INTRODUCTION

The increased rate of change of technology and the speed at which companies now can adopt new technology has reduced the “new toy,” or first-to-market, effect in many industries. Today, consumers take for granted that every company will incorporate the newest available technology in its products. Customers want the newest features while getting the best value for their money. This is true whether the customer is a purchaser of medical devices for a health maintenance organization, a government agent purchasing multi-million-dollar defense equipment, or an everyday consumer of digital cameras. Because of these customer expectations, operational efficiency—the ability to quickly and reliably design and produce high-quality products at low cost—is now a major differentiating factor between companies. Operational efficiency drives profit, return on investment, and ultimately, shareholder value. It is companies that can bring well-designed new products to market quickly, operate efficiently with minimal overhead, and produce high-quality products with minimal scrap or rework that will succeed and grow.

A critical factor in operational efficiency is the ability to design and build high-quality products. This book focuses on one aspect of quality: variation in product dimensions and features and its impact on the performance, cost, and safety of a product. Variation in production impacts many aspects of operational efficiency (Fig. 1-1): inventory, touch time, warranty and product returns, and capacity utilization. Ultimately, variation increases waste and reduces profit.

When observing quality initiatives of many companies, one sees an interesting contradiction emerge. Most companies talk about the importance of
designing and building high-quality products that are robust to variation and produced at a low cost. They can quote fluently such authors as Crosby, Deming, and Taguchi (Crosby, 1979; Deming, 1986; Taguchi, 1992) and many have Six Sigma Black Belts on staff. However, when actually designing a product, they say, “Robust design is great, but we cannot apply it everywhere. We just don’t have time.” Schedule takes precedence, and consequently, manufacturing often is handed a product that is difficult to build reliably with a high degree of quality. The question arising from this contradiction is: “If companies understand variation reduction tools and the need for them, why do companies continually struggle to apply them?”

A similar contradiction is apparent in regard to products already being manufactured. Organizations understand the need to improve product quality to save cost. They have many tools in place to do variation reduction including Six Sigma, continual process improvements, Total Quality Management (TQM), and statistical process control (SPC), to name a few, but after an initial push do not continue the efforts. They do provide adequate support to help employees understand where to apply the tools. People identify Six Sigma projects without questioning where variation is showing the most impact across the organization. Often the easy projects are identified—not the right ones. In some cases, companies are able to show polished presentations of current quality improvement projects; however, it is often the case that few projects are completed; or, if they are, returns are never as large as promised.
In some cases, implications of a change on the whole organization are not understood and improvements in one area increase costs in others. For example, measurements can be added to control variation; but the step creates a bottleneck in the factory, increasing cycle time and increasing back orders. Although the cost of variation for one group goes down, the total cost to the organization goes up. Other companies with successful Six Sigma programs can demonstrate that their projects have a positive return on investment but can not demonstrate that the projects they picked were the best projects to work on. Given the cost of deploying a Six Sigma or variation reduction program, it is a waste to not assign teams to projects with the highest return on investment and ensure the projects are completed.

In a large range of companies—from automotive to aerospace to medical to component manufacturers—familiarity with tools is not the problem. Three interrelated challenges face companies that wish to successfully apply these tools. First, companies often do not know how to apply limited

**Why Is Product Development Difficult?**

Several quality experts have stated that “quality is free” (i.e., any improvement in quality will return a positive return on investment (ROI)) and that it is less costly to build a good product than to build a defective product. This is true in the production environment. Once a product is in full production, it is easy to identify problems, fix them, and quantify the returns. Most improvements will have a net positive return. However, in design the cost/benefit tradeoff is not as clear.

It is much more difficult and costly to design a good product than to design a bad one. Good product development requires thought, many iterations, and the willingness to challenge your immediate assumptions about the best solution. In addition, designing for cost-effective quality involves multidimensional trade-offs. The design team needs to simultaneously consider the product requirements, cost, manufacturing processes, and variation. Teams also need to be supplied with the right tools and data to be able to successfully balance these often competing requirements. Work done to remove the sources and impact of variation in the design phase can have a significant and beneficial impact on the overall quality and cost of the product. However, it is often not possible to quantify the benefit derived from the effort spent during the design process.
resources effectively. Schedules dictate time spent in product development. In production, a limited number of people are allocated to manufacturing process improvement. Second, teams do not know how to agree on the most critical issues and come to a consensus on how to address them. As a result, organizations tend to operate in a fire-fighting mode and have too many ongoing projects that are rarely finished on time. Third, quality is typically addressed on a part-by-part basis rather than optimizing quality and its impact across the entire organization.

