Foreword by Stephen R. Covey, Author, The 7 Habits of Highly Effective People

2nd Edition

Six Sigma FOR DUMMIES®

Learn to:

- Grasp what Six Sigma is and how it works
- Achieve quantum leaps in performance and impact the bottom line
- Utilize the DMAIC problem-solving method

Craig Gygi
Executive VP of Operations, MasterControl
Co-author, Six Sigma Workbook For Dummies

Bruce Williams
Senior Vice President, Software AG
Co-author, Lean For Dummies

with Neil DeCarlo

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About the Authors of the Revised Edition

Craig Gygi began studying and applying the elements of Six Sigma and Lean before they were formalized into today's renowned improvement methodologies. As a graduate student in Mechanical Engineering at Brigham Young University, he integrated these cutting-edge improvement techniques into his coaching of student product development teams. Upon beginning his career at Motorola, he was formally introduced to the emerging Six Sigma method. It resonated deeply with his previous findings. From that time, Craig has applied, taught, and led Six Sigma in all his endeavors, including technical, management, and executive capacities at Iomega, General Atomics, ES3, and Fiji Water.

Craig now serves as Executive VP of Global Operations for MasterControl. MasterControl produces software solutions that enable regulated companies to manage their critical quality procedures and get their products to market faster, while reducing overall costs and increasing internal efficiency.

A Master Black Belt, Craig has wielded Six Sigma and Lean techniques now for over 18 years, spanning projects from design to manufacturing to business process management, and at companies as varied as Abbott Labs, American Express, and the US Air Force. He is also an expert teacher, having instructed and mentored at all levels.

Craig lives in Utah with his wife and children, where they enjoy its varied landscape and outdoor activities.

Bruce David Williams has been fascinated with complex systems since the launch of Sputnik on his birthday. With degrees from the University of Colorado in physics and astrophysics, he embarked on a career in aerospace systems, where he first encountered Six Sigma after Motorola won the inaugural Baldridge Award in 1988. Later, with graduate degrees from Johns Hopkins and Colorado in computer science and technical management, and as a member of the Hubble Telescope development team, he became intrigued with how large system failures could result from the breakdown of small components. He entered the Six Sigma industry in the late-1990s when he co-founded a software company to develop products for life-cycle traceability.

Bruce has since been the co-founder of two Six Sigma research and technology firms, including the Six Sigma Management Institute. He was co-founder and CEO of Savvi International, a provider of solutions for business performance improvement. He joined webMethods in 2006 to integrate enterprise-class information technologies with business process management and now is the Senior Vice President for Software AG, a leading global provider of technologies and solutions for Business Process Excellence.

Bruce resides in the desert foothills of north Scottsdale, Arizona, with his wife and assortment of dogs, cats, birds, horses, and varied native wildlife.

Dedication

Craig Gygi: To Esti, my unexpected joy.

Bruce Williams: To Hannah and Evan, my remarkable children, as they transition into independent adulthood and put the concept of variance reduction to practical use.

About the Co-Author of the First Edition

Neil John DeCarlo was a professional communicator in the continuous improvement, Lean, Six Sigma, sales and marketing, innovation, and corporate finance fields for nearly 25 years, beginning with his work at Florida Power & Light Company when it won the coveted Deming Prize for quality. Following that time, he authored, ghostwrote, or edited more than 150 articles and eight books in association with such companies as General Electric, DuPont, Bose Corporation, BMGI, McKinsey & Company, UPS, AT&T, the Six Sigma Academy, and many others. Neil also worked with several CEOs and consultants, including Japanese quality expert Dr. Noriaki Kano and the original co-architect of Six Sigma, Dr. Mikel Harry.

In addition to his writing accomplishments, Neil managed communication and publishing campaigns for a variety of companies, most notably BMGI, an international consulting firm that teaches and deploys Lean Six Sigma, innovation, and such other methods as Hoshin strategic planning. While not working, Neil enjoyed most all outdoor sports, reading, questioning everything, and practicing yoga. He lived in a small town called Fountain Hills, just outside Scottsdale, Arizona, with Jeannie — his lovely wife and best friend.

Dedication

To Wanda Texon, who helped me believe in myself a long time ago, and who has been a constant source of support and intellectual stimulation for many years.

Authors' Acknowledgments to the 2nd Edition

We're grateful for those who contributed their efforts and support to this 2nd edition of *Six Sigma For Dummies*.

Our deepest gratitude and thanks to Dr. Stephen R. Covey for his foreword — but much more so for his profound life-long insights and contributions to the betterment of individual leadership. Only a few weeks before the printing of this 2nd edition, Dr. Covey passed away. His passing poignantly reminded us of the transcendent power of the individual — both in the example of his own life and his remarkable influence on the world — and in the similar potential he taught resides within each of us.

Thank you also to Natalie Sayer, co-author of both the 1st and 2nd editions of *Lean For Dummies* (Wiley), for her expert collaboration and assistance.

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We're proud of this book; please send us your comments at http://dummies.custhelp.com. For other comments, please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993, or fax 317-572-4002.

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Foreword

The world is on the verge of a new economic era. For the past century, the Industrial Age has been defined by tools and skills targeted at control, efficiency, specialization, delegation, scalability, and replicability. Accounting makes people an expense, a piece of equipment, an investment, and people are motivated by the great jackass theory of the carrot and stick. But although this paradigm has led to a 50-fold increase in productivity over the previous farming mindset, it has also led to a control paradigm, an entrenchment of a "leadership by position" mentality, with organizational hallmarks of lack of clarity regarding high priorities, lack of commitment or emotional connection by the workforce, lack of line-of-sight translation to specific action, disenabling systems and processes, no synergy — interpersonally and interdepartmentally — and a lack of accountability.

Studies show that the vast majority of employees possess far more talent, more intelligence, more capability, more creativity, and more ability than their jobs require or even allow. Their deep potential remains dormant, untapped, and unused. Today, the Industrial Age is ending, and the Information Age or Knowledge Worker Age is opening. This new, emerging age is defined by "leadership is a choice" with an empowerment or unleashing-potential mentality; choices guided by values in the light of unchanging principles. In the new paradigm, the greatest asset in any organization is its people — whole people — with their bodies, minds, hearts, and consciences all engaged and contributing, and all receiving benefit in the progress of the organization. A trim tab is a small rudder on a boat or airplane that, through its relatively small motion, allows the bigger rudder to achieve the greater effect and leverage. The leaders of the Information Age act as trim tabs within organizations. Their relatively small actions at the bottom or middle can effect a much greater change throughout an entire organization.

Six Sigma has become a key enabling skill of the new Knowledge Workers of the next generation of trim tabs. One of the great values I admire of Six Sigma is the science, the database — and the careful analytic thought processes of problem solving using that data. Six Sigma empowers and enables you to effect remarkable change, no matter your position in your organization. The maturing world has transformed the previously exclusive, academic knowledge of Six Sigma into must-have best practices for everyone wishing to advance and contribute. In a knowledge economy where 70 to 80 percent of the value added to goods and services comes from knowledge work, can you imagine the results flowing from having the entire workforce Six Sigma literate?

That's why *Six Sigma For Dummies* is a book to be read by everyone.

Stephen R. Covey

Author, *The 7 Habits of Highly Effective People, The 8th Habit,* and *The Leader in Me: How Schools and Parents Around the World Are Inspiring Greatness, One Child at a Time*

Introduction

Six Sigma is the single most effective problem-solving methodology for improving business and organizational performance. There's not a business, technical, or process challenge that Six Sigma can't improve. The world's top corporations have used it to increase their profits collectively by more than $100 billion over the past ten years. In certain corporations, indicating Six Sigma proficiency on your résumé is now a prerequisite to moving into a position in management.

If you're part of a *Fortune* 500 company — particularly a manufacturing company — you've heard about Six Sigma. You may even have been through a training regimen and been part of a corporate initiative or an improvement project. If so, you know the capabilities of Six Sigma; you've witnessed its achievements firsthand.

But if, like many people, you're outside of the upper echelons of big business, you may know Six Sigma by name only. It has been too expensive and complicated for small- and medium-sized businesses, public institutions, not-for-profit organizations, educational environments, and even aspiring individuals. Its potential has remained out of reach for the vast majority of professionals and organizations worldwide.

All this is changing. As the methods and tools of Six Sigma have spread, it has become easier to understand and more straightforward to implement. The mysteries of Six Sigma have been revealed.

Simply stated, Six Sigma is about applying a structured, scientific method to improve any aspect of a business, organization, process, or person. It's about engaging in disciplined data collection and analysis to determine the best possible ways of meeting your customers' needs while satisfying yours and minimizing wasted resources and maximizing profit in the process. *Six Sigma For Dummies,* 2nd Edition, helps you do just that.

About This Book

This book makes Six Sigma accessible to you. We wrote it because Six Sigma is applicable everywhere — not only in large and complex corporations but also in the less complex and more intimate worlds of professional performance and personal accomplishment.

We wrote this book for you, the individual. You may be a small business owner, an ambitious career person, a manager who wants to know what Six Sigma is and how to apply it, a college student, or an applicant who wants to have an edge on upcoming job interviews. For you, this book is the place to turn.

Six Sigma For Dummies, 2nd Edition, is more than an overview or survey of Six Sigma. It's a comprehensive, actionable description of the methods and tools of Six Sigma. In this book, you find

- A reference book that's organized into parts, chapters, and sections so that you can flip right to what you need, when you need it
- A comprehensive text that addresses both the statistics of Six Sigma and the improvement methodology
- A description of how Six Sigma and Lean now combine to form the best of both improvement methodologies
- A guide for leading a Six Sigma initiative, selecting and managing Six Sigma projects, and executing specific Six Sigma tools and analytical procedures
- A step-by-step instruction manual for the Define, Measure, Analyze, Improve, and Control phases of the Six Sigma process
- A set of resources you can go to for additional help

Sure, Six Sigma is rigorous, technical, and analytical. But we've taken this difficult subject and made it understandable through examples, simple explanations, and visual aids.

Conventions Used in This Book

When a specialized word first appears in this book, we italicize it and provide a definition. For many terms and phrases that industry practitioners use as acronyms, we define the term first and then use it in its abbreviated form going forward. Additionally, we use **bold** text to highlight the steps you take in numbered lists and the keywords in bulleted lists. Websites appear in `monofont`.

When we use the term *data,* we always mean it in the plural sense. Although statisticians debate about using *data* in both a plural and singular sense, we stick with the plural only because our editor told us we had to. Otherwise, *datum* is the singular form.

We do use some business management and statistical concepts and language. If you want to get extra smart, check out the latest editions of *Managing For Dummies* by Bob Nelson and Peter Economy and *Statistics For Dummies* by Deborah Rumsey (both published by Wiley).

What You're Not to Read

We know you're busy, so if you're short on time, you can skip the text in the gray-shaded *sidebars* and anything flagged by a Technical Stuff icon. These tidbits are interesting but contain more historical or technical detail than you need to understand the basic topic at hand.

Foolish Assumptions

We assume you've heard about Six Sigma and are intrigued and compelled to find out more for any one or more of the following reasons:

- You're contemplating applying Six Sigma in your business, and you need to understand what you may be getting yourself into.
- Your business is implementing Six Sigma, and you need to get up to speed. Perhaps you've even been tapped to participate as a Champion, Black Belt, Green Belt, or Yellow Belt.
- You believe Six Sigma is a pathway to better performance in your job and can help you advance your career.
- You're considering a career or job change, and your opportunities require you to understand Six Sigma.
- You're a student in industrial engineering or business school and realize that Six Sigma is part of a path to success.

We also assume that you realize Six Sigma demands a rigorous and structured approach to problem-solving that calls for capturing data and applying statistical analysis to discover the true causes of the challenges you may be facing in manufacturing, service, healthcare, or even transactional environments. For that reason, several chapters of this book describe and define the statistical tools of Six Sigma.

How This Book Is Organized

We break this book into six separate parts. Each is written as a stand-alone section, permitting you to move about the book and delve into a given topic without necessarily having to read all the preceding material first. Anywhere we expound upon or extend other material, we reference the chapter or part of origin so that you can tie the discussions together.

Part I: Getting Acquainted with Six Sigma Basics

Part I is an overview of the Six Sigma methodology, the system of deployment, roles, and responsibilities. In this part, we address the key principles underlying the science of Six Sigma and its applications. Chapter 1 is a comprehensive overview of Six Sigma. Chapter 2 connects quality improvement to business performance. Chapter 3 introduces the key principles. Chapter 4 discusses roles and phases in the implementation of a Six Sigma deployment.

Part II: DMAIC: Defining and Measuring

Part II is where we begin digging into the depths and details of practicing Six Sigma by presenting the information in the context of Six Sigma's DMAIC problem-solving road map. The first two phases, Define and Measure, enable you to properly scope and launch a project (Chapters 5 and 6) and then objectively identify all possible causes of problems (Chapters 7, 8, and 9).

