problems stating only the vital few (20%) factors that are responsible for producing most (80%) of the problems in the process. It is also known as 'separating the vital few from the trivial many' or '80-20 Rule'. It can be applied to quality and process improvement by correcting the few key problems and thereby improving the overall process.

Quality Function Deployment: This is a decision analytical tool used to meet the customer quality requirements by incorporating the 'Voice of the Customer' throughout the product development cycle. It helps in product improvement, reduction in defects thereby increasing the customer satisfaction leading to higher market share. House of Quality is the matrix structure used to define the 'Voice of the Customer' and then incorporating this 'Voice of the Customer' into each phase of the product development cycle.

Failure Mode and Effects Analysis (FMEA): This is a bottom-up approach to reliability analysis. It helps in identifying the potential failure modes and their causes.

Design of Experiment (DOE): This is a structured statistical methodology for evaluating the relationship between the independent variables or factors affecting the process and the experimental outcome of that process.

Statistical Process Control (SPC): Six Sigma uses SPC and control charts in different ways to measure, analyze, and control the variation in processes. SPC is used to monitor the consistency of processes. SPC consists of four major steps which start from measuring the process, eliminating variation in the process thereby introducing consistency, monitoring the process and improving it further to its best target value. SPC consists of different control charts each of which work best on different kinds of data. Some of the control charts used in SPC are:

- X bar R Control Charts
- XmR Control Charts
- C Control Charts
- p Control Charts
- np Control Charts
- u Control Charts

Through these charts process capability and performance control is evaluated and measured.

Process Capability Analysis (PCA): Process Capability Analysis is used to analyze how consistent or variable the process is and to bring the process under statistical control and compares long-term process performance to the management requirements. If the process falls under a Normal Distribution then approximately 99.73% of the output would fall within the Six Sigma limits.

The tools of Six Sigma are most often applied through various performance improvement methodologies such as [2]:

- DMAIC: Design, Measure, Analyze, Improve and Control
- DMADV: Define, Measure, Analyze, Design and Verify
- DMEDI: Define, Measure, Explore, Design and Implement
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Usually, DMAIC is used for improvement of product, process and services, while DMADV and DMEDI are used for design and development of new product, process and services. The flow charts for application of DMAIC and DMADC are illustrated in Figures1 and 2 respectively [2].