To address these challenges, the methodology entitled variation risk management (VRM) was developed. VRM refers to the proper allocation of limited resources to variation control efforts in order to improve quality and reduce cost as efficiently and effectively as possible. In other words, given a large number of opportunities to apply variation control and reduction tools, variation risk management identifies the best opportunities on which to focus. The VRM methodology is based on two fundamental concepts: (1) a holistic view of variation and (2) the identification, assessment, and mitigation (I-A-M) process. Variation risk management can be applied either proactively in the product development process or to an existing product. Variation risk management requires the integration and participation of all functional groups that have influence over product quality, including design engineering, manufacturing, quality, system engineering, customers, procurement, and suppliers.

The existing literature on variation and quality is substantial. A simple search returned 94 books on Six Sigma, 43 books on product development and quality, and 151 books on SPC some of which are listed in the bibliography. Given the amount of material on variation reduction, why write another book? Most books on the market talk about applying specific techniques such as Six Sigma, SPC, robust design, variation reduction, and manufacturing process improvement. Still others promote the importance of quality and reducing variation, but only provide minimal guidelines on the technical and practical aspects of implementing a program.

This book presents proven quantitative methods that have helped many product development and production organizations effectively and efficiently reduce the total impact and cost of variation. The VRM methodology has helped companies identify key areas for improvement, significantly reduce cost, and improve quality. It has been used to guide where Six Sigma, robust design, and other quality improvement efforts are applied to get the best re-

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1The term process has many meanings in this book. We will differentiate by describing what type of process we are discussing—for example, manufacturing processes (those that are used to build the product) versus product development processes (those used to design the product).
The tools in this book have been used on a wide range of products and technologies including aircraft, automotive, engine design, medical devices, electromechanical devices, optical assemblies, printed wiring boards, and microelectronics.

This book is fundamentally different from other quality and product development books in that it presents quantitative methods, teaches you to look at a product as a system rather than as individual parts, shows you how to target limited resources, and provides methods for ongoing tracking and reduction of variation costs. It provides a fact-based and rigorous approach enabling teams to agree on priorities. One goal of this book is also to demystify the “magic” used by consultants to analyze organizations. It will teach the reader how to think holistically about variation in products.

Some tools presented in the book are good engineering put in a clear framework. This book will help the entire organization to behave in the same way that your best engineers do. In addition new tools that have not appeared before are presented.

1.1. THE COMPETITIVE ADVANTAGE OF VRM

The Ability to Reduce the Impact of Variation Is Critical to Being Competitive. Companies that minimize variation successfully will see lower costs and higher customer satisfaction. CEOs and Wall Street value bottom line improvements because savings accrued by a company can have a large impact on shareholder value. For example, if a company trades at a P/E (price to earnings) ratio of 10 to 1, a recurring saving of $1 million after tax can increase total equity value of the company by $10 million. An organization can use variation risk management tools to:

- **Develop Better Products.** As has been pointed out in a large number of books and articles, the product development team has the greatest control over both cost and quality early in product development (Fig. 1-2). The earlier that variation is used as a criteria to select concepts, parts, and manufacturing processes, the better. When teams address variation late in the product delivery processes, their choices and options for reducing the impact of variation are more limited, are more expensive, and have a smaller impact. The VRM methodology helps teams efficiently identify the best opportunities to improve the design early, resulting in improved customer satisfaction, less scrap and rework, fewer defects, and a leaner production process.

- **Avoid Excessive Precision in Parts.** To avoid potential defects, it is tempting to include expensive precision parts “just in case.” Tightening turns.
the specifications limits is often used to mitigate quality issues, but this approach often adds excess costs and decreases operational efficiency. Teams must have a thorough understanding of the acceptable level of variation in order to choose the appropriate quality level of parts and manufacturing processes. The VRM methodology identifies parts that have the largest impact on product quality and allows the team to effectively prioritize where additional precision is required and identify alternative, less costly solutions.