Part III: DMAIC: Analyzing

In this part, we discuss the Analyze phase of Six Sigma's DMAIC problem-solving road map. This phase is where you objectively eliminate trivial and non-important factors, zeroing in on the true root cause. Chapter 10 shows how you can use basic charts and graphs in this effort. Chapter 11 discusses value analysis, while Chapters 12 and 13 cover normal variation and analyzing for capability. In Chapter 14, you discover the important topic of analyzing your own measurements, and Chapter 15 discusses how to glean insight just from watching a process in operation. Chapter 16 concludes this part by showing you how to measure the risk and confidence in your analysis decisions.

Part IV: DMAIC: Improving and Controlling

Part IV wraps up the methods and tools used in the DMAIC problem-solving road map. The intent of the Improve and Control phases is to synthesize an improvement and then lock in the gains that you've achieved. Chapter 17 introduces the science of making predictions about future performance, and Chapter 18 gives you the lowdown on how to design, conduct, and analyze powerful experiments. In Chapter 19, we show you ways to make newly achieved improvements permanent. Chapter 20 covers the important topic of statistical process control.

Part V: Looking at the Six Sigma Technology Tool Landscape

In this part, we present a comprehensive listing of the technology tools and information systems Six Sigma practitioners use. Chapter 21 covers process characterization tools, Chapter 22 deals with analysis tools, and Chapter 23 discusses the important technology tools needed to manage local or enterprise-wide improvement.

Part VI: The Part of Tens

In the *For Dummies* tradition, this part is a compilation of key reference points. Chapter 24 discusses ten top do's and don'ts for success. Chapter 25 addresses how to improve on improvement by integrating Lean with Six Sigma. In Chapter 26, we tell you about additional places you can go for help.

Icons Used in This Book

Throughout the book, we use small symbols called *icons* in the margins to highlight special types of information. Our goal is to help you better understand and apply the material. When you see any of the following icons, they mean the following:

TIP: These notes are key points that can help you implement Six Sigma successfully.

WARNING!: When you see this icon, we're cautioning you to beware of a particular risk or pitfall that may cause you trouble.

TECHNICAL STUFF: This icon flags a detailed technical issue or reference. Feel free to skip right over these paragraphs if you don't want to dig deeper.

REMEMBER: We use this icon to summarize information into short, memorable thoughts.

Where to Go from Here

The beauty of a *For Dummies* book is that you don't have to start at the beginning and slowly work your way through. Instead, each chapter is self-contained, which means you can start with whichever chapters interest you the most. You can use *Six Sigma For Dummies,* 2nd Edition, as a reference book, jumping in and out of certain parts, chapters, and sections as you want.

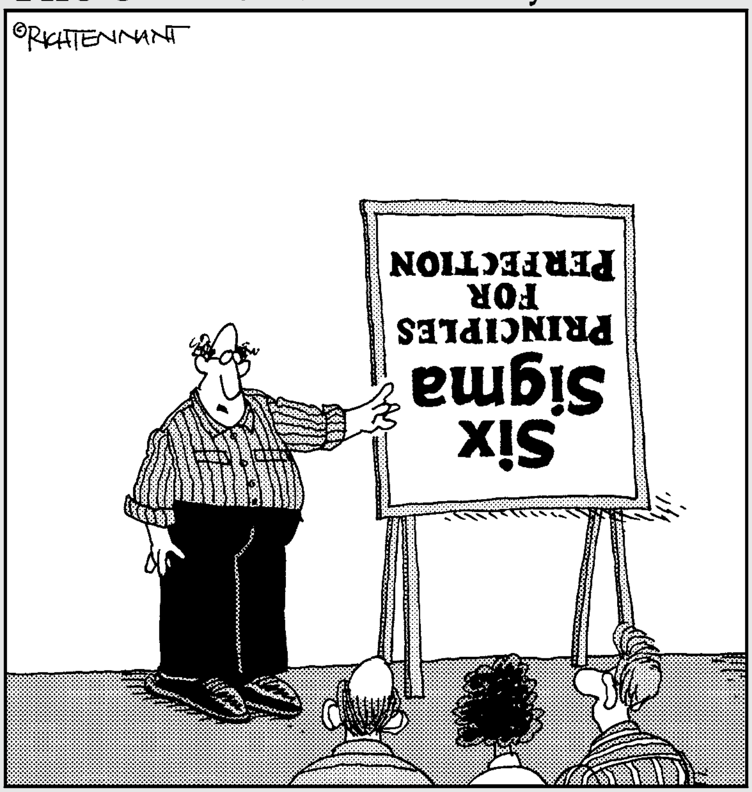
Here are some suggestions on where to start:

- If you're brand-new to Six Sigma, start at the beginning with Chapter 1.
- Want to know all about those Belts you're hearing about? Head to Chapter 4.
- If you're interested in how to launch a Six Sigma project, go to Chapter 6. To find out all about tools and technologies, check out Part V.
- Want to know all the gritty statistical measurement and analysis of Six Sigma? Jump in at Chapter 9.

Part I

Getting Acquainted with Six Sigma Basics

The 5th Wave   By Rich Tennant



"Six Sigma is a system to eliminate defects as this PowerPoint presentation demonstrates."

In this part . . .

Six Sigma is an applied methodology for improving business and organizational performance. But before you apply the Six Sigma methodology, you can benefit from knowing what it is, where it came from, why it works, and who uses it. This part provides all this information so you can understand the basics of Six Sigma.

Chapter 1

Better Business and Better Performance: Defining Six Sigma

In This Chapter

- Looking at the many definitions and synonyms of Six Sigma
- Introducing the proven managerial horsepower of Six Sigma
- Recognizing that Six Sigma isn't just another initiative-du-jour
- Identifying a formidable business force

It's not often that a *For Dummies* book topic first needs a formal definition. After all, you know in general what gardening, dating, and even marathon training are. But "Six Sigma"? Even if you remember that sigma is the 18th letter of the Greek alphabet, why six of them? And what happened to the first five sigma?

In this chapter, we offer you a foundational knowledge of Six Sigma so that the rest of this book makes sense and you can get the most out of the rest of the book, which ultimately helps your business improve by leaps and bounds.

Discovering What's Behind the Name

It's okay if you don't know what Six Sigma is at all, or don't understand every aspect of it. That's because Six Sigma — once a precise, narrowly-defined term — has grown over time to represent a number of concepts:

- *Six Sigma* is a problem-solving methodology. In fact, it's the most effective problem-solving methodology available for improving business and organizational performance.
- *Six Sigma performance* is the statistical term for a process that produces fewer than 3.4 defects (or errors) per million opportunities for defects.
- A *Six Sigma improvement* is when the key outcomes of a business or work process are improved dramatically, often by 70 percent or more.

- A *Six Sigma deployment* is the prescriptive rollout of the Six Sigma methodology across an organization, with assigned practices, roles, and procedures according to generally accepted standards.
- The *Six Sigma toolset* is the collection of methods and tools, including statistics and analytics, that Six Sigma practitioners use to consistently achieve breakthrough levels of improvement.
- The *Six Sigma* methodology is often combined in practice with Lean methods in a hybrid practice known as *Lean Six Sigma* or *Lean Sigma.*

Six Sigma is a methodology for minimizing mistakes and maximizing value. Every mistake an organization or person makes ultimately has a cost — a lost customer, the need to do a certain task over again, a part that has to be replaced, time or material wasted, efficiency lost, or productivity squandered. In fact, waste and mistakes cost many organizations as much as 25 to 40 percent of their revenue! That's a shocking number. Imagine throwing 25 to 40 percent of your money away in the garbage every time you cash a check. It may sound ludicrous, but that's what many organizations do.

All businesses, organizations, and individuals have room to improve. No operation is run so tightly that another ounce of inefficiency and waste can't be squeezed out. By their nature, organizations tend to become messy as they grow. Processes, technology, systems, and procedures — the ways of doing business — become cluttered with bottlenecks, meaning work piles up in one part of the organization while other parts sit idle with nothing to do.

Work is often performed incorrectly, or the outcome is flawed in some way. When this situation happens, you scrap products and services and have to do the work over again. You consume additional resources to correct a problem before it's delivered to the customer, or the customer asks later for a "redo" — a new product or a more satisfactory service.

Sometimes, flaws and defects aren't the problem, but a product or service simply takes too long to produce and deliver. Think about the problems a mortgage company would have if it processed home loans perfectly but did so five times more slowly than the competition. That's a perfect disaster.

Six Sigma was once a quality-improvement methodology, but now it's a general-purpose approach to minimizing mistakes and maximizing value: How many products can you produce, how many services can you deliver, or how many transactions can you complete to an expected level of quality in the shortest possible amount of time at the lowest possible cost?

REMEMBER

Six Sigma takes effort and discipline and requires you to go through the discomfort of change. But soon the pain is transformed into improved performance, lower costs, more success, and happier customers.

No pain, no gain

The Six Sigma approach isn't for the faint of heart or for the unprepared organization. It's intense and rigorous, and it entails a thorough inspection of the way you do everything. Six Sigma sets ambitious business objectives and measures performance in a way that forces accountability. It doesn't allow a management team to become complacent; rather, it exposes waste that otherwise would remain largely invisible.

Six Sigma takes a business out of its comfort zone, but for a relatively short time. After the first project gains materialize and the money starts flowing to the profit margin, a cultural change takes hold. The early discomfort of changing business processes gives way to success, problems become opportunities for improvement, and the organization begins to enthusiastically leverage the methods and tools of Six Sigma more pervasively and with a keen eye on value.

Tackling Six Sigma from the Managerial Perspective

Although Six Sigma has many definitions (see the preceding section), Six Sigma action occurs on two levels: the *managerial* and the *technical.* This chapter introduces the managerial level, while Chapter 2 begins to look at the technical side.

At the managerial level, a Six Sigma initiative includes many units, people, technologies, projects, schedules, and details to be managed and coordinated. It also involves developing many plans, taking many actions, and completing a lot of specialized work. For all these factors to work in concert, and for the technical elements of Six Sigma to be effective, you have to set the proper management orientation.

Bridging science and leadership

From a management standpoint, you use Six Sigma to achieve predictability and control of performance in a business or a business process by applying the methods of science to the domain of leadership.

The achievements of machinery, technique, process, and specialization of labor have collectively enabled the explosion of mass production and the consumer society. Science dictates how all the parts, materials, machines, and people on the assembly line interact to turn out many "widgets" at the highest possible speed and the lowest possible cost.

Chalking up radical corporate success

Six Sigma helps organizations achieve breakthrough improvement, not incremental improvement. In short, Six Sigma is a path to dramatic improvement in value for your customers and your company. Companies engaged in Six Sigma have realized staggering business success.

- **General Electric** profited between $7 to $10 billion from Six Sigma in about five years.
- **Dupont** added $1 billion to its bottom line within two years of initiating its Six Sigma program, and that number increased to about $2.4 billion within four years.
- **Bank of America** saved hundreds of millions of dollars within three years of launching Six Sigma, cut cycle times by more than half, and reduced the number of processing errors by an order of magnitude.
- **Honeywell** achieved record operating margins and savings of more than $2 billion in direct costs.
- **Motorola,** the place where Six Sigma began, saved $2.2 billion in a four-year time frame.

And Six Sigma isn't just for large organizations; small and medium businesses use Six Sigma to add to both revenues and profits.

REMEMBER

Managerially speaking, the goal of Six Sigma is to inject control, predictability, and consistency of results into the production of a successful organization, such that the widgets are produced with great consistency and minimal variation.

TECHNICAL STUFF

Early in the 20th century, Henry Ford applied the principles of science to the production of cars. By following set processes and by optimizing repeatable processes, Ford and others made goods that displayed little variation in their final states and could be mass-produced without requiring extensive education and years of finely honed skills among the assembly-line staff.

Countless times every day in the United States, people open a water faucet and experience the flow of clean, clear water, which is possible because reliable purification systems treat the water and pressure systems ensure the water is there. This kind of dependability is what Six Sigma provides: It treats the processes in a business so that they deliver their intended results reliably and consistently.

REMEMBER

The methodology of Six Sigma was first applied in a manufacturing company, but it also works in service and transactional companies (such as banks and hospitals), where it has been implemented many times with great success. Six Sigma dramatically improves the way any process works — whether that process is in the chemical industry, the oil industry, the service industry, the entertainment industry, or any other field.

Management system orientation

Six Sigma is so appealing to managers because it delivers business management results. Managers need to see a return on investment, commitment, accountability, transparency, and a clear path to success. Six Sigma provides all these things.

Clear value proposition and ROI

Six Sigma is characterized by an unwavering focus on business return on investment (ROI). A Six Sigma project can improve a business characteristic by 70 percent or more, stimulating increased operating margins for businesses while increasing the value those businesses provide to their customers. (More on this topic in Chapter 2). Six Sigma initiatives and projects have a direct, measurable financial focus and impact.

Top commitment and accountability

A Six Sigma initiative begins at the top. The leadership and management of an organization must actively commit to the Six Sigma initiative, setting performance goals and developing tactical implementation plans. Management team members must be personally accountable for achieving the performance improvement goals they set for their respective organizations and business units.

