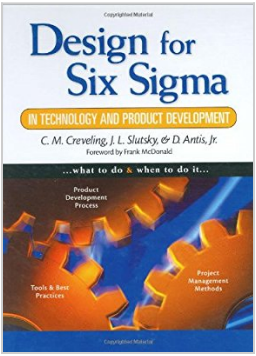

Design for Six Sigma in Technology and Product Development

By Clyde M. Creveling, Jeff Slutsky, Dave Antis

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Editorial Review

From the Back Cover

- Implementing DFSS at the critical early stages of technology development and product design
- Linking DFSS to best-practice tools and project management practices
- Leveraging Critical Parameter Management, a breakthrough in the management of complex product development
- Step-by-step techniques, detailed flow diagrams, scorecards, and checklists

Build Six Sigma quality into the critical early stages of technology development and product design.

Technology companies can only achieve the full benefits of Six Sigma if they implement it proactively, starting with the earliest stages of technology development and product design. To succeed, they must tightly link Design For Six Sigma (DFSS) to the phases and gates of a well-structured product development process, and carefully manage it through a rigorous project management discipline. *Design for Six Sigma in Technology and Product Development* is the first book to show them how. Coverage includes:

- Proven techniques for integrating DFSS with program and cycle-time management, technology development, product design, system architecture, and system engineering processes
- Comprehensive coverage of Critical Parameter Management (CPM), the breakthrough technique for managing complexity in product development
- Step-by-step techniques and flow diagrams for integrating DFSS tools and best practices into development and design
- Practical scorecards and checklists for applying DFSS concepts in modern Phase-Gate processes
- Crucial leadership, financial, and value management issues associated with successful DFSS deployment

Design for Six Sigma in Technology and Product Development is a serious text for serious practitioners-and an essential resource for anyone committed to maximizing quality in technology and product development.

Process Improvement Series

Foreword by Frank McDonald, Motorola University

> "The authors of this book have worked as designers and consultants leading the transition from build, test, and fix to disciplined, fact-based designs that delight customers and stakeholders alike. I am not aware of any other book that discusses Design for Six Sigma in such a comprehensive and practical way as this one. This is the right book for leaders and designers who want to change from hoping for the best to expecting the best."

—Steve Schaus, VP of Operational Excellence, Sequa Corporation

About the Author

Clyde "Skip" Creveling is the president and founder of Product Development Systems & Solutions Inc.

(PDSS) (http://www.pdssinc.com). Since PDSS' founding in 2002, Mr. Creveling has led Design for Six Sigma (DFSS) initiatives at Motorola, Carrier Corporation, StorageTek, Cummins Engine, BD, Mine Safety Appliances, Callaway Golf, and a major pharmaceutical company. Prior to founding PDSS, Mr. Creveling was an independent consultant, DFSS Product Manager, and DFSS Project Manager with Sigma Breakthrough Technologies Inc. (SBTI). During his tenure at SBTI he served as the DFSS Project Manager for 3M, Samsung SDI, Sequa Corp., and Universal Instruments.

Mr. Creveling was employed by Eastman Kodak for 17 years as a product development engineer within the Office Imaging Division. He also spent 18 months as a systems engineer for Heidelberg Digital as a member of the System Engineering Group. During his career at Kodak and Heidelberg he worked in R&D, Product Development/Design/System Engineering, and Manufacturing. Mr. Creveling has five U.S. patents.

He was an assistant professor at Rochester Institute of Technology for four years, developing and teaching undergraduate and graduate courses in mechanical engineering design, product and production system development, concept design, robust design, and tolerance design. Mr. Creveling is also a certified expert in Taguchi Methods.

He has lectured, conducted training, and consulted on product development process improvement, design for Six Sigma methods, technology development for Six Sigma, critical parameter management, robust design, and tolerance design theory and applications in numerous U.S, European, and Asian locations. He has been a guest lecturer at MIT, where he assisted in the development of a graduate course in robust design for the System Design and Management program.

Mr. Creveling is the author or coauthor of several books, including *Six Sigma for Technical Processes*, *Six Sigma for Marketing Processes*, *Design for Six Sigma in Technology and Product Development*, *Tolerance Design*, and *Engineering Methods for Robust Product Design*. He is the editorial advisor for Prentice Hall's Six Sigma for Innovation and Growth Series.

Mr. Creveling holds a B.S. in mechanical engineering technology and an M.S. from Rochester Institute of Technology.