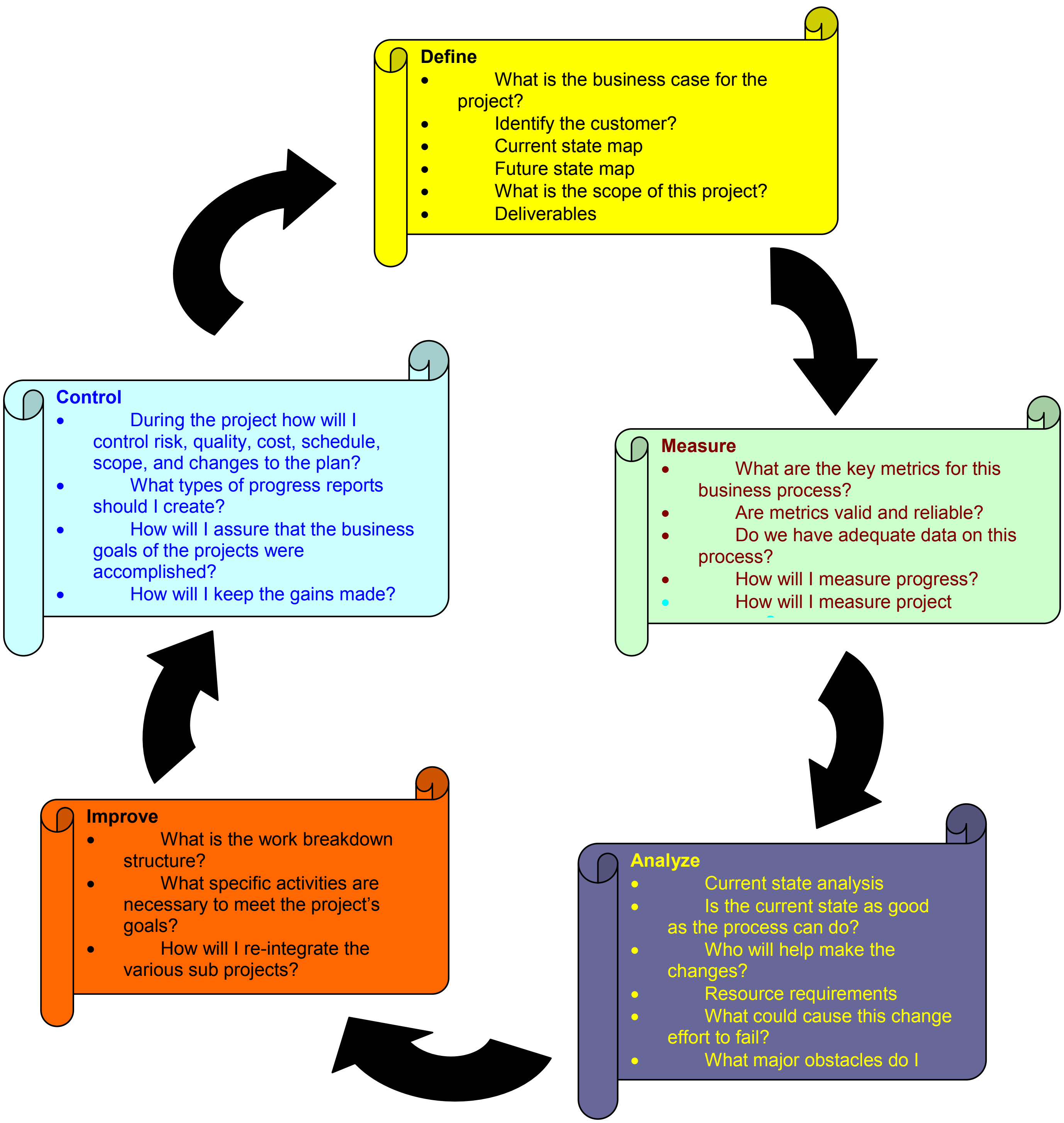

Figure 1. Flow Chart of Application of DMAIC Methodology [2]

