Six Sigma Operational Methods

DESIGN FOR SIX SIGMA STATISTICS

59 Tools for Diagnosing and Solving Problems in DFSS Initiatives

- Measurement System Analysis
- Process Capability Analysis
- Statistical Tools for Non-Normal Distributions

Andrew Sleeper

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To Công Huyền Tôn Nữ Xuân Phư'o'ng, the love of my life.

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FOREWORD

I first met Andy Sleeper in the late 1980s when I was conducting several quality-improvement training seminars for Woodward Governor Company in Fort Collins, Colorado. A young engineer just out of college, Andy was extremely eager to learn everything he could about how statistics could be utilized to improve the performance of a manufacturing process. Throughout the time I spent working for this client, I always recall being impressed by Andy's enthusiasm for, and instinctive understanding of, statistics because not only did he ask a lot of questions, he asked a lot of really *good* questions.

Since that time, Andy has continued to passionately pursue his study of statistics, and he is now completing his doctorate degree in this subject. Today he operates his own highly regarded consulting firm. In addition to joining several professional societies so he could network with others in the quality field, Andy has written many articles about various quality-related topics. But more importantly than just having an impressive list of credentials, Andy has demonstrated his mastery of statistics by successfully helping numerous manufacturing companies design and produce their products better, cheaper, and faster.

Andy was also among the first quality professionals to comprehend the enormous potential for process improvement offered by the "Six Sigma" philosophy. Six Sigma (6σ) is all about improving the performance of your organization by using a structured approach for minimizing mistakes and waste in all processes. The 6σ strategy was developed by Motorola, Inc. in the mid-1980s to help boost the quality level of its products. After Motorola became the first company to win the Malcolm Baldrige National Quality Award in 1988, the ensuing media exposure introduced the 6σ approach to many other manufacturing companies, most notably Allied Signal (now Honeywell International) and General Electric. Today, with thousands of companies around the world adopting this philosophy, 6σ is arguably the most popular process improvement strategy ever devised.

Over the past several years, some quality practitioners have spent a lot of time arguing whether or not 6σ is really anything new. They point out that most of the statistical theory and techniques associated with this approach were developed decades before Motorola created their 6σ program. For example: Dr. Ronald Fisher had already developed the design of experiments by the 1920s; Dr. Walter Shewhart had invented control charts back in 1924; Dr. Edwards Deming had taught the Plan-Do-Check-Act problem solving strategy to the Japanese shortly after World War II; Dr. Armand Feigenbaum had introduced his concept of total quality management in the late 1950s; and Dr. Joseph Juran had published his breakthrough strategy in 1964. Thus, these practitioners argue, just what is really new about this 6σ approach?

Creativity often is defined as being either (1) creating of something new or (2) rearranging of the old in new ways. I believe 6σ meets this definition of creativity on both counts. Without a doubt, 6σ incorporates much of the old quality methodology, but it is certainly arranged and applied in a novel way. In addition, there are definitely some brand new aspects to 6σ as well.

The Rearranging of the Old

6σ has done an admirable job of organizing statistical techniques with a solid strategy (DMAIC) for applying them in a logical manner to efficiently enhance process performance. However, as mentioned in the previous paragraph, all this has been done before in various forms. One of the reasons 6σ is still around today—and the others aren't—is because 6σ evolved from its original focus on *quality* improvement to concentrate on *profit* improvement.

Previous improvement strategies stressed the need for senior management involvement. Although these managers often verbally supported the latest quality initiative (who isn't for better quality?), their hearts and minds never deviated very far from the "bottom line." If a quality program didn't quickly deliver better numbers for the next quarterly report, it wasn't too long before top managers shifted their attention elsewhere.

6σ guarantees top management interest because all of its improvement activities involve projects that are vital to the long-term success of the organization. And because companies need to make a profit in order to remain in business, this means that the majority of 6σ projects are focused on making money for the company. With projects that capture the attention of senior management, it is relatively easy to secure financial and moral support for continuing 6σ.

The Creation of the New

In order to align 6σ projects with the long-term strategic objectives of the organization, a new infrastructure was needed. 6σ employs Champions who are intimately aware of the company's goals. Champions convey these strategic aims to a Master Black Belt, who translates them into specific projects, each of which is assigned to a Black Belt. A Black Belt then forms a team of subject experts, often referred to as Green Belts, who will help the Black Belt complete the project on time. This type of an extensive formal structure, with full-time people working in the roles of Master Black Belts and Black Belts and other personnel in part-time supporting roles, was rarely seen in earlier quality-improvement initiatives.