Customer focus

Six Sigma, through its *voice of the customer* (VOC) tools (see Chapter 11), drives business processes through customer requirements. No operational, process, and business improvements can occur without a definitive understanding of who the customers are and what they need, want, and are willing to buy. Six Sigma managers become savvy about the needs and requirements of customers in a way that also enables the business to become stronger and more profitable.

Connected business metrics

Six Sigma is different from other performance improvement approaches in its focus on business financials and measurable operational improvements. To support this focus, the Six Sigma management system must include performance measures that are readily accessible and visible to everyone whose actions or decisions determine performance levels and operational quality. You can read about metrics and measures in Parts II and III.

Process orientation

Six Sigma improves the performance of any business or work process — specifically, how those processes effectively and efficiently transform material and other inputs into the desired outputs. This trait is the focal point of using Six Sigma to improve performance: the design, characterization, optimization, and validation of processes. Chapter 7 gives you the lowdown on processes.

The historical perspective

The Six Sigma methodology was formalized in the mid-1980s at Motorola. This organization combined new theories and ideas with basic principles and statistical methods that had existed in the quality engineering domain for decades. These building blocks, enhanced by business and leadership principles, formed the basis of a complete management system. The result was a staggering increase in the levels of quality for several Motorola products, and the inaugural Malcolm Baldrige National Quality Award was bestowed on the company in 1988.

Everyone wanted to know how Motorola had done it. Then-president Robert Galvin chose to share Motorola's Six Sigma secret openly, and by the mid-1990s, corporations like Texas Instruments, Asea Brown Boveri, Allied Signal, and General Electric had begun to reap similar rewards. By 2000, many of the world's top corporations had a Six Sigma initiative underway, and by 2003, over $100 billion in combined savings had been tallied.

By the mid-2000s, Six Sigma became the global standard of quality business practice, embraced by the American Society for Quality. Universities worldwide now offer courses in Six Sigma, and dozens of consulting and software companies have brought Six Sigma products and tools to market. Six Sigma also became equally known by the market designations "Lean Six Sigma" and "Lean Sigma," communicating the benefits of a combined Six Sigma and Lean approach. (For more on these topics, check out *Lean For Dummies* by Natalie Sayer and your trusty coauthor Bruce Williams [Wiley]).

Today, over 2,000 books on Six Sigma are in print, and doing an Internet search for the term *Six Sigma* returns millions of hits. Six Sigma has quite literally become the de facto standard for operations and improvement everywhere in the world.

Project focus

The Six Sigma project is the tool by which processes and systems are characterized and optimized. Program leadership identifies opportunities for Six Sigma improvement projects and assigns Six Sigma specialists to execute them. We provide details about how to select Six Sigma projects in Chapter 5, how to conduct projects in Chapters 6 through 20, and how to manage projects by using technology aids in Part V.

Enabling technology tools

Properly managing a Six Sigma initiative that spans an entire organization or a significant part of an organization requires the ability to simultaneously manage many projects, processes, analyses, data banks, training activities, and people. Generally speaking, several classes of technology tools help accomplish this feat:

- Tools for designing, modeling, managing, and optimizing processes
- Tools for the broadscale and enterprise-level management of multiple projects across multiple organizational units

- Tools for collecting data, conducting analytical calculations, and solving performance problems
- Tools for training, educating, transferring knowledge, and managing knowledge

We provide a comprehensive view of the many Six Sigma technology tools in Part V.

An infrastructure for change

Installing and managing a Six Sigma management system requires a certain infrastructure — an underlying set of mechanisms and structures on which to develop the Six Sigma improvement strategies and enact project implementation and process improvement. The key elements of an effective Six Sigma infrastructure include the following. For more information on setting up this infrastructure, check out our *Six Sigma Workbook For Dummies* (Wiley).

- A fully documented Six Sigma leadership system, strategic focus, and business goal configuration, plus deployment plans, implementation schedules, and activity tracking and reporting techniques. More on these items in Chapter 4.
- A strategy, methodology, and system for training and preparing executives, managers, Champions, Black Belts, Green Belts, Yellow Belts, financial auditors, process owners, and all others involved in the Six Sigma initiative. We define and describe all the Six Sigma job roles in Chapter 4.
- Competency models and compensation plans, Six Sigma participant and leader selection guidelines, position and role descriptions, reporting relationships, and career-advancement policies and plans.
- Guidelines for defining project-savings criteria; aligning accounting categories with Six Sigma goals and metrics; forecasting and validating project savings; and auditing, evaluating, and reporting project ROI.
- Hard criteria for selecting projects, designating project-type categories, developing project problem-definition statements, targeting intended project savings and ROI, approving selected projects, and managing projects through to completion. We give you information about project management in Chapter 5.
- Information-technology-related structures, procedures, and dashboards, as well as tools and systems for designing and managing processes, tracking project and initiative progress, reporting results, storing information and data, and performing analytical functions. We look at these tools in depth in Part V.
- A strategy for consistently communicating the Six Sigma initiative across the enterprise, including an Internet or intranet site that provides a common reference and knowledge base that contains important information, motivational content, recognition stories, educational material, contact information, and so on.

- A management review process for assessing the effectiveness of Six Sigma from the top to the middle to the bottom of the organization:
  - At the top, the focus is on the aggregate process, projects, and results for implementation in entire business units.
  - In the middle, the focus is on the process and results of operational units with multiple Six Sigma projects.
  - At the lower levels, the focus of management review is on making sure individual projects are on track and yielding their intended process-improvement and financial results.

Complete culture change

A Six Sigma initiative often begins with outside consultants providing methods, tools, and training, but over time, the knowledge is internalized and applied organically within the organization. The ultimate goal is for everyone in the organization to have a working ability to understand customers' requirements, collect data, map processes, measure performance, identify risks and opportunities, analyze inputs and outputs, and make continuous improvements. In Chapter 4, we provide more details about culture change.

Chapter 2

Linking Quality and Business

In This Chapter

- Defining the voice of the customer through specifications
- Understanding the basis of true quality
- Recognizing that the quality of a system's individual pieces aggregates to form the whole
- Introducing the sigma scale of quality

You make judgments on what is and what isn't good quality all the time. For example, you recognize when you eat a lousy sandwich or when your cellphone provider has bad service. But in the world of Six Sigma, quality is a deeper topic. To understand quality in Six Sigma terms, you need a transformational definition of what quality actually is; you can then use that definition to guide and gauge your work activities. In the end, how closely you adopt this definition of quality largely determines the viability of your improvement efforts.

In this chapter, we cover quality: how customers drive it and ask for it, what it looks like, and how to rate it. The discussions here give you a good grasp on why quality matters so much and prepare you to strive for the best.

Specifications: Listening to the Voice of the Customer

When you buy a Coca-Cola, you, as a customer, expect a certain experience. You expect your experience to be the same each time you open a new can. If the drink had too much sugar one time or not enough secret ingredient another time, you'd notice and feel dissatisfied. The Coca-Cola Company knows this fact about you, its customer, and so it very carefully controls the amount and makeup of each ingredient going into its drinks.

The way that Coca-Cola controls its product (and your experience) is through *specifications.* Each specification represents what the customer requires to be satisfied. In this section, we explain how to set specifications appropriately.

How close is close enough? Understanding the need for specifications

Before the 1800s, all products were manufactured one at a time by craftsmen. A gunsmith, for example, would shape a single barrel of a gun and then expertly carve a single wooden stock to match the barrel's dimensions. The pieces fit together because the craftsman adjusted each part to match the other.

A revolution was ignited when specialists began to separately create each of the components of a product. Because the specialists each focused on a smaller area, they became more expert and efficient in producing that piece. The overall result was an economy that produced goods and services much more quickly and at a much lower cost than before.

It was in this environment of economic revolution that specifications were born. Getting Billy Bob's barrels to fit into Cletus's wooden stocks required some formal coordination. Specifications told the specialists what size or shape to make their parts. That way, when all the separate parts were assembled together, they would still fit.

Defining specifications

A *specification* is the value separating acceptable from unacceptable performance. You probably consider spending more than $200 a month on movie tickets unacceptable for your personal budget. But what about $100? $50? At what dollar value is movie ticket spending acceptable or unacceptable? That's your specification. This definition holds for all process or characteristic performance measures.

You can find several different types of specifications, several of which are shown in Figure 2-1:

- **Specification limit (*SL*):** Any value designating acceptable from unacceptable performance.
- **One-sided specification:** A specification limit that designates only a single transition point from acceptable to unacceptable performance. For example, if you care only that the characteristic or process performance not exceed a certain upper value, that is a one-sided specification.

- **Two-sided specification:** A pair of specification limits creating an interval of acceptable performance between the two limits.
- **Upper specification limit (*USL*):** A value designating an upper limit above which the process or characteristic performance is unacceptable.
- **Lower specification limit (*LSL*):** A value designating a lower limit below which the process or characteristic performance is unacceptable.
- **Target (*T*):** The single designated value you want the process or characteristic to perform at. (A specification target is an ideal. Variation prevents the process or characteristic from exactly hitting the target every time.)

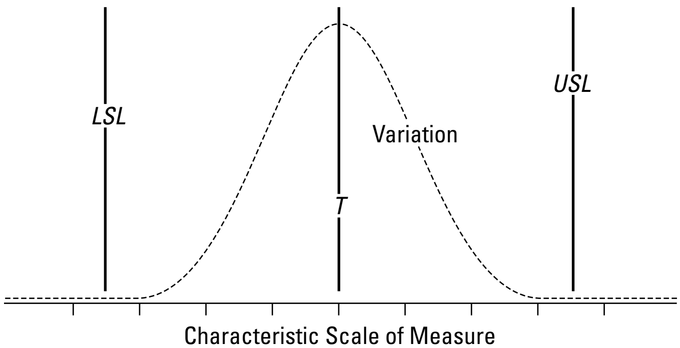


Figure 2-1: Target and specification limits for a characteristic of a product or process.

REMEMBER

If set up correctly, specifications represent the range of values at which a characteristic is still acceptable to the customer. Often, customers aren't directly involved in your work; you never directly interact with them or see them. But a characteristic's specification is always available to you! In this way, specifications are said to represent the *voice of the customer* (*VOC,* for short).

Do you do the RUMBA? Creating realistic specifications

You should never create specifications arbitrarily. Unless they actually represent the values that separate good from bad performance, specifications become a stumbling block to progress. If you set a specification too loosely, your customer will be dissatisfied or upset with the performance of what you provide, even though it meets the specification. If a specification is set too tightly, you spend more resources than you should to always perform within your overly narrow goal post.

Imagine a specification requiring a delivered pizza to be between 120.4 degrees Fahrenheit and 120.6 degrees Fahrenheit when it arrives at the customer's door. To be within this required temperature range, the pizza company would have to take some pretty complicated and expensive actions. Maybe they'd have to use space-age ceramic pizza boxes made out of space shuttle tiles. In any case, meeting that specification would take a lot of work and expense.

But do customers really require this extent of control over the temperature of their pizzas? Probably not. A less troublesome specification, and one just as satisfactory to the customer, may be 115 degrees Fahrenheit to 125 degrees Fahrenheit.

Six Sigma uses a mind-jogging acronym, RUMBA, to help you evaluate the appropriateness of any specification:

- **Reasonable:** Is the specification based on a realistic assessment of the customer's actual needs? Does the specification relate directly to the performance of the characteristic?
- **Understandable:** Is the specification clearly stated and defined so that no one can misinterpret it?
- **Measurable:** Can you measure the characteristic's performance against the specification? If not, a lot of debate will ensue between you and your customer as to whether the specification has been met.
- **Believable:** Have you bought into the specification setting? Can you and your coworker peers strive to meet the specification?
- **Attainable or achievable:** Can the level and range of the specification be reached?

You need to review each specification to make sure that it passes the RUMBA test. If it falls short in any of the RUMBA categories, begin to develop a plan to bring the rogue specification back into control.

Very often, an improvement project is fast-tracked or solved through a simple RUMBA review and adjustment of the involved specifications; the performance of the characteristic or process never has to be changed! Always review the appropriateness of specifications early in your Six Sigma project.

Examining What Quality Truly Is

To begin understanding the technical side of Six Sigma, you have to first answer a seemingly straightforward question: What is quality? A traditional and widely held definition is

Quality = compliance with specifications

The following mental experiment walks through the traditional definition of quality and highlights why measuring quality this way is a flawed approach.

Figure 2-2 shows an important characteristic of a process or product — any characteristic that is critical to your customer. The horizontal axis of the figure represents the scale for the measurement for this critical characteristic. It may be the diameter of a part (in inches), the cycle-time of a process (in seconds), or the cost of a service (in dollars) — whatever characteristic is critical to your customer. The target (*T*) and upper and lower specification limits (*USL* and *LSL*, respectively) are also shown for this characteristic.

Now imagine you come across four parts that have come out of this process. You measure each one for how it performs on this critical customer characteristic. Part 1 measures far outside the allowed specification window. Part 2 is just outside the allowable window by the smallest margin possible. Part 3 is just inside the allowable window, also by the smallest of margins. And part 4 is nearly right at the ideal target value.