J. L. Slutsky has 20 years' experience designing and developing complex medical and image processing products. He is now Master Consultant for a major Six Sigma Consulting firm, specializing in DFSS, statistical engineering, robust design, and product development best practices.

D. Antis, Jr., CEO of a new global consulting firm and former Vice President of Operations for SBTI, has deployed DFSS for over a dozen clients, drawing on best practices from Motorola, Kodak, GE, Black & Decker, and other leading firms. He formerly served as European Director of Operational Excellence and Total Quality for the Engineered Materials Sector of AlliedSignal, overseeing quality initiatives throughout Europe.

Preface

In its simplest sense, DFSS consists of a set of needs-gathering, engineering and statistical methods to be used during product development. These methods are to be imbedded within the organization's product development process (PDP). Engineering determines the physics and technology to be used to carry out the product's functions. DFSS ensures that those functions meet the customer's needs and that the chosen technology will perform those functions in a robust manner throughout the product's life.

DFSS does not replace current engineering methods, nor does it relieve an organization of the need to pursue excellence in engineering and product development. DFSS adds another dimension to product development, called Critical Parameter Management (CPM). CPM is the disciplined and focused attention to the design's functions, parameters, and responses that are critical to fulfilling the customer's needs. This focus is maintained by the development team throughout the product development process from needs gathering to manufacture. Manufacturing then continues CPM throughout production and support engineering. Like DFSS, CPM is conducted throughout and embedded within the PDP. DFSS provides most of the tools that enable the practice of CPM. In this light, DFSS is seen to coexist with and add to the engineering practices that have been in use all along.

DFSS is all about preventing problems and doing the right things at the right time during product development. From a management perspective, it is about designing the right cycle-time for the proper development of new products. It helps in the process of inventing, developing, optimizing, and transferring new technology into product design programs. It also enables the subsequent conceptual development, design, optimization, and verification of new products prior to their launch into their respective markets.

The DFSS methodology is built upon a balanced portfolio of tools and best practices that enable a product development team to develop the right data to achieve the following goals:

1. *Conceive* new product requirements and system architectures based upon a balance between customer needs and the current state of technology that can be efficiently and economically commercialized.
2. *Design* baseline functional performance that is stable and capable of fulfilling the product requirements under nominal conditions.
3. *Optimize* design performance so that measured performance is robust and tunable in the presence of realistic sources of variation that the product will experience in the delivery, use, and service environments.
4. *Verify* systemwide capability (to any sigma level required, 6s or otherwise) of the product and its elements against all the product requirements.

DFSS is managed through an integrated set of tools that are deployed within the phases of a product development process. It delivers qualitative and quantitative results that are summarized in scorecards in the context of managing critical parameters against a clear set of product requirements based on the "voice of the customer." In short it develops clear requirements and measures their fulfillment in terms of 6s standards.

A design with a critical functional response (for example, a desired pressure or an acoustical sound output) that can be measured and compared to upper and lower specification limits relating back to customer needs would look like the following figure if it had 6 sigma performance.

The dark black arrows between the control limits (UCL and LCL, known as *natural tolerances* set at 1/2 3 standard deviations of a distribution that is under statistical control) and the specification limits (USL and LSL, known as VOC-based performance tolerances) indicates design latitude that is representative of 6 sigma performance. That is to say, there are 3 standard deviations of latitude on each side of the control limit out to the specification limit to allow for shifts in the mean and broadening of the distribution. The customer will not feel the variability quickly in this sense. If the product or process is adjustable, there is an opportunity to put the mean back on to the VOC-based performance target or to return the distribution to its desired width within its natural tolerances. If the latitude is representative of a function that is not serviceable or adjustable, then the latitude is suggestive of the reliability of the function if the drift off target or distribution broadening is measured over time. In this case, Cp (short-term distribution broadening with no mean shift) and Cpk metrics (both mean shifting and distribution broadening over long periods of time) can be clear indicators of a design's robustness (insensitivity to sources of variation) over time. DFSS uses capability metrics to aid in the development of critical product functions throughout the phases and gates of a product development process.

Much more will be said about the metrics of DFSS in later chapters. Let's move on to discuss the higher level business issues as they relate to deploying DFSS in a company.