- **Allow Faster Transition to Production.** Transition to production is the stage in product development when the product is introduced into the factory and production rates are vamped to full production. During this time, the team works out any bugs in the product and manufacturing processes. It is expensive to redesign at this stage because equipment and tooling has already been purchased and installed. Proactive variation risk management can reduce the number of yield and quality issues that surface during transition to production as well as reduce the time to identify and fix unexpected issues.

- **Continually Improve Product Quality and Reduce Cost Throughout the Life Cycle of the Product.** Companies can lose market share be-
cause of a real (or perceived) problem with quality. Proactive variation risk management will help organizations improve product quality before it gets into a customer’s hands. In addition, VRM helps identify why products are being returned and links customer return data to manufacturing processes and, best of all, to product design.

- **Reduce Rework and Scrap.** Rework and scrap waste time and resources without providing long term benefits. The occurrence of scrap and rework indicates potential problems, which include a less than robust product design or excessive variation in production processes. Not only do rework and scrap increase the average labor content of a product; they also impact flow through the factory. VRM ensures, through good design, that the product will have a lower scrap and rework rate. During production, VRM identifies key opportunities for reducing costs and quickly implements solutions.

- **Increase Interchangeability and Replaceability.** In military and aerospace applications, the term “interchangeable and replaceable” refers to the ability to replace parts or systems on a product without rework tuning or custom fitting. For example, historically, doors on aircraft were built to match individual aircraft. If a door got damaged, it was not possible to simply install a new door; it had to be custom-fit specifically to the plane. Low variation in mating parts, and robust assembly schemes reduce the need for individual part adjustment, thus reducing the labor required in the manufacturing process and decreasing ongoing maintenance costs. Improving interchangeability is especially important for airlines, where delayed or grounded aircraft cause great expense and poor customer satisfaction.

**The Ability to Utilize Limited Resources Effectively to Control the Impact of Variation Is a Competitive Advantage.** Variation control tools are not new, nor are they proprietary or patentable. Every company has access to the same tools and methods; any company can develop or purchase a Six Sigma program or hire an SPC expert. Using variation reduction tools only brings a company to the same level playing field. If executed poorly, these programs can have no effect at best, and at worst, negative effects such as delaying the launch of a design or consuming significant resources in production.

Companies must ask themselves, “Given that my competitor has access to the same tools, how do I apply them more effectively, get better results, and spend less money?” One way to improve operational efficiency is to use variation risk management for planning and execution. This means making decisions about design concept, manufacturing processes, and part tolerances that minimize the cost, performance, and safety impacts of variation at the lowest cost with minimal impact to the product development schedule. In
production, this means (among other things) picking projects that will have
the highest return on investment for the entire enterprise (not just one func-
tion) and executing them to get returns quickly. In summary, organizations
need to manage variation, not just reduce it.

1.2. GUIDE TO READERS

This book teaches the reader how to determine where to apply variation re-
duction and quality tools given a limited set of resources. It describes quanti-
tative tools and methods (illustrated with examples) that will provide a com-
petitive advantage in developing, producing, and delivering products. These
methods can be applied during either product development or production. Ide-
ally, variation risk management should be included in the way of doing busi-
ness rather than as a separate program. This book provides guidelines on the
implementation of corporate-wide variation risk management programs.
However, individuals or teams looking for tools and methods to apply immedi-
ately can use individual chapters and subsections to guide their efforts. This

Low versus High Volume—Does VRM Apply?

While many products are produced at high volume, there is also a wide
range of products produced at a low volume—for example, aircraft
and satellites. A low production volume is often used as an excuse not
to apply variation management tools in design and production. In fact,
variation risk management is as or more critical in low-volume prod-
ucts for several reasons.

First, low-volume products are typically more likely to require sig-
ificant rework and tuning to perform correctly. Rework and tuning
are expensive, especially considering the cost of the parts and labor.
Second, products that need to be tweaked in the factory are more likely
to experience field failures because they typically function on the edge
of their operating ranges. Third, often technology and processes de-
veloped for one low-volume product will be reused for future product
generations. While the initial production volumes are low, the end re-
sult is a relatively high volume. Because of these factors, ensuring a
design that is insensitive to the existing process variation is critical to
the cost, performance, and quality and ultimately the profitability of
any low-volume or high-volume product.
book assumes that the organization is using an integrated product team (IPT) approach to product design where representatives from all functional groups are involved throughout the product development process (see Chap. 10).