Deciding which of these four parts has the worst quality — which one you never want to get into the customer's hands — is pretty easy: Part 1 is clearly the worst. And picking the highest-quality part is easy, too; part 4 almost matches the ideal target value from the customer. But what about parts 2 and 3? Which of these two has higher quality?

Remember, part 2 is just outside the specification limit. Part 3 is just inside. Does that mean part 2 is "bad" and part 3 is "good"? Think of how these two parts will perform in the customer's hands; will part 2 definitely fail before part 3? With only the slightest imaginable difference between parts 2 and 3, do you think the customer will perceive a difference in their performance?

The answer is no. From the customer's perspective, parts 2 and 3 are the same. And from your perspective — the producer's perspective — parts 2 and 3 don't present any tangible difference in warranty returns or the cost of lost customer loyalty. So even though one part is within specification (or *in spec*) and the other is out, no difference in their quality really exists.

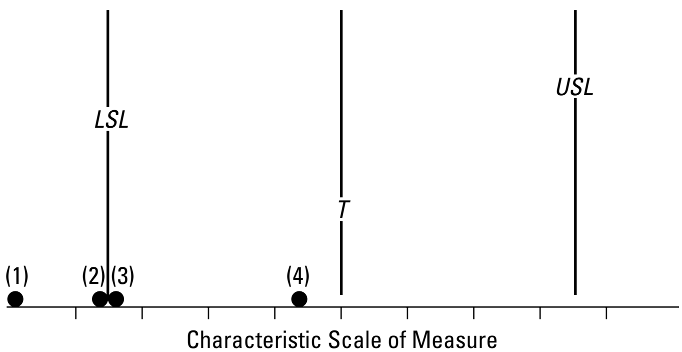


Figure 2-2: Four different outputs for a critical characteristic on a product or process.

Ford's hard lesson

In the 1980s, Ford Motor Company had a wake-up call about its understanding of what quality is and isn't. Back then, its Batavia, Michigan, plant religiously followed a quality policy based on the belief that compliance with customer specifications was what defined a high-quality product: Make the part in spec, and it would be "good"; make the part out of spec, and it would be "bad." Ford made sure that its operating policies and procedures were set up and that all its employees were trained so that nothing was allowed to advance in production or to leave the factory unless measured proof indicated that the characteristic was within the required limits.

At this same time, Ford was working with Mazda in a joint venture — both companies produced the exact same automatic transmission from the exact same blueprints with the exact same critical characteristics and specifications. Ford transmissions went into their Probe vehicles, while Mazda's went into their MX-6s. You may remember these cars.

As both companies built transmissions and as reports started to come back from customers, Ford began to see a stark difference in the data — transmissions Ford built were several times more likely to have a problem and require warranty service than the same transmissions built by Mazda. How could this discrepancy be? Ford had never worked harder to make sure every critical characteristic was within the required spec limits. It had strictly followed its quality procedures and had made sure that no parts exceeding the spec limits ever left the factory. Why, then, were Mazda's transmissions so much more profitable? Ford had to know why, so it acquired several transmission samples — some from its own factory and some from Mazda — and began tearing them apart and studying them to find the root cause.

First, Ford compared the transmissions for vibration. A good transmission with high reliability runs smoothly, with little vibration. In the tests, Mazda transmissions had vibration levels so much lower than Ford had ever seen that Ford first thought its vibration test equipment was broken! But the tests ended up being accurate; Mazda's transmissions just ran that much more smoothly than Ford's.

The folks at Ford also did dimensional checks of all the transmission's critical parameters. What they found was that the distribution of measurements from the Ford samples did meet the goal of being within customer specifications, but the variation in the parts used up the entire width of the spec window, with just as many parts near the edges of the spec limit as were in the middle. Mazda's transmissions, on the other hand, showed a marked difference in consistency; all their measurements were lumped at the center of each spec, always very close to the ideal target value.

Ford quickly began to understand the reason for its lower profitability and performance. The quality it sought didn't come from just getting in the spec window. Instead, Ford found that quality sprang from working to get all the parts to be on-target with minimal variation.

Ford's chief of operations even published an internal video of the findings from the study. In it, he admitted that Ford's quality policy and procedures had been "wrong" — that its very own policies had led it to the poor quality and business problems it was experiencing. This painful experience was one of the things that motivated Ford to change the way it thought of quality.

REMEMBER

Contrary to the traditional definition, quality is *not* equivalent to a part's or process's compliance with specifications. A better, more realistic definition of quality is

Quality = on-target performance with as little variation as possible

This definition of quality is so important because, in reality, quality problems increase more and more the farther and farther that performance strays from the specified ideal target, even while performance is still within specifications. Using the true definition of quality, you can see that the target — not the limits — is the most important part of a specification. And getting a characteristic to operate on target with as little variation as possible should be your focus.

Discovering the cost of poor quality curve: Football and Taguchi's loss function

What's poor quality really costing your business? Figure 2-3 graphically compares the flawed traditional perspective and the Six Sigma perspective on specifications and their relation to quality and costs.

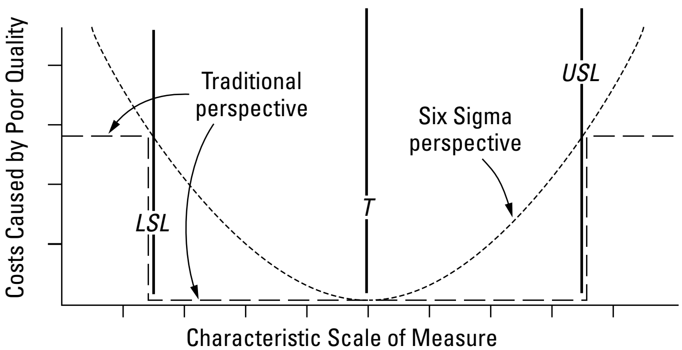


Figure 2-3: The traditional and the Six Sigma views on specifications and the costs caused by poor quality.

Traditionally, companies have thought that quality is like kicking football field goals; as long as the ball goes between the uprights, you get the full three points regardless of whether it goes straight down the middle or it hits the upright and bounces in. This "goal post" kind of thinking is the traditional perspective shown with the specification in Figure 2-3. The thinking under this mentality goes that when a critical characteristic lands inside the spec limits, it adds no additional costs to the company. But when it falls outside the specs, the company incurs a fixed cost, such as for repair or replacement or for lost customer loyalty.

Unfortunately, this goal post definition of quality costs just doesn't match reality. What actually happens is that costs begin to increase with *any* deviation from the ideal customer target — even while the characteristic is still in spec! These incremental costs — such as disrupted production flow, increased inventories, incrementally reduced product performance, and lessened product reliability — usually aren't accounted for immediately, but they always occur eventually. And the farther the characteristic gets away from the ideal target, the more and more it costs the company.

This cost of quality curve is the Six Sigma perspective shown in Figure 2-3 (labeled "Six Sigma perspective"). It was originally proposed by a Japanese engineer named Genichi Taguchi and is widely known today as the Taguchi loss function.

Exposing the hidden factory

Very few companies can actually achieve Six Sigma (fewer than 3.4 defects per million opportunities) or even five sigma (fewer than 233 defects per million opportunities) performance in their final products because so many critical processes, process activities, machines, people, and materials have to interact along the entire value stream.

For example, for system X to reliably yield its intended outcomes, it has to rely on the following chain of factors to operate in sync within certain limits of variation: the chemical properties of the catalyst, which is combined with the base material (which is mixed by the processing machine, which is controlled by the in-line gauges, which are operated by John), which is inspected by Sally, packaged by robots, stored in the warehouse, and shipped to the customer. Remembering, too, that before any of this execution, the whole system, including the product itself, was designed by a team of engineers who are by no means infallible.

If any one of the many critical activities is compromised or doesn't function to its expectation, risk and error propagate throughout the entire system. The system itself is also an opportunity-rich environment for hiding risk and error because problems arising in one part of the chain actually originate in an earlier part, and tracing the root of the problem is difficult without a quality control system like Six Sigma.

Among Six Sigma practitioners, this reality of fixing the results of propagated error is known as the *hidden factory* or *hidden operation*. You can almost see the wheels of the hidden factory turning the rework and coverups, the hours and days of wasted time in a company of people who constantly correct mistakes. Every time a corrective action is taken, a machine is rerun, or a warranty claim is processed, you incur unnecessary rework. When you accept these events as "that's just the way it is," you've mentally hidden all these activities from your improvement potential. Servicing the hidden factory wastes both time and money — a company's two most precious commodities. Six Sigma eliminates the hidden factory and, therefore, returns precious time and money back to the business.

With this realistic Taguchi cost model in place, ask yourself where you want the production of your critical characteristics to be: out near the boundaries of the spec, where significant costs increase, or spread out evenly across the whole range of the spec? Or would you rather have your parts lumped consistently near the target, where quality costs are minimized or eliminated?

Avoiding the hidden factory

Several research studies have shown that typical companies spend an amount equal to about 25 to 40 percent of their sales revenues on issues related to poor quality. For example, a company with $100 million in sales probably spends between $25 and $40 million dollars each year addressing the problems caused by poor quality.

That estimate may seem high to you. If so, that's probably because most of the costs of poor quality aren't immediately obvious and are often difficult to measure directly. Items like scrap, rework, inspection, and warranty costs are easy to see and account for. But the price tag for unseen quality-related items such as design changes, material expediting costs, lost customer loyalty, late deliveries, excess inventory, and so on are much higher than most people realize. They're a *hidden factory* of quality-related costs a lot like the bulk of the iceberg hidden beneath the water's surface. Figure 2-4 gives you a visual of these lurking costs compared to the more readily visible ones.

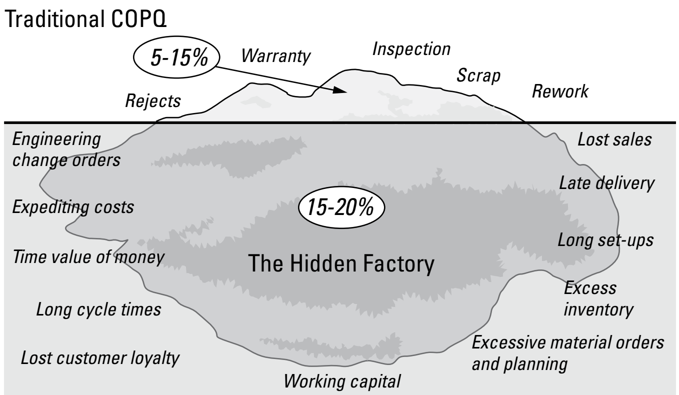


Figure 2-4: The total cost of poor quality includes many elements that aren't readily seen or detected.

Looking at How Quality Beliefs Determine Behavior

Simply changing a company's belief system — its philosophy — from a goal post quality mentality to a Six Sigma "on target with minimal variation" mentality immediately and naturally begins to alter the behavior of employees for the better. (See the earlier section "Discovering the cost of poor quality curve: Football and Taguchi's loss function" for details on these belief systems.) We look at some of these changes in this section.

Comparing belief systems side by side

When you alter your beliefs about quality to the Six Sigma ideal, you notice a big change in how your organization performs. We compare the differences between a goal post quality belief system and the Six Sigma belief system in Table 2-1.

Table 2-1 Naturally Resulting Behaviors from Quality Belief Systems

Goal Post Belief System	*Six Sigma Belief System*
Inconsistency across the range of the allowable window is fostered.	Consistent performance centered on a single/standard target value is rewarded.
Work procedures are continually adapted and improvised in an effort to get parts into the allowable spec window.	Efforts to standardize process performance occur prior to experiencing out-of-spec conditions and are never-ending.
Meeting the spec ends individual responsibility and engagement in improvement.	Never-ending obligation to continually reduce variation naturally extends up the value stream.
Efforts and resources are expended to reactively authorize/justify just-out-of-spec parts.	Efforts and resources are expended to proactively identify, understand, and eliminate causes of inconsistency.
Focus is on yield, a dead-end metric disconnected from the reality of quality.	Focus is on capability, a never-ending scale of improvement mirroring the reality of quality.

As you can see, the Six Sigma mentality's focus on proactive measures and continual improvement fosters a much more successful environment than the goal post mentality, which simply reacts to problems as they arise. Imagine the drastic differences that begin to occur in your work and in your company with this single, simple belief change! Its effect is truly remarkable.

Journeying from one to many

In this section, we look at the numbers to relate probability to quality. Consider a company whose product relies on many individual components and characteristics that must fit and work together. That company must operate at high levels of quality on a pretty minute scale so that each individual part is up to snuff. For example, the average car has about 10,000 individual quality characteristics, or CTXs. That's a lot of stuff that has to work together. If you work at an automotive company, how many cars do you make? How many papers do you have to process every day? How many materials and supplies do you order and purchase in every month? Millions upon millions — billions.

Six Sigma practitioners call this concept of compounding defect risk *rolled throughput yield,* and we explain it mathematically in Chapter 6. In practical terms, the reality of rolled throughput yield means you have to establish an extremely high probability of success for each individual component characteristic if you ever expect your final products, services, and transactions to be highly successful and defect-free.