At the highest level, any business that wants to excel at product development must have the following three elements in strategic alignment:

Design For Six Sigma fits within the context of a key business process, namely the product development process. DFSS encompasses many tools and best practices that can be selectively deployed during the phases of a product development process. Specifically, DFSS integrates three major tactical elements to help attain the ubiquitous business goals of low cost, high quality, and rapid cycle-time from product development:

1. A clear and flexible product development process
2. A balanced portfolio of development and design tools and best practices
3. Disciplined use of project management methods

The product development process controls the *macro-timing* of what to do and when to do it using a flexible structure of phases and gates. A balanced portfolio of tools and best practices are what to do within each phase of the product development process. The disciplined application of project management in the form of PERT charts of work breakdown structures defines the *micro-timing* for the critical path of applying tools and best practices within each phase.

DFSS works equally well in technology development organizations and in product design organizations. This book will demonstrate complete approaches to applying DFSS in both a technology development process and a product design process.

The metrics of DFSS break down into three categories:

1. Cycle-time (controlled by the product development process and project management methods)
2. Design and manufacturing process performance capability of critical-to-function parameters (developed by a balanced portfolio of tools and best practices)
3. Cost of the product and the resources to develop it

DFSS is focused on CPM. This is done to identify the few variables that dominate the development of baseline performance ($Y_{avg.}$), the optimization of robust performance (S/N and δ), and the certification of capable performance (Cp and Cpk) of the integrated system of *designed parameters*. DFSS instills a system integration mind-set. It looks at all parameters—within the product and the processes that make it—as being important to the integrated performance of the system elements, but only a few are truly critical.

DFSS starts with a sound business strategy and its set of goals and, on that basis, flows down to the very lowest levels of the design and manufacturing process variables that deliver on those goals. To get any structured product development process headed in the right direction, DFSS must flow in the following manner:

- ***Define business strategy****: Profit goals and growth requirements*
- ***Identify markets and market segments****: Value generation and requirements*
- ***Gather long-term voice of customer and voice of technology trends***
- ***Develop product line strategy****: Family plan requirements*
- ***Develop and deploy technology strategy****: Technology and subsystem platform requirements*

- ***Gather product specific VOC and VOT****: New, unique, and difficult needs*
- ***Conduct KJ analysis****: Structure and rank the VOC*
- ***Build system House of Quality****: Translate new, unique, and difficult VOC*
- ***Document system requirements****: New, unique, and difficult, and important requirements*
- ***Define the system functions****: Functions to be developed to fulfill requirements*
- ***Generate candidate system architectures****: Form and fit to fulfill requirements*
- ***Select the superior system concept****: Highest in feasibility, low vulnerability*

DFSS tools are then used to create a hierarchy of requirements down from the system level to the subsystems, subassemblies, components, and manufacturing processes. Once a clear and linked set of requirements is defined, DFSS uses CPM to measure and track the capability of the evolving set of Ys and xs that comprise the critical functional parameters governing the performance of the system. At this point DFSS drives a unique synergy between engineering design principles and applied statistical analysis methods. DFSS is not about statistics—it is about product development using statistically enabled engineering methods and metrics.

DFSS does not require product development teams to measure quality and reliability to develop and attain quality and reliability. Product development teams apply DFSS to analytically model and empirically measure fundamental functions as embodied in the units of engineering scalars and vectors. It is used to build math models called *ideal* or *transfer functions* Y 5 f(x) between fundamental ($Y_{response}$) response variables and fundamental (x_{inputs}) input variables. When we measure fundamental ($Y_{response}$) values as they respond to the settings of input (x_{inputs}) variables, we avoid the problems that come with the discontinuities between continuous engineering input variables and counts of attribute quality response variables.

DFSS avoids counting failures and places the engineering team's focus on measuring real functions. The resulting fundamental models can be exercised, analyzed, and verified statistically through Monte Carlo simulations and the sequential design of experiments.

Defects and time-to-failure are not the main metrics of DFSS. DFSS uses continuous variables that are leading indicators of impending defects and failures to measure and optimize critical functional responses against assignable causes of variation in the production, delivery, and use environments. We need to prevent problems—not wait until they occur and then react to them.

If one seeks to reduce defects and improve reliability, avoiding attribute measures of quality can accelerate the time it takes to reach these goals. You must do the hard work of measuring functions. As a result of this mind-set, DFSS has a heavy focus in measurement systems analysis and computer-aided data acquisition methods. The sign of a strong presence of DFSS in a company is its improved capability to measure functional performance responses that its competitors don't know they should be measuring and couldn't measure even if they knew they should! Let your competitors count defects—your future efficiencies in product development reside in measuring functions that let you prevent defective design performance.