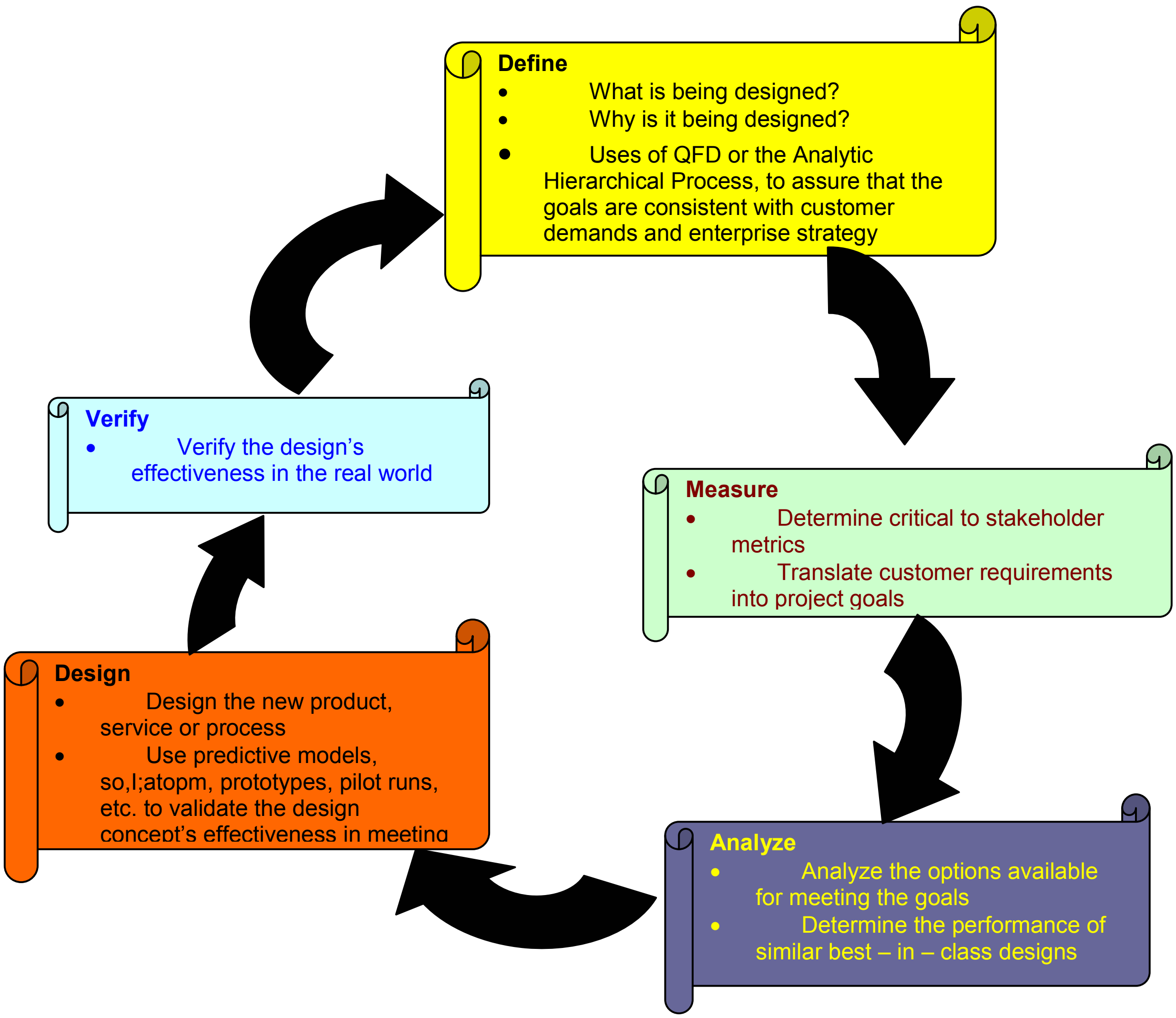

Figure 2. Flow Chart of Application of DMADV Methodology [2]

3. Integration of Six Sigma into the Undergraduate Engineering Curriculum

Integration of Six Sigma into the Undergraduate engineering/ technology curriculum requires the implementation of the following three steps:

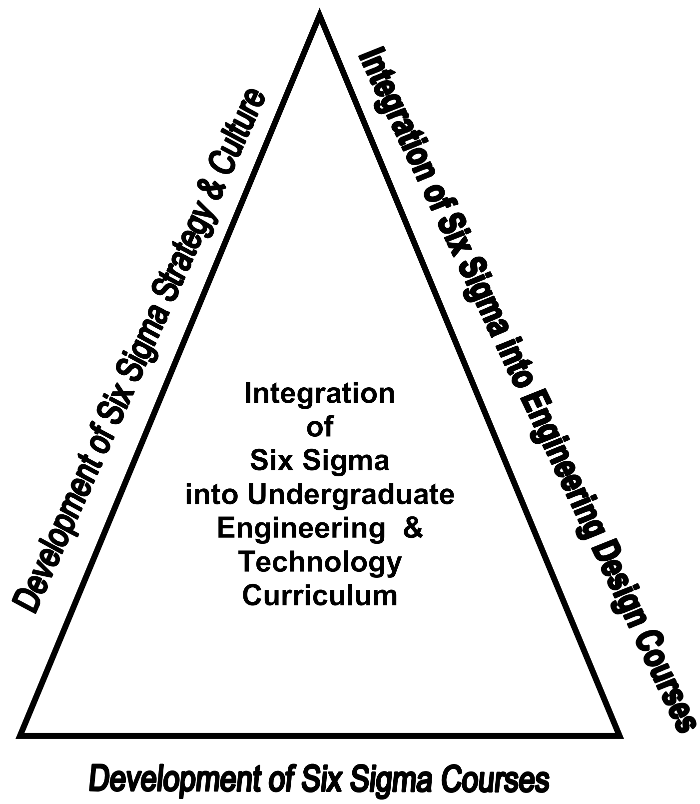

Figure 3. Strategies for Integration of Six Sigma into the Undergraduate Engineering/Technology Curriculum.