TIP

Suppose that every time you roll a *1* on a die, that's considered a defect. With a six-sided die, then, you have one chance in six (17 percent) of rolling a defect, or a five out of six chance (83 percent) of success. But imagine that now you have a pair of dice, and you roll them both together. Now the chance of success — no defects — is only 69 percent. (We show you how to calculate these probabilities in Chapter 6.) With 3 dice, the chance of a defect-free roll decreases to 58 percent. With 100 dice, you're almost certain to have a defect. (The actual probability of never getting a *1* when rolling 100 dice is less than one in 82 million!)

Connecting quality and variation

Whatever probabilities your process has in the short term will change in the long term. Machines, process inputs and outputs, and single characteristics all vary, which cause their assemblies to vary as well.

To get a good picture of what your product's overall quality looks like, try visually plotting the associated behaviors and looking at them like a picture. Such a plot helps you see immediately that every characteristic you can measure has a performance distribution.

Furthermore, you can plot behavior today, plot it again next week, and compare the difference. Comparing a single snapshot to the accumulated variation over time is an example of the change in behavior from the short term to the long term. Figure 2-5 shows two probability distributions for a critical characteristic: short term (solid line) and long term (dotted line). As you can see, in the long term, the variation in the behavior of the characteristic expands.

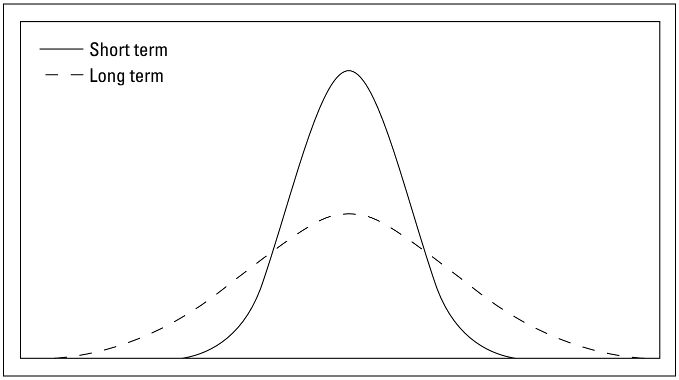


Figure 2-5: Short-term and long-term variation.

This distribution is a common occurrence. Here's what's happening: The probability of a defect in the short term doesn't account for certain changes that take place over the long term. Examples include the variation among different batches of incoming material, the impact of seasonal road traffic on delivery time, and the different working styles and habits of different personnel. Joe may be a great machine operator, but he can't work 24 hours a day. Eventually, he has to be relieved by Jim, who works a little differently from Joe. Each one has his own performance variations, but combined they enlarge the range.

Short-term variation doesn't necessarily refer to a specified period of time for every type of performance distribution. The time period involved in short-term performance variation for a restaurant meal is different from the period involved for the performance of electricity delivered to your home by a power plant. Chapter 5 provides more detail and understanding on why this discrepancy occurs and what it means for the Six Sigma practitioner.

Calculating Six Sigma quality

The term *Six Sigma* comes from the statistical basis of the approach and methodology used to address the concerns from the two preceding sections: the roll-up of characteristic behaviors and the natural increase in variation in each characteristic over the long term.

The sigma scale is a universal measure of how well a critical characteristic performs compared to its requirements. The higher the sigma score, the more capable the characteristic. For example, if a critical characteristic is defective 31 percent of the time, you say that this characteristic operates at two sigma. But if it runs at 93.3-percent compliance, you say that it operates at three sigma. Table 2-2 shows the sigma scale.

Table 2-2 The Sigma Scale

Sigma	*Percent Defective*	*Defects per Million*
1	69%	691,462
2	31%	308,538
3	6.7%	66,807
4	0.62%	6,210
5	0.023%	233
6	0.00034%	3.4
7	0.0000019%	0.019

If a characteristic operates at three sigma, that means the variation in its performance exceeds acceptable levels 6.7 percent of the time. This breakdown may be an invoicing process that goes longer than the company's allowed time limit, a forged bolt that is longer than customer requirements, and so on. Whatever the critical characteristic may be, if it's three sigma, it's defective 6.7 percent of the time, or 66,700 times out of a million. In Chapter 13, we explain more detail of how the sigma scale is created and why it's called "sigma."

What the originators of Six Sigma discovered is that when they worked to have each critical characteristic in the system — the product, the service, the transaction — perform at a Six Sigma level, the risk of the individual characteristics being incorrect was small enough (0.00034 percent or 3.4 defects per million opportunities) that the overall system still performed at an exceptional level when all the parts were assembled together. And even when long-term effects inevitably entered into each characteristic, the overall system performance remained high. These companies then had a method for competing at a whole new level on the global market. That's why six is the magic number.

So why six and not five sigma? The complex products for which this method originated had enough characteristics rolled together and enough long-term degradation that only six would do. Four or five sigma just didn't provide enough relief from these two constraints.

The systems and environments of transactional and service companies now adopting Six Sigma are often less complex; they don't have as many critical characteristics coming together, so they don't necessarily need to have each critical characteristic operating at Six Sigma. In these cases, four or five may actually do.

But the magnitude of the earlier success of Six Sigma has made the name stick. And almost all companies, regardless of their size or complexity, recognize the benefits of aiming for a Six Sigma goal. Even if the milestone of Six Sigma is never reached, the act of working toward that goal drives breakthrough changes.

In some instances, great companies are able to produce Six Sigma quality in their final products, services, and transactions — especially when safety or human life is involved. For example, did you know that you're about 2,000 times more likely to reach your destination when you fly than your luggage is? That's because airline safety operates at a level higher than Six Sigma, while baggage reliability operates at about four sigma. Table 2-3 highlights quality levels for a 99-percent quality level (3.8 sigma) compared to those for Six Sigma for some everyday occurrences.

Table 2-3 How Good Is Good?

99% Good (3.8 Sigma)	*99.99966% Good (Six Sigma)*
20,000 lost articles of mail per hour	7 articles of lost mail per hour
Unsafe drinking water for almost 15 minutes per day	1 unsafe minute of drinking water every seven months
5,000 incorrect surgical operations per week	1.7 incorrect surgical operations per week
2 short or long landings at major airports every day	1 short or long landing at major airports every five years
200,000 incorrect drug prescriptions each year	68 incorrect drug prescriptions each year
No electricity for almost 7 hours each month	One hour without electricity every 34 years
11.8 million shares incorrectly traded on the NYSE every day	4,021 shares incorrectly traded on the NYSE every day
3 warranty claims for every new automobile	1 warranty claim for every 980 new automobiles
48,000 to 96,000 deaths attributed to hospital errors each year	17 to 34 deaths attributed to hospital errors each year

Chapter 3

Examining the Principles and Language of Six Sigma

In This Chapter

- Mastering the basic equation of Six Sigma: $Y = f(X) + \varepsilon$
- Recognizing that determinism and variation affect your outputs
- Examining the role of measurement in managing processes
- Becoming aware of the power of leverage
- Balancing risk with precision of outcomes

Like all grand constructions, Six Sigma sits upon a solid foundation. Beneath all the charts, experiments, projects, colored belts, and catchy phrases lie a few fundamental principles that guide and define the whole Six Sigma methodology.

In this chapter, you discover the one fundamental equation and five basic principles that comprise Six Sigma's foundation; in doing so, you begin to think the Six Sigma way.

Starting Out with One Simple Equation: $Y = f(X) + \varepsilon$

All of Six Sigma can be summarized with what's called the *breakthrough equation* — one general-purpose equation that shouldn't intimidate even the least mathematically inclined: $Y = f(X) + \varepsilon$, where

- Y is the outcome(s) or result(s) you desire or need.
- X represents the inputs, factors, or pieces necessary to create the outcome(s). You can have several Xs.

- f is the *function,* the way or process by which the inputs are transformed into the outcome.
- ε is the presence of *error,* or uncertainty surrounding how accurately the Xs are transformed to create the outcome.

Figure 3-1 translates the equation into plain English; read the annotations from 1 to 4.

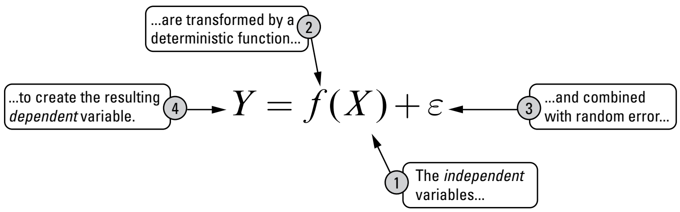


Figure 3-1: Six Sigma's breakthrough equation.

In other words, a set of input variables is transformed by a function (or process) and combined with error to form the output. The Y results from, or is a function of, the Xs. To determine a desired outcome, you apply a transformation process or function, f, on the inputs.

You make a loaf of bread by taking flour, yeast, salt, and the other ingredients and transforming them through mixing and baking into a desired outcome. The ingredients and oven settings are the Xs, the mixing and the baking are the transformation process function f, and the resulting yummy loaf of bread is the Y. But extra error (ε) enters in from the myriad of factors you don't account for, like the local humidity the day you bake the bread or the freshness of the flour.

REMEMBER

In the real world, no matter how hard you try, nuisance factors always add extra effect to the outcome; you always experience some degree of uncertainty as to how well your controlled actions produce their desired or expected result.

The $Y = f(X) + \varepsilon$ breakthrough equation is the underlying form of all the statistical tools in Six Sigma, from correlation to curve fitting to design of experiments to hypothesis tests, and so on. The interpretation and objective are always the same: What portion of the product or process situation's output (the Y) can you attribute to the critical few input factors (the Xs), and how much remains in the uncertainty or error (ε)? The objective is to discover an appropriate level of knowledge regarding the Xs and their deterministic effect on Y so that only a tolerable level of ε risk remains. (We discuss determinism in the following section.)

Principle 1: Recognizing Determinism

If you're like most people in Western society, you're results-oriented. You ask questions such as "How did it turn out?", "What finally happened?", "What was the final score?", "How long did it take?", and "What's the bottom line?" Everyone is always looking at the results. After all, results are the whole point of all the toil and trouble in the first place, right?

But *how* did the results happen? *Why* did they happen? What *specifically* caused them to happen? You want to know the answers to these questions because, if good things happen, you want to know how to make them happen again. And if bad things happen, you just as surely want to know how to prevent them next time. This focus on the process stems from determinism.

REMEMBER

Determinism is the principle that you can create a desired outcome by configuring and controlling the inputs in a specific manner. In Six Sigma, you analyze the inputs and the process and then implement the best possible combination to achieve your objective. By doing so, you exercise direct control over your environment instead of allowing your environment to control you. You're deterministic, not reactionary, in your thinking.

Many companies and organizations want to improve their performances. They recognize intuitively that their performance results are the outcome of all their business and work processes. These processes are quite literally "the way" business is done. So, to improve the outcomes, a company has to change the way it does business. It wants to change the processes — the function *f* in the breakthrough equation from the preceding section — and combine the business inputs in a way that produces a better outcome. It's not a wishful notion and not a trick for getting everyone to work harder. The call to change the way you do business is a legitimate search for a better way (and there's always a better way). In this section, you find out how to determine the cause-and-effect relationships inherent in your system and how to sidestep common cause-and-effect illusions.

Seeking cause and effect

To know how you came to the result you have (or to get the result you want), you have to examine your deterministic process. Look behind every result (output) and examine the inputs, the process, and the error that combine to produce it. When you know what causes the outcome, you can begin to position yourself to control the outcome next time — and again and again in the future. Understanding the root cause-effect relationship is the first step to controlling outcomes.

Here's a simple example: The guy gets the girl. That's the outcome. How did that outcome happen? Well, as all razor companies would have you know, it's because he has a smooth, sexy face. What caused that? It's the result of his shaving process and choice of ingredients — combining hot water, shaving cream, a mirror, a particular razor, and a steady hand to get a close shave. If anything's wrong with the outcome — if the girl thinks the guy's face is too scruffy despite the shave — you examine the ingredients and shaving process to determine the root cause of the problem.

Regardless of complexity, literally every result has one or more causes. The more you can single out these causes and understand them, the better your opportunity to change them for the better. In Six Sigma speak, you'd say that knowing the *X*s, the function *f,* and the amount of uncertainty ε means you know what caused the outcome *Y.* Cause and effect.

Correlation doesn't imply causation: Resisting superstitious delusions

Be careful not to confuse coincidence with cause and effect. Just because two events happen together doesn't mean that one caused the other. People often assume that events that are closely connected — either spatially or temporally — are somehow also connected causally. These mistaken assumptions are called *superstitious delusions* (the Latin term is *non causa pro causa,* which means "non-cause for the cause").

Superstitious delusions are why a football coach who once won an important game while wearing red socks now wears them for every game. Did the socks cause his team to win, or did the win stem from some other input or inputs?