As far as new statistical techniques are concerned, 6σ introduced the idea of calculating defects per opportunity. In the past, a product's quality was often assessed by computing the average number of defects per unit. This last metric has the disadvantage of not being able to fairly compare the quality level of a simple product, one with only a few things that could go wrong, to that of a complex product, one with many opportunities for a problem. By estimating the defects per opportunity for two dissimilar products, we now have a means for meaningfully comparing the quality of a bolt to that for an entire engine.

6σ also created a metric known as rolled throughput yield. This new metric includes the effects of all the hidden rework activities going on inside the plant that were often overlooked by traditional methods of computing first-time yield.

Although it has generated a lot of discussion, both pro and con, I believe anyone who has been introduced to the “1.5σ shift” concept has to admit that this is definitely an original method for assessing process capability. This unique factor allows an estimate of the long-term performance of a process to be derived by studying only the process’s short-term behavior. The conversion is achieved by making an upward adjustment in the short-term estimate of nonconforming parts to allow for potential shifts and drifts of up to 1.5σ that may occur in the process average over time. This modification was made to provide a more realistic expectation of the quality level that customers will receive.

Probably one of the most important new facets of 6σ is the emphasis it places on properly designing products and processes so that they can achieve a 6σ quality level when they are manufactured. This vital aspect of 6σ is the one Andy has chosen for the topic of this book.

Designing for Six Sigma (DFSS)

Initially, 6σ concentrated on improving existing manufacturing processes. But companies soon realized that it is very difficult to consistently produce high-quality products at minimum cost on a poorly designed process.

Growing up on a farm in northern Wisconsin, I often heard this saying, “You can’t make a silk purse out of a sow’s ear.” Many of the processes producing parts today were designed to achieve only a 3σ (66,807 ppm), or at best, a 4σ (6,210 ppm) quality level. I doubt if the engineers who designed products and processes 25 years ago could ever have anticipated the increasing demand of the past decade for extremely high-quality products. With skill and hard work, a Black Belt might be able to get such a process to a 4.5σ (1,350 ppm) or even a 5σ (233 ppm) level, which represents a substantial improvement in process performance. But no matter how skilled the Black Belt, nor how long he or she works on this process, there is little hope of getting it to the 6σ quality level of only 3.4 ppm.

Therefore, to achieve 6σ quality levels on the shop floor, forward-thinking companies must start at the beginning, with the design of the product and the process that will produce it. Improving a product in the design phase is almost always much easier (and much cheaper) than attempting to make improvements after it is in production. By preventing future problems, DFSS is definitely a much more proactive approach than the DMAIC strategy, which is mainly used to fix existing problems.

In addition, DFSS ensures that processes will still make good products even if the key process input variables change, as they often do over time. Processes designed with DFSS will also be easy to maintain, have less downtime, consume a minimum amount of energy and materials, generate less waste, require a bare minimum of work in process, produce almost no defects (both internal and external), operate at low cycle times, and provide better on-time delivery. With an efficiently designed process, fewer resources are consumed during production, thereby conserving energy, reducing pollution, and generating less waste to dispose of—all important benefits to society and our environment.

By designing products to be less sensitive to variation in factors that cannot be controlled during the customer's duty cycle, they will have better quality, reliability, and durability. These enhancements result in a long product life with low lifetime operating costs. If the product is designed to be recycled, it can also help conserve our scarce natural resources.

When DFSS is done right, a company will generate the right product, with the right features, at the right time, and at the right cost.

About this Book

One of Andy's goals in writing this book was to share the many valuable insights and ideas about process improvement that he has accumulated over his years of work in this field. In addition to accomplishing that objective, Andy has kept his book practical; meaning that he discusses the various statistical techniques without burying them in theoretical details. This allows him to devote the majority of his discussion to (1) illustrating the proper application of the methods and (2) explaining how to correctly interpret and respond to the experimental results. I believe Andy's approach achieves the right balance for the majority of practicing Black Belts; not too theoretical, not too simplistic, yet extremely useful.

You will discover that this book is written in a straightforward approach, making the concepts presented easy to understand. It is packed with lots of practical, real-life examples based on Andy's extensive experiences applying these methods in companies from numerous industries. Most of these case studies highlight what the data can tell us and what they can't. As an added benefit, he includes numerous step-by-step demonstrations of how to use Excel and/or MINITAB to handle the mundane "number crunching" involved with most statistical analyses.

This book would definitely make an excellent addition to every Black Belt's library, especially if he or she is involved with product and/or process design.

With this book, Andy, you have certainly made this former teacher of yours very proud of your continuing contributions to the quality field.

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PREFACE

As an engineer realizing the benefits of statistical methods in my work, I found few reference materials that adequately answered my questions about statistics without inundating me by theory. The everyday challenges of planning experiments, analyzing data, and making good decisions require a rich variety of statistical tools with correct, concise, and clear explanations. Later in my career, as a statistician and Six Sigma Black Belt, I found that statistical books for the Six Sigma community were particularly inadequate to address the needs of practicing engineers. In the process of simplifying statistical tools for a mass audience, many books fail to explain when each tool is appropriate or what to do if the tool is inappropriate.