Step 1: Development of Strategy and Culture:

The very first step towards integrating Six Sigma into undergraduate engineering/technology curriculum is to develop strategies and culture to promote and integrate quality controls, reliability and productivity management concepts in the undergraduate engineering/technology curriculum. This step requires commitment, collaboration and communication among all stakeholders: students, faculty and administrators.

Step 2: Development of an Interdisciplinary Six Sigma Course:

Development of a Six Sigma course that focuses on fundamentals and application of Six Sigma tools and methodologies is extremely important. The primary objectives of the Six Sigma course are as follows:

1. Provide mathematical and statistical foundation of Six Sigma and quality controls.
2. Provide understanding of basic tools for measurement, analysis, and quality control.
3. Provide ability to identify, analyze and solve problems to improve process, products and services provided by the industry.
4. Provide understanding of methodologies to implement Six Sigma.
5. Provide ability to use the techniques, skills and modern tools necessary to implement Six Sigma.

The above educational objectives can be achieved through an introductory Six Sigma course. A tentative outline of an Introductory Six Sigma course is given below [1,2]:

I. Six Sigma Background and Overview
- Definition of Six Sigma
- History of Six Sigma
- Six Sigma measurement concepts
- Introduction to Six Sigma methodology and concepts of quality control.
- Implementation of Six Sigma methodology in modern industry.

II. Six Sigma Tools and Technologies
- Introduction to Probability and Probability Distributions
- Introduction to Statistics
- Data Analysis and Data Visualization
- Process Maps
- Cause and Effect Diagrams
- Quality Function Deployment
- Failure Modes and Effect Analysis
- Test of Hypothesis
- Analysis of Variance (ANOVA)
- Linear and Multiple Regression
- Reliability Testing and Quality Controls

III. Implementation of Six Sigma

- Introduction to Project Management tools for Six Sigma
- Introduction to Six Sigma Process Enterprise, Project Integration and Execution
- Black Belts, Green Belts and Master Black Belts
- Introduction to Design for Six Sigma: DMAIC, DMADV and DMEDI
- Six Sigma Project Case Studies

Senior Design Courses

APPLICATION OF SIX SIGMA

Implementation of Six Sigma Projects **Application of DMAIC, DMADC, DMEDI**

Sophomores and Junior Design Courses

SIX SIGMA TOOLS AND TECHNOLOGIES

Six Sigma Tools **Quality Control & Reliability Analysis** **Project Management**

Freshman Design Courses

INTRODUCTION TO SIX SIGMA

Concepts **Background** **Overview**

Figure 4. Integration of Six Sigma into Engineering Design Courses

The Introductory Six Sigma course should be designed for Sophomore and Junior students. We also recommend the development of an advanced Six Sigma course titled: Design for Six Sigma [3]. This course should be targeted for senior engineering/technology students.

Step 3: Integration of Six Sigma into Engineering Design Courses:

The Six Sigma management concepts can also be integrated into the freshman, sophomore, junior and senior design projects and courses. A schematic diagram of integration of Six Sigma engineering into design courses is given in Figure 4.

4. Conclusions.

Six Sigma is truly interdisciplinary. Six Sigma courses should be developed and taught from interdisciplinary viewpoints. Students should be provided with a broad foundation of basic statistical tools intertwined with quality and reliability controls, project management and productivity improvements. Use of modern statistical software such as MINITAB [4] should be integrated in Six Sigma courses. Every effort should be made to integrate Six Sigma projects from industry as case studies. Six Sigma project executioners and leaders from the industry (Black Belts, Green Belts and Master Black Belts) should be invited as guest speakers. Integration of Six Sigma in engineering design courses would significantly enhance students learning experience in project management and prepare them to provide leadership in implementing Six Sigma in industry.

References

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