Businesses are just as likely as superstitious coaches to confuse coincidence with causation. Think about the company that ramps up capacity after just a single great month of sales because it believes this sales boost indicates a market expansion. Only later does the company discover that no expansion was forthcoming and that the increased sales were correlated to a different factor.

Even if two variables are legitimately correlated, they don't necessarily have a causal relationship. One may fluctuate in relation to the other due solely to chance. Or each variable may be strongly affected by one or more other outside (or *confounding*) variables that haven't been identified yet.

However, a causal connection probably does exist if you can establish all three of the following conditions:

- A reasonable explanation exists for cause and effect.
- The connection happens under different environmental conditions.
- You've ruled out potential confounding variables.

One way to determine these conditions is through a designed experiment where you expose groups strongly similar to one another in terms of the most important variables to different conditions and then analyze them to see whether the variable of interest performs differently. One or more control groups are also held constant and not subjected to treatment(s). You can read more about designing experiments in Chapter 18.

Principle 2: Reducing Variation

You're playing a great round of golf. Everything's dropping. All you have to do is win the last hole, and you're going to beat all your buddies for the first time ever. You step up on the 18th tee, cast an eye down the fairway, draw your club back, uncork your winning swing, and . . . splash! Right in the drink! You lose. What happened?

Variation happened. Error happened. Whatever you did 17 times in a row, you didn't do it the last time. Dang! Consistency is a pain. How do the pros do it?

In general, variation is undesirable because it creates uncertainty in your ability to produce a desired outcome. Professional results, in anything, demand consistency. In the world of business and organizational life, the goal is to produce a work product or deliver a service in a predictable manner. That means you get the variation in your inputs — the *X*s — under control.

Some variation — within limits — may be okay. A little too much variation here or there, and you may have some repairs or rework on your hands. Too much variation altogether, and you're either out of a job or out of business.

REMEMBER

The characterization, measurement, analysis, and control of variation is a central theme of Six Sigma. Reducing unwanted variation is the key to achieving Six Sigma improvements. To jump right into the statistics of variation, go to Chapter 9.

Understanding variation

Very simply, *variation* is deviation from expectation. If you toss a coin, what's the chance of it landing on heads? Fifty percent. Therefore, if you toss a coin ten times, your *expectation* is to get five heads and five tails. Take out a coin and toss it ten times. What happened? Did you meet your expectation?

Try it again. What happened the second time? Try performing successive sets of ten coin tosses. Every time you repeat your ten coin tosses, the output — the number of heads and tails — varies. The extent to which your experience deviates from expectation is the extent to which variation has occurred.

When you closely measure any output *Y,* you find that it varies — always. This point is important to understand: Every output varies. Each time you park your car, it doesn't fit exactly in the same place between the parking lines. Every single product a company makes varies, however minutely, from every other single instance of the same product on every dimension, such as weight, size, durability, and so on. Every time you call a company for help as a customer, you get a different level of service, and you leave the call with a varying degree of satisfaction.

The size, trends, nature, causes, effects, and control of variation are the undying obsession of Six Sigma. Nothing is more examined, or more addressed, in Six Sigma than this principle.

The variation of actual occurrence versus the mean is a comparison you make frequently in Six Sigma. If you measure the occurrence of something many times, it's going to vary around some average — or mean — value. The *mean* is the central tendency of your process. Flip that coin enough times, and you see that the mean tends toward 50 percent heads and 50 percent tails.

Anytime you measure the value of a given occurrence or event, it's going to vary from the mean. A player's batting average may be .302 for the season, but Friday night he went 2-for-5 and batted 0.400, nearly 100 points above his average. And then Saturday he went 0-for-4. That's all thanks to variation.

Categorizing common cause versus special cause variation

Variation comes from two sources: common causes and special causes. Some variation is just natural; you can't eliminate it. That's *common cause variation.* The natural forces of nature work to mix things up. It's simply part of the normal course of events. Consider the earlier coin-toss example; the variation in the number of heads from set to set is perfectly normal. Or consider the variation in the time between waves at the beach or in the height of trees in a forest. These items are all examples of naturally occurring variation.

Now consider a few examples in human systems. Think about the time each day when the mailman comes or how long it takes to process a credit card application. They all vary, and the variation is a natural part of their systems.

You can act to reduce common cause variation, but you can't eliminate it. It's natural, and it's part of every system. It's in there and it's not going away! It's embodied in the ε of the breakthrough equation (see the earlier section "Starting Out with One Simple Equation: $Y = f(X) + \varepsilon$").

Special cause variation is completely different — it's directly caused by something special. If the mailman usually comes at about 11:30 each day but gets a flat tire on Tuesday and doesn't come until noon, that's a special cause of variation. If it normally takes 15 minutes to process a credit card application, but the network connection goes down and prolongs the procedure, that's a special cause. These *special causes* are specific things you can identify and do something about. Special cause variation is captured in the *X* input factors of the breakthrough equation.

With Six Sigma, you spend particular effort to understand the difference between common cause and special cause variation because they're so different and because you go to special effort to identify which type is causing the variation and how it's affecting the outcome.

Coping with variation

In general, you should work on reducing special cause variation before trying to reduce common cause variation. When you have special cause variation, the process isn't stable or predictable, and you can't be sure of what is happening. But after you've taken the special cause variation out of a system or process, you can then improve its common cause variability.

For example, suppose a coffeehouse is getting a lot of complaints about inconsistent drink quality. If the coffeehouse first eliminates the special employee-to-employee differences in making a cup of coffee, it can then effectively work on improving the inherent, common cause quality of the coffee itself. But if the initial focus is on fixing the inherent quality of the coffee first, the special employee-to-employee differences (such as the fact that Bob doesn't put the correct amount of coffee grounds in the machine) will cloud the situation, blocking all efforts to determine what's really going on.

The goal is to understand variation, control it, and minimize its impact, while accepting that it's part of everyday life and a part of every organization. Just like you can understand and characterize the relationship between the *X*s and the *Y,* you can characterize variation and error in the ability to produce desired outcomes consistently over time. This measure of control provides the foundation and framework for implementing real changes in the way you do what you do — changes that have the greatest probability of yielding positive results.

We're adrift: Peeking at short-term and long-term variation

Another important characteristic of variation is the way in which it changes over time. Recognizing the difference between short-term variations and long-term variations is important.

Here's an example: "That mailman used to come at 11:30, give or take a few minutes, but lately he's been coming later and later, and now it seems he's here closer to 12:15, which is really annoying because we're at lunch and he has to leave the packages out in the rain." In this example, the short-term variation of a few minutes was inconsequential and well within the workers' tolerance level, but when the mean time of arrival experienced a long-term variation (perhaps caused by a seasonal shift in weather or the holidays), drifting out by 45 minutes, it became a problem. Chapter 9 covers short- and long-term variation in more detail.

Principle 3: Measuring for Success

The principle of measurement is one of the fundamental tenets of Six Sigma. You may boast lots of knowledge about your processes, but until you translate that knowledge into numbers through measurement, you're bound to the world of gut-feel, guessing, and marginal improvement. Likewise, you may work very hard to bring significant resources to a performance problem or improvement goal, but without measuring your *Y*s and *X*s, your ability to improve will be weak. (This idea is nothing new; British scientist Lord Kelvin brought it up in 1891. You can read more about his comments, including the important original quotation, in Chapter 9.)

REMEMBER

Taking measurements is a matter of using information and data to quantify the relationship between inputs, outputs, and error in a given system, process, or operating model.

TIP

Measuring many of your inputs and outputs may seem impossible, but resist the urge to rationalize yourself into believing that some things just aren't measurable. In the long term, achieving your goals without the measurement data that can help you is going to be much more difficult.

Minding your Ys and Xs

Measurement begins with the output *Y*s and then extends to the input *X*s to understand the causes. For example, you'd probably love to have $1,000 in your bank account (the output *Y*). To measure how you're doing on this objective, you can check your account each day and see how much money is there. You'll probably discover that your performance toward this objective is well below what you want. As you analyze the situation, you'll discover that the amount of money in your account is a function of how much money you earn, how much is taken out of your earnings in taxes, and how much you spend on necessities. These factors are the *X*s.

You can't affect the amount of money in your account directly; you have to do something to the identified *X*s to make *Y* change. To affect a change in the output *Y,* you start to measure and control the performance of the causal *X*s (perhaps earn more and spend less).

Many people never get past the *Y.* They watch it, like the money in their account, hoping that it will change simply by being measured. Such *Y*-dominated thinking and measurement is an easy pitfall. Consider the company that continues to work harder and force productivity in an attempt to improve results (the *Y*) without quantitatively investigating the contributing factors to success (the *X*s of scrap, excess inventory, poor quality, and so on). This approach has a tendency to self destruct in its blind push toward a goal.

Summing it up with data

Understanding how to measure certain input and output variables is easy because they're, by their very nature, accommodating of such measurement. Examples include the time it takes to complete a certain job, the number of days that transpire between a customer order and the delivery of the product, and so on. These measures are all numerically quantifiable.

Such measurement-friendly events, processes, variables, and transactions are well supported by certain measurement tools, such as software, a spreadsheet, a clock, and so on. Using various quantitative scales such as width, length, time, rigidity, and density, you can quantify the behavior of many *Y*s and *X*s, and their relationships.

Other *Y*s and *X*s, however, aren't so easy to measure because they're not as easily quantified or because the time, cost, and effort involved in doing so is extreme. How, for example, do you measure customer satisfaction or a customer's opinions?

Even when numbers or direct measurements aren't available, you can create them indirectly. In this sense, you take a deterministic approach to measurement: You don't give in to the lack of data; you find the data you need or create estimates in accordance with sound practice. (Head to the earlier section "Principle 1: Recognizing Determinism" for details on this Six Sigma principle.)

In these cases, measurement instruments have to be specifically designed, such as a survey question that ranks responses. With such instruments, you can make otherwise qualitative data much more quantitative in nature.

Principle 4: Applying Leverage

If you've ever tried to move a huge rock or boulder, or even your washing machine, you can appreciate the meaning of leverage. Although you may lift and pull on the boulder with all your strength, it just won't budge. But if you use a long pole and an object for a fulcrum, you maximize the force of your limited strength. You use leverage to move the rock and accomplish your goal.

In Six Sigma terms, *leverage* is the ability to apply effort toward the critical few *X*s that have the greatest impact on your desired *Y*. You have to expend a little effort to find the leverage, but when you do, it catapults you over your problems and through the obstacles that stand between you and your goal.

The vast majority of leverage, or impact power, in creating any desired outcome comes from a surprisingly small number of contributors. This fact is true for the simplest of goals as well as for the most-complex systems. Improving the outcome all comes down to finding those critical few inputs that give you the leverage. These vital few enable you to move the "boulders" in your life, your process, or your organization.

Appreciating the difference between the critical few and the trivial many

The law of the critical few versus the trivial many comes from the work of early 20th-century Italian sociologist and economist Vilfredo Pareto. You may also know this law as the *80-20 rule,* where 20 percent of the inputs in any system account for 80 percent of the influence on that system. In his dedication to exploring the nature of individual and social action, Pareto determined mathematically that, although many factors are connected to a given outcome, only a few carry the weight to change that outcome in a significant way.

In a process, a few key variables are the cause of most performance problems or defects. This principle holds true even when you analyze the impact of dozens upon dozens of variables involved in complicated assemblies and sub-assemblies with hundreds of separate parts. When you look for leverage in business, you search for the minority of variables that provide the majority of power in solving problems in manufacturing, assembly, distribution, procurement, accounting, finance, customer service, and so on.

Although businesses often employ sophisticated statistical tools to find leverage, you may or may not need such tools for finding leverage as individuals. The key is to know with certainty that, whatever your goal or situation, leverage does exist; some factors in a given situation are more powerful than others.

Similar to illusions of cause-and-effect addressed earlier in this chapter, leverage may not exist where you think it does; the obvious isn't always the correct answer. Look closely, apply tests, and challenge your assumptions to find the true sources of leverage.

Note also that the factors that represent leverage in one situation may not represent leverage in another similar situation. Each process or problem has its own unique dynamics and interactions.

Pick your (critical few) battles

You just can't manage all the factors, contingencies, and dynamics when you're trying to break through to new levels of performance and success. Attempting to control every detail is a slippery slope; the trivial many will bury you in a pile of unnecessary cost, trouble, worries, wasted energy, and valueless action.

No one, and no company, has the luxury or reason to manage all the details. Instead, the right path is to manage only those that are critical to producing the outcomes you desire. Focus on the inputs that really matter and leave the rest alone unless they become significant.

TIP

After you determine that a factor is insignificant, don't waste time and energy putting attention on it; you'll just spread your energy too thin and minimize your ability to create positive change. The key is to engage in a filtering process by which you weed out the many trivial variables that compete for your time but offer no real advantage. By doing so, you disable the force of confusion and achieve clarity of focus around your efforts to resolve an issue, solve a problem, or reach a goal.