In this book, I attempt to fill this gap. The 59 tools described here represent the most practical and effective statistical methods available for Six Sigma practitioners in manufacturing, transactional, and design environments. While reasonably priced statistical software supports most of these tools, other tools are simple enough for hand calculations. Even in the computer age, simple hand tools are still important. Six Sigma practitioners who can sketch a stem-and-leaf diagram or perform a Fisher sign test or a Tukey end-count test will enjoy the benefits of their rapid, accurate decisions.

This book differs from other statistical and Six Sigma texts in several ways:

- Tools are organized and chapters are titled according to the results to be attained by using the tools. For example, Chapter 7 introduces hypothesis tests under the title "Detecting Changes."
- As far as practical, this book presents confidence intervals with the estimators they support. Since confidence intervals express the precision of estimators, they ought to be an integral part of every estimation task. Organizing the book in this way makes it easier for practitioners to use confidence intervals effectively.
- Recipes are necessary to perform complex tasks consistently and correctly. This book provides flow charts and step-by-step recipes for applying each tool. Sidebar boxes provide deeper explanations and answer common technical questions about the tools.

As an engineer and statistician, this is a reference book I always wanted but could not find. I am grateful for the opportunity to write this book, and I hope others will find these tools as useful as I have.

Using this Book

Although the chapters in this book are sequential, each chapter is written to minimize its dependency on earlier chapters. People who need a quick solution may find what they need by jumping directly to the appropriate section. Those who read the chapters in order will gain greater understanding and insight into why the tools work and how they relate to each other and to practical applications.

Chapter 1 introduces DFSS terminology and lists the 59 tools discussed in this book. An example of robust design illustrates the power of DFSS tools.

Chapter 2 focuses on graphical tools as means of visual analysis. Since graphs play vital roles in decision making, the examples illustrate the importance of graphical integrity.

Chapter 3 presents rules of probability and tools for describing random variables. This chapter provides theoretical background for the rest of the book.

Chapter 4 introduces point estimators and confidence intervals for many common Six Sigma situations, including reliability estimation.

Chapter 5 provides measurement systems analysis tools for variable and attribute measurement systems.

Chapter 6 discusses process capability metrics, control charts, and capability studies.

Chapters 7 through 9 provide tools of hypothesis testing, with applications to Six Sigma decision-making scenarios. Chapter 7 presents tests that assume a normal distribution. Chapter 8 presents tests for discrete and categorical data. Chapter 9 presents goodness-of-fit tests and alternative procedures for testing nonnormal distributions.

Chapter 10 discusses the design, execution, and analysis of experiments. This chapter emphasizes efficient experiments that provide the right answers to the right questions with minimal effort.

Chapter 11 teaches tolerance design tools, which engineers use to analyze and optimize the statistical characteristics of their products, often before they build a single prototype.

This book includes two types of boxed sidebars containing specialized information for quick reference.

How to …

Perform a Task with Software

This style of sidebar box contains click-by-click instructions for performing a specific task using a commercial software application. Written for new or occasional users, this sidebar box explains how to duplicate examples in the book or how to implement statistical tools using the features provided by the software.

Learn more about …

A Specific Tool

This style of sidebar provides technical background for specific tools. Optional reading for those who simply want a recipe, these boxes answer some common technical questions, such as “Why does the standard deviation formula have $n - 1$ and not n?”

The examples in this book illustrate applications of statistical tools to a variety of problems in different industries. The most common theme of these examples is manufacturing of electrical and mechanical products. Other examples are from software, banking, food, medical products, and other industries. Readers will benefit most by thinking of applications for each tool in their own field of business.

Many examples present data without any units of measurement. This is an intentional device allowing readers to visualize examples with English or SI units, as appropriate for their environment. In practice, engineers should recognize that real data, tables, and graphs must always include appropriate labels, including all relevant units of measurement.

Selecting Software Applications

Most of the tools in this book require statistical software. In a competitive market, practitioners have many software choices. This book illustrates statistical tools using the following products, because they are mature, well-supported products with wide acceptance in the Six Sigma community:

MINITAB® Statistical Software. Illustrations and examples use MINITAB Release 14.

Crystal Ball® Risk Analysis Software. Crystal Ball provides simulation tools used for tolerance design and optimization. Crystal Ball professional edition includes OptQuest® optimization software, required for stochastic optimization. Examples in this book use Crystal Ball 7.1.

Microsoft® Excel. Excel provides spreadsheet tools adequate for many of the