What should you expect to get out of this book?

- A set of tools for identifying where to apply variation reduction techniques and guidance on what techniques to apply
- The opportunity to use real data from your factory, previous designs, and financial reports to prioritize efforts and create a plan for addressing your specific variation issues
- Project management guidelines that will keep your team on track and focused
- Knowledge of common pitfalls so you can avoid them
- An implementation template from which you can design your own VRM program

What types of people will be helped by this book?

- **Those Who Have Been Told to Implement a Variation Reduction Program** (VRM Implementation Leaders). Often, a small team is tasked with identifying and developing a company-wide program for implementing a variation risk management program. This book provides necessary information for developing such a program.
- **Product Leaders Who Want to Apply VRM to a New Product** (Product Leaders). This book provides a step-by-step guide to integrating variation risk management into a product development process.
- **Plant Managers Interested in Reducing Production Costs and Improving Quality** (Production Leaders). This book provides a step-by-step guide to implementing a variation risk management program for products already in production. It will teach techniques to track ongoing quality costs and identify key areas for improvement.
- **Those Who Have Been Asked to Identify Six Sigma Projects** (Six Sigma Champion). This book helps identify where to apply Six Sigma projects to get the most benefit out of limited resources.
- **Members of Integrated Product Teams Asked to Apply VRM Tools during Product Development** (Product Development IPT Members). This book gives details of the VRM methodology and specific tools and methods needed to execute it.
- **Members of Teams Requested to Reduce Costs on an Existing Product** (Production IPT Members). This book provides basic tools and methods that are used to execute production improvements.
The book can be used at many different levels and for several purposes. Each chapter provides a broad overview and guide as well as very specific tools and methods. Most chapters are divided into two sections: one for those using VRM in product development and one for those using it on products already in production. Reader types listed above will want to read different sections depending on their needs and level of knowledge. Figure 1-3 shows a map pointing different reader types to the most important chapters for them. A filled-in dot (●) indicates that the reader should read the section in detail, a circle (○) the sections the reader could read in less detail. The sections with no marker may contain information of less interest to the given reader. It is highly recommended that readers identify which chapters should be read first and begin with those.

This book is divided into three sections. The first section (Chaps. 2–8) provides an overview of the entire VRM methodology and details the identification, assessment, and mitigation procedures. The second section (Chapters 9–11) describes organizational structures and requirements for implementing a VRM methodology. Appendixes A, B, C, and D discuss information and implementation tools that can help in deploying VRM within an organization. Each chapter begins with an introduction of the basic concepts covered and then describes, through examples, how to apply them to either a new design or an existing product in production.

The subject matter of the chapters is as follows:

- Chapter 2 introduces basic concepts of variation, a holistic view of variation, and the three-step process of identification, assessment, and mitigation. In addition, it introduces the application of variation risk management in product development and production.
- Chapters 3 through 8 cover the three procedures in the VRM methodology (identification, assessment, and mitigation). Tools and methods for each procedure are presented along with examples.
- Chapter 9 describes how VRM should be integrated into product development, transition to production, and production.
- Chapter 10 provides a list of tasks and responsibilities for each member of the organization, including in-house team members as well as suppliers.
- Chapter 11 provides a structured approach to implementing a VRM program in an organization.
- Chapter 12 reviews the book highlights.
- Appendix A provides a benchmarking tool, the VRM maturity model, used to measure the weakness and strengths of an organization’s VRM process.
- Appendix B describes how to build a database of process capability information that can be used to select processes and assess the capability of achieving tolerances.
Appendix C describes how VRM can be integrated with other improvement initiatives such as Six Sigma, Lean, and Kaizen.

Appendix D provides copies of the flow diagrams for the identification, assessment, and mitigation procedures.

**Figure 1-3.** Chapter map.

- Reader should spend time to read in detail.
- Reader can skim to get main points.