Separating and utilizing the critical few

The way you find the critical few is to follow a structured process for defining, measuring, and analyzing all the cause-and-effect relationships. In Six Sigma, structured and powerful tools help you brainstorm the possible causes (*X*s) of performance problems and operational issues; the chapters in Parts II, III, and IV give you the nitty-gritty on the appropriate processes and tools. Collect performance data that reflect the behavior of the many *X*s, as well as the behavior of your *Y* of concern. Analytical tools enlighten you as to which *X*s are the critical ones and which are the trivial.

The results of these operations tell you — and show you objectively and clearly — which *X*s you need to focus on to impact your *Y*. They also show you which *X*s are *out of control,* or behaving too erratically. Such variation is the primary cause of problems in performance predictability.

When you have your baseline of measurements and understand numerically how your *X*s interact and impact your *Y*, you can then implement countermeasures — different *X*-related actions that ultimately improve your *Y*. Head to Part IV for details.

Using your same data framework, you can take new measurements to test the impact of your countermeasures. You have established a data-oriented baseline against which to prove that the new way of doing business is truly a better way, and you've validated that the critical few *X*s are truly the critical few. This confirmation is the essence of the Six Sigma principle of finding the leverage.

Principle 5: Managing Risk

In a perfect world, there would be no error — the ε in the breakthrough equation earlier in the chapter. The input *X*s and transfer function *f* would completely describe the output *Y*. In this world, weather forecasts would be exactly right, financial stock charts would display perfectly smooth and predictable trends, and a card player's selected strategy would fully determine the outcome of the game he was playing.

But the world isn't perfect. Every system, scenario, and situation has some amount of uncertainty and risk. Although the $f(X)$ term in the breakthrough equation represents exact determinism, the ε term captures all this uncertainty or risk. It expresses the fuzziness around which the final answer always varies. (We discuss determinism in the earlier section" Principle 1: Recognizing Determinism.")

You must match risk to the business decision you're making. In some situations, risk (ε) must be painstakingly minimized. In making go/no-go decisions for space shuttle launches, the control center painstakingly minimizes uncertainty in its temperature forecasts because a small variation in temperature can create more risk than the system can tolerate.

Other situations or decisions can tolerate much more risk. If the mission control director misjudges the temperature as he's picking out his clothes on launch day, the fact that he's overdressed or underdressed isn't going to pose significant risk to the mission.

Business processes are exactly the same. Some require very tight risk control; others don't. One of the arts of Six Sigma is knowing how much of the ε in the breakthrough equation must be reduced to fit the business decision at hand. Six Sigma gives you the tools needed to quantify risk and know whether you're making an appropriately accurate analysis or have succumbed to the ravages of the all-too-common disease of analysis paralysis! We discuss risk throughout Parts II, III, and IV.

Chapter 4

Organizing for Improvement

In This Chapter

- Summarizing the Define, Measure, Analyze, Improve, Control (DMAIC) project methodology
- Understanding the many areas of Six Sigma application
- Reviewing roles and responsibilities in a Six Sigma deployment
- Following the deployment and implementation process

Six Sigma changes the lives of individuals and the conduct of organizations. Unlike most other business improvement initiatives, Six Sigma isn't just "feel good" stuff. It's an aggressive, targeted regimen — a pervasive, challenging, systematic eradication of waste and inefficiency. Six Sigma helps you uncover defects and problems that develop and hide in your organization. This chapter introduces the five phases of the Six Sigma DMAIC project methodology — Define, Measure, Analyze, Improve, and Control — that we deal with in much more detail in Parts II through IV of this book.

In this chapter, you find out how to apply the DMAIC methodology in specific areas of the organization and read about the individuals who take on specific roles and responsibilities in a Six Sigma initiative. Finally, you see that the deployment and implementation processes follow a prescriptive road map in the five stages of a Six Sigma project.

DMAIC: Introducing Your Project Strategy

At the business level, Six Sigma projects are the players in the overall game plan of a breakthrough performance improvement initiative. The business perspective is that a Six Sigma project is the agent of action that executes the business strategy and returns the results.

Every Six Sigma project follows a standardized and systematic method named for each of its phases: *Define, Measure, Analyze, Improve, Control,* and known by its acronym, *DMAIC*. This method defines a formalized problem-solving procedure that can improve any type of process in any organization by improving the process's efficiency and effectiveness. You can see a breakdown and graphical representation in Figure 4-1.

- **Define:** Set the context, key metrics, and objectives for the project.
- **Measure:** Capture the current baseline performance and capability of the process or system being improved. Identify all possible contributing factors.
- **Analyze:** Narrow the pool of possible factors down to the critical few. Use data and tools to understand the cause-and-effect relationships in the process or system.
- **Improve:** Develop and validate the modifications that lead to an improvement in the process or system.
- **Control:** Establish plans and procedures to ensure the improvements are adopted and sustained.

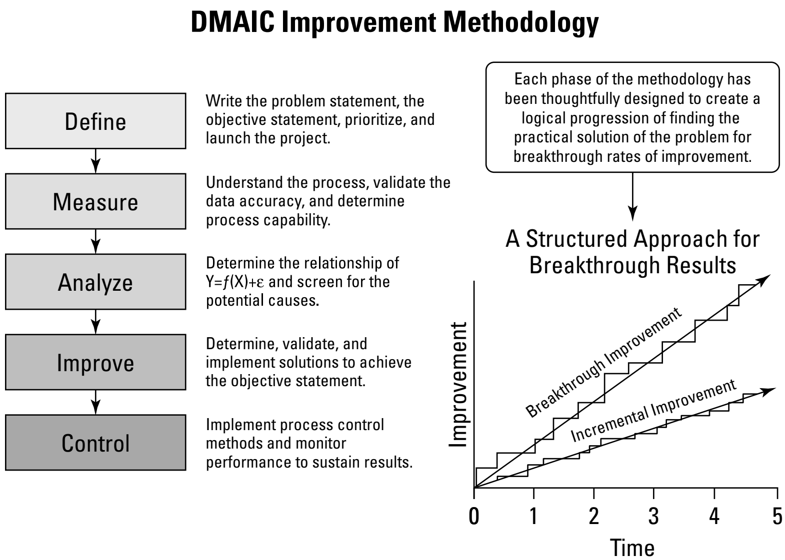


Figure 4-1: The Six Sigma breakthrough strategy (DMAIC).

DMAIC is applied by highly trained practitioners who complete improvement projects that are managed to financial targets. This book is designed to help you become one of those practitioners. In DMAIC, business processes are improved by following a structured method with set steps, or *tollgates.* Only as you start and complete one step are you ready to move on to the next. After moving through all the steps, and only when you can show that the DMAIC project has generated breakthrough benefit, can you then say you've completed a Six Sigma project.

Parts II, III, and IV of this book cover the details of executing each of these phases in detail, including the methods and tools you need to complete a DMAIC project.

TIP

Note: Some companies and Six Sigma practitioners place an *R* for Recognize before the *D* for Define, indicating that you must first recognize and choose the right problem to solve or need to improve before you can define what the problem or need is. But we start with the *D* in this book.

Venturing to the Domains of Activity

You can apply Six Sigma to four areas, or *domains of activity:*

- **Thinking for breakthrough:** The domain of thinking focuses on improving the capacity and efficiency of every employee.
- **Processing for breakthrough:** The domain of processing focuses on improving existing processes, and a large number of employees are involved in this task.
- **Designing for breakthrough:** Fewer people are directly involved in designing, which focuses on improving the designs of new products and processes.
- **Managing for breakthrough:** Every organization has a small number of leaders who are responsible for setting strategy and driving overall business results.

In the following sections, we cover these domains in more detail.

Thinking for breakthrough

Thinking for breakthrough is a set of guiding principles that fuels culture change and gets many people speaking the same language of performance improvement. Thinking for breakthrough is the realm of activity focused on the underlying principles of Six Sigma (see Chapter 3) because directives and procedures aren't the only things that guide the performance of a business. Improvement projects and initiatives aren't just about methods and tools. And wholesale change isn't driven by the minority but by large masses of people who together constitute real and lasting culture change. Sweeping culture change and improvement require you to get everyone in an organization aligned to the same direction, values, and way of thinking.

The traditional path of Six Sigma has been to first lead and then do. First stimulate change and then perform the change process by following a stepwise methodology. Six Sigma change agents apply the guiding principles of Six Sigma as they lead and do.

Thinking for breakthrough emerged only after Six Sigma was proven and became pervasive and only after its underlying principles were well understood by so many practitioners. Whereas processing, designing, and managing for breakthrough are methodology- and tool-driven, thinking for breakthrough is mind-driven.

Processing for breakthrough

Processing for breakthrough is the realm of activity that focuses on optimizing the performance of existing business and operational processes. Any process is theoretically capable of operating at its *entitlement level,* the performance level it has demonstrated it can operate at in the best case, even if it doesn't perform to that level all the time. (Head to Chapter 5 for more on entitlement.)

If a budgeting process is capable of operating at a 95-percent acceptance level for several weeks out of the year, you can say that 95 percent is the entitlement level for that process. Generally speaking, entitlement is the very best a process, product, service, or transaction can do without needing a redesign.

When you're processing for Six Sigma, you take actions and implement improvements that enable your process to perform to its utmost potential all the time, not just part of the time, within the limitations of its current design. You do so by applying the DMAIC methodology through Six Sigma improvement projects — all of which are focused on improving processes that are aligned with business priorities set by management.

The people who are directly responsible for processing for breakthrough are called Process Owners, Project Champions, Master Black Belts, Black Belts, Green Belts, Yellow Belts, and sometimes White Belts. You get a full description of who these people are and what they do in the "Filling the Roles: Who You Need to Know" section later in this chapter.

Designing for breakthrough

Designing for breakthrough is the realm of activity focused on optimizing the design process prior to manufacturing products, delivering services, or conducting transactions for customers. *Design for Six Sigma* (DFSS) is an approach for planning, configuring, qualifying, and launching products, services, transactions, processes, systems, and events that move quality upstream in an organization.

By *upstream,* we mean that DFSS methods and tools enable you to anticipate the source of development, manufacturing, or performance problems before they occur so that you can design and plan in a way that allows you to avoid them. Designing quality into products, services, transactions, processes, systems, and events from the beginning is what prevents the hidden factory from arising, eroding value, and ultimately eating away at profits. (Chapter 2 gives you the lowdown on *hidden factory,* where rework and fixes occur from not doing the job right the first time).

DFSS maximizes the confidence that a product, service, transaction, process, system, or event design will perform to its entitlement level in the presence of uncertainties that can't be feasibly managed. First, DFSS reduces the risk in the performance and attributes of a design (customer satisfaction issues). Second, it lowers the risks associated with the business and operational viability of a design (provider satisfaction issues).

REMEMBER

DFSS isn't just an area of focus for design engineers in a company; it's applicable to the design process within any domain. DFSS enables you to build quality into processes and outcomes such that the opportunity for damaging variation and defects never occurs.

Managing for breakthrough

Managing for breakthrough entails all the plans, systems, and processes for leading improvement within an organization. It's the mechanism by which an organization drives and supports the activities in the domains of thinking, processing, and designing for breakthrough (which we cover in the preceding sections).

W. Edwards Deming (1900–1993), arguably the most influential thought leader in the realm of quality over the last 100 years, asserted that the realm of management is where quality improvement starts and where its solution resides. In fact, Deming said that management is responsible for 85 percent of all problems because it creates the systems that prevent workers from being fully effective.

Managing for breakthrough involves selecting and training the right people; installing an improvement infrastructure; assimilating certain software tools; and establishing a management system, methods, and practices that are robust enough to set an organization on a new performance path. More information on the management aspects of selecting Six Sigma projects is in Chapter 5, and you can find a complete rundown on all the important tools for managing Six Sigma in Part V.

REMEMBER

Because Six Sigma is an intervention that sets an organization on a new performance path, managing for breakthrough is a matter of leadership. Positive leadership moves people and organizations in a new direction, disrupting the status quo. The executives, Champions, and deployment leaders are directly responsible for managing the Six Sigma initiative. Sometimes a Master Black Belt is also involved in managing for breakthrough. You can get a full description of who these people are and what they do in the following section.

Filling the Roles: Who You Need to Know

The full deployment and implementation of a Six Sigma initiative in an organization requires the collective participation of numerous people, each of whom is responsible for fulfilling specific roles and obligations at both the managerial and technical levels. Most often, these people are drawn from within the ranks of the company and are specially trained to the requisite skills.

The rigorous nature of a Six Sigma deployment compels an organization to call on its very best people to participate. When you're involved in a Six Sigma initiative, you're working with the best and brightest, and you're part of a structured assembly of talent that works together to achieve the breakthrough goals of Six Sigma improvement.

One of the single greatest characteristics of Six Sigma is that it develops leadership. Regardless of your role or function, you develop leadership characteristics you didn't have before. Your personal and professional lives have new potential and new meaning. Six Sigma requires energized thinking, an open mind, and an unquenchable thirst for truth and betterment. The Six Sigma mindset is one that initiates change, sees problems as opportunities, and formally questions fundamental assumptions until the root causes are characterized, optimized, and controlled. These are principles and practices of leadership, and they're a fundamental part of the character of everyone who carries the Six Sigma flag.