DFSS requires significant investment in instrumentation and data acquisition technology. It is not uncommon to see companies that are active in DFSS obtaining significant patents for their inventions and innovations in measurement systems. Counting defects is easy and cheap. Measuring functions is often difficult and expensive. If you want to prevent defects during production and use, you have to take the hard fork in the metrology road back in technology development and product design. Without this kind of data, CPM is extremely difficult.

The technical metrics of Critical Parameter Management in DFSS are as follows:

Information is represented by analog and digital logic and control signals.

What to measure is the mass, energy, and controlling signals within and across your systems. *When to measure* is defined by your micro-timing diagram (*critical path*) of tool and best practice applications within the phases of your product development process.

The underpinnings of DFSS deserve a brief review before we turn you loose on the rest of the book. DFSS, like Six Sigma for Production Operations, follows a roadmap. Six Sigma for Production Operations follows a process roadmap outlined by the **MAIC** acronym, which stands for **M**easure, **A**nalyze, **I**mprove, and **C**ontrol. This is based, in large part, on the historic work of Walter Shewhart when he devised the underlying principles of statistical process control for production processes. Unfortunately this has little to do with the *process* of product development. Many in the Six Sigma business have tried to tell the R&D community that all they need to do is put a "**D**" in front of the MAIC process and voilá! you get DFSS. NOT TRUE!!! Define, measure, analyze, improve, and control is not a proper process recipe for product development. We know many have started DFSS within this SPC context, but there is a better, more appropriate process context in which to conduct DFSS.

This book is written by technology development and product design engineers for readers with the same or similar backgrounds. A major part of the book's intent is to establish a proper set of roadmaps that fit the paradigms and process context of technology development and product development. These roadmaps are set up in the format of a Phase/Gate product development process structure.

The I^2DOV Technology Development Process Roadmap:

- Invent and Innovate Phase and Gate
    - Develop Phase and Gate
        - Optimize Phase and Gate
            - Verify Phase and Gate

The CDOV Product Design Process Roadmap:

- Concept Development Phase and Gate
    - Design Development Phase and Gate
        - Optimization Phase and Gate
            - Verification of Capability Phase and Gate

As much as we love and respect the MAIC process for production and transactional processes, it simply has no rational application context for DFSS, if you run your company based on a modern product development process. Leaders such as Admiral Raborn of the Polaris program or later proponents such as Cooper, Wheelwright and Clark, or Clausing and Pugh might be reasonable candidates to be the patron saints of modern Phase/gate product development processes, but it surely is not and should not be Walter Shewhart! Shewhart and his process provide great historical underpinnings for production operations; however, we will not lean too heavily on his work, at least as far as running the phases and gates of a product development process, until the final steps in transitioning from product design into production. In that sense, then, the I2DOV technology development process roadmap flows into the CDOV product design process roadmap, which in turn flows into the DMAIC production process roadmap.

This book is organized in seven sections:

1. Organizational Leadership, Financial Performance, and Value Management Using Design For Six Sigma
2. Product Development Processes Using Design For Six Sigma
3. Critical Parameter Management in Design For Six Sigma

4. Tools and Best Practices for Invention, Innovation, and Concept Development
5. Tools and Best Practices for Design Development
6. Tools and Best Practices for Optimization
7. Tools and Best Practices for Verifying Capability

These sections will build on this brief introduction to the disciplined and rigorous world of DFSS for technology and product development. We hope you enjoy this overview describing what "hard stuff" your technology and product development teams need to do (and when they need to do it) in order to take your company to the next level of success in our evolving world of product development excellence.

How to Get the Most From This Book

This text on DFSS was written to serve several types of readers:

1. Executives, R&D directors and business leaders
2. Program managers, project managers and design team leaders
3. Technical practitioners who comprise design teams

If you are an executive, R&D director, or some other form of business leader, we wrote the Introduction and Part I for you.

If you are a program manager, project manager, or a design team leader, we wrote Parts II and III primarily for you.

If you are a technical practitioner who will be applying the tools of DFSS on technology and product design programs and projects we wrote the Tool chapters in Parts IV through VII for you.

An extensive glossary at the end of the book is intended for all readers.

Parts II through VII of this book were designed to serve as a reference to be used over and over as needed to remind and refresh the reader on what to do and when to do it during the phases and gates of technology development and product design. These parts can be used to guide your organization to improve discipline and rigor at gate reviews and to help redesign your product development process to include Six Sigma metrics and deliverables.

If you want to understand any DFSS tool and its deliverables prior to a gate review, we recommend reading the appropriate tool chapter(s) prior to the gate review.

—Skip Creveling
Jeff Slutsky
Dave Antis

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