REMEMBER

For every participant, Six Sigma is a breakthrough leadership initiative. Just like the breakthrough performance returns realized by the organization, everyone involved in Six Sigma realizes a nearly unbounded sense of potential. Barriers and limitations melt away. Anything is possible. After you've stepped through the Six Sigma looking glass, there's no turning back — you're transformed. Energized thinking and thirst for truth become part of your being. You feel naturally compelled to question assumptions, search for root causes, and characterize and optimize things. You become a leader.

Starting at the top

A Six Sigma initiative begins with a team of executives and business unit senior managers who approve the Six Sigma deployment program, endorse projects, and are accountable for achieving the results. They inject the initial dose of vision and ambition into the organization and apply the business savvy and people skills to stimulate the drive for change.

Six Sigma is a top-down initiative. Although Six Sigma methods and tools are applicable at all levels, breakthrough organizational performance requires a fully coordinated commitment, and that can only come from the top.

You may be tempted to try to introduce a Six Sigma initiative from the bottom up, perhaps because you see the potential of and have control over your area of business or because your senior management "just doesn't get it." You may be successful in applying the Six Sigma methodology in your local business area to achieve a significant level of process improvement, but getting the rest of the organization to embrace Six Sigma has to originate at the top. Prepare yourself to take your success to senior management and take it from the top going forward.

Assembling the core team

We can't overemphasize the critical importance of a cross-functional core leadership team in ensuring the efficient and effective rollout of a Six Sigma initiative. The core team is a unified body whose members perform an organizational assessment, benchmark products and services, conduct detailed gap analyses, create the operational vision, and develop implementation plans. The core team ensures completeness of deployment throughout the organization by taking the following actions:

- Making the initiative highly visible through active and personalized leadership, commitment, and passion for change
- Installing the measurement system that tracks the progress, installs accountability into the initiative, and provides a visible dashboard of progress and efforts
- Benchmarking products, services, and processes so that the organization can truly understand its relative position in the marketplace
- Setting stretch goals that focus on changing the process by which work gets done rather than tweaking existing processes, leading to leapfrog rates of improvement
- Providing knowledge and education to all levels of people because certain methods and tools are necessary to initiate and sustain breakthrough improvement
- Evangelizing success stories that demonstrate how Six Sigma methods, technologies, and tools have been applied to achieve dramatic operational and financial improvements in other organizations
- Developing and implementing a supporting infrastructure that enables Six Sigma to naturally occur and flourish in a company

Core team members include the following people and departments:

- Key executive representatives
- Functional representatives, including
  - Finance
  - Training
  - Information technology (IT)
  - Human resources
  - Communications
- Six Sigma deployment leader
- Business unit leaders

Focusing on functional representatives

Functional representatives are senior corporate staff members who run their respective departments or have large responsibility in those departments. They're well respected leaders who can drive short-cycle change initiatives because they know the people and have the knowledge they need to set new initiatives in place. Functional representatives include the following:

- Finance representative:
  - Is the single point of contact for Six Sigma finance issues and coordinates all project auditing and validation activities
  - Determines how project costs and savings are defined, valued, and reported
  - Develops a project savings audit process and leads finance participation in the project selection and review processes
  - Defines accounting and budgeting requirements for Six Sigma-related expenses
- Training representative:
  - Is the single point of contact for Six Sigma training issues and coordinates Six Sigma training activities for the entire corporation
  - Configures all training curricula and courseware for the Six Sigma initiative, including executive, Champion, Master Black Belt, Black Belt, Green Belt, Yellow Belt, DFSS, awareness training, and thinking for breakthrough
  - Schedules and coordinates all Six Sigma training courses, logistics, materials, and supplies and also develops training sign-up, tracking, and reporting processes

- Information technology representative:
  - Is the single point of contact for Six Sigma IT issues and coordinates Six Sigma IT activities in all organizations
  - Arranges for purchase and distribution of Six Sigma software — along with the hardware necessary to support it — for training and knowledge transfer, analytical work, project management, and process improvement
  - Prepares and executes plans for providing end-user support for Six Sigma software
- Human resources representative:
  - Is the single point of contact for Six Sigma human resources and coordinates all Six Sigma-related HR activities
  - Writes job descriptions for all Six Sigma positions and prepares an organizational chart that identifies the roles
  - Develops compensation packages for all Six Sigma positions and works with business leadership to configure reward, recognition, and career-development plans
- Communications representative:
  - Is the single point of contact for all Six Sigma communication activities and leads the development and implementation of communication plans
  - Organizes a process for communicating internal successes and coordinates communication with stock analysts, suppliers, customers, partners, and investors
  - Arranges for the distribution of reference, informational, educational, and background material throughout the company

Each Six Sigma role-player works with other members of the team, as shown in Figure 4-2, keeping the project as the central focus.

Spotting the deployment leader

The Six Sigma deployment leader is the single most important individual in the deployment process. The deployment leader is often a senior manager or executive who reports directly to the corporate-level person responsible for launching and sustaining Six Sigma.

The *deployment leader* ensures the effective alignment of corporate strategic goals with business unit deployment plans. She monitors progress and sustains performance at target levels as Six Sigma is executed throughout the organization. In this role, the deployment leader develops the Six Sigma roll-out plan; helps select Champions, Black Belts, Green Belts, and Yellow

Belts (who we introduce later in the chapter); and ensures proper training. The deployment leader also works closely with the Six Sigma Champion and serves as a conduit between Champions and executive management as higher-level goals and objectives are communicated downward and goals and plans are aligned with implementation actions.

The power of Six Sigma revolves around Black Belt and Green Belt projects, and involves many others.

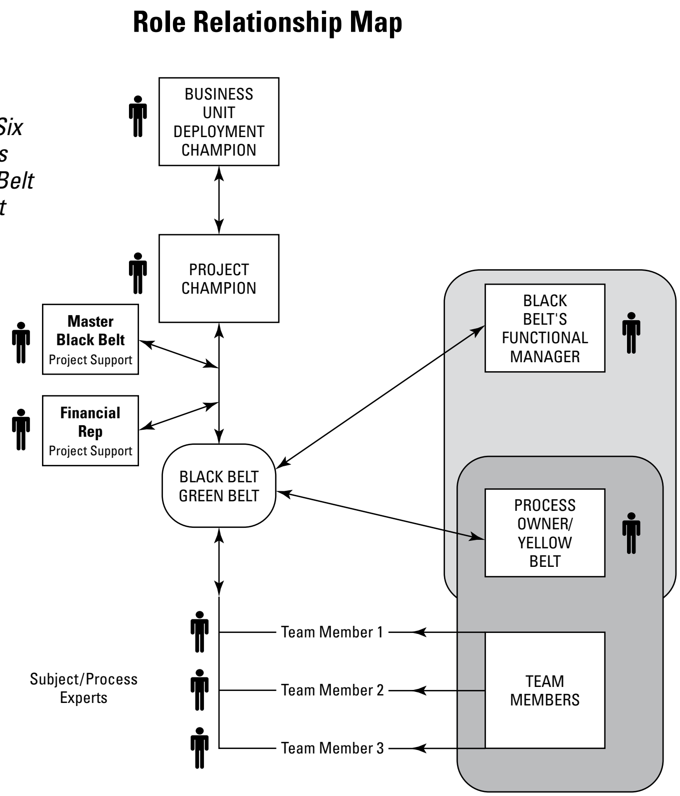


Figure 4-2: The project is the center point of Six Sigma activity.

Specific responsibilities of the deployment leader also include the following:

- Ensuring accountability for the results of Six Sigma
- Driving the vision and mission for Six Sigma into the organization
- Removing barriers to successful implementations
- Internally publicizing Six Sigma goals, plans, progress, results, and best practices
- Creating and maintaining passion and commitment to Six Sigma goals
- Updating executive leadership on the progress of the business units

Large corporations made up of many business units may need deployment leaders at the business unit level. Reporting directly to a business unit executive leader, the business unit deployment leader is responsible for initializing and implementing Six Sigma within her particular organization. In smaller organizations, the roles of the deployment leader and the Six Sigma Champion may be combined and filled by a single individual.

Naturally, the Six Sigma deployment leader has a great deal of rapport with her peers and has typically functioned as a manager or team leader. She's responsible for developing and communicating the corporate vision for Six Sigma and ensuring that appropriate resources and support structures are in place.

Meeting the Six Sigma Champion

Six Sigma *Champions* are responsible for disseminating and successfully applying Six Sigma technical know-how. They develop a plan for transforming their organizations to "Six Sigma as the way we think and work." They're also responsible for ensuring the success of Black Belts and Green Belts. Champions have long-standing rapport with key managerial and staff people and a demonstrated ability to pull people and resources together on short notice to achieve key objectives. The Six Sigma Champion

- Identifies, selects, scopes, prioritizes, and assigns projects and aligns projects to business strategies
- Selects Black Belts, Green Belts, and Yellow Belts and ensures that they're appropriately trained, tasked, and deployed
- Supports Black, Green, and Yellow Belts through the removal of organizational barriers, securing necessary resources, coaching, and reviewing project implementation status
- Establishes an adequate backlog of projects and ensures that all Belts and Master Black Belts are fully dedicated to Six Sigma activities
- Reports progress against target metrics to Champions
- Promotes best-practices sharing and leverages solutions and improvements across organizational boundaries

Large corporations made up of many business units may have a Senior Champion, as well as Champions at the business-unit level. As we note in the preceding section, smaller organizations may combine the roles of the deployment leader and the Six Sigma Champion and fill them with a single person.

Number-crunching karate: Black Belts and their brethren

Solving problems the Six Sigma way requires varying degrees of skill in applied statistics. Solving complex problems requires considerable statistical expertise, but dealing with moderate problems or routine work takes less skill.

In Six Sigma, the highest level of statistical skill is called *Black Belt,* the medium skill level is *Green Belt,* and the everyday level is *Yellow Belt.* The nearby sidebar explains where the belt terminology came from.

REMEMBER

The martial arts connotation really does make sense. A Six Sigma Black Belt is so expertly skilled and so experienced that she understands the true nature of her opponent (an underperforming process), and she knows how to apply the right skills and tools with grace and minimal effort to channel its energy and fully achieve the organization's goals.

WARNING!

Although the Belt terminology is universally understood, it's not universally accepted. Many companies and industries apply it as a broad standard, but the nomenclature is downright unfashionable in some circles.

Figure 4-3 shows the hierarchy of practitioners; you can read more about the roles and skills of the various Belts in the following sections.

Tightening your belt around Six Sigma roles

In the early 1990s, Motorola was assisting Unisys in solving complex problems associated with the production of large-scale multilayer printed circuit boards for military applications. They found the solutions by applying the advanced statistical analysis tools of Six Sigma. The managers wanted to promote the value of the expertise developed within the team. One evening, while unwinding after a long day's work at the Unisys facility in Salt Lake City, they hit on the idea of calling these engineers Black Belts — a term that captured the mystique of their discipline and skill. "Now that's a name I can sell!" proclaimed the Unisys manager.

And it did sell. As the Six Sigma methodology flourished, so did the title of Six Sigma Black Belt as the master of statistical problem-solving. Later, as the need for lesser degrees of skill was identified, the terms Green Belt and Yellow Belt were added. Across the global Six Sigma landscape, you can also find additional variants, including Blue Belt, Brown Belt, and even White Belt (but only before Labor Day — just kidding). You'll even hear jokes about Chartreuse Belts (part Green, part Yellow), Polka-Dotted Belts, and more.

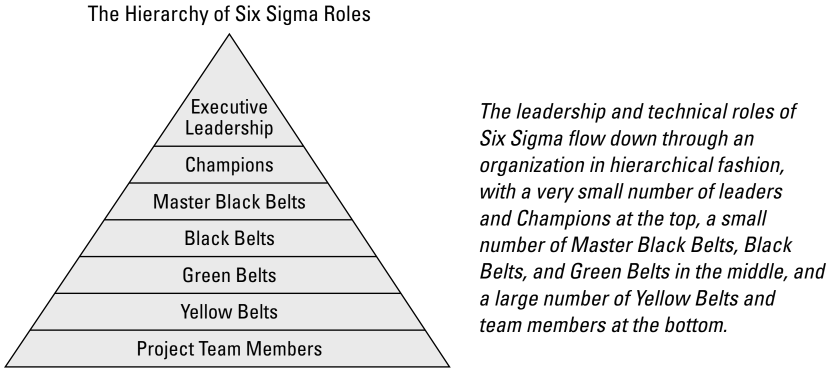


Figure 4-3: The hierarchy of Six Sigma roles.

Master Black Belts

Master Black Belts (MBBs) are the trainers. They're accomplished Black Belts with teaching skills — hands-on experts who teach and mentor Black, Green, and Yellow Belts and who often own the Six Sigma training curricula and Six Sigma knowledge content for their organizations. As mentors, MBBs consult other Belts on fundamental business issues as well as specific project application issues, challenges, and problems.

Black Belts

Black Belts are the most highly trained experts in the complete set of Six Sigma methods and tools. They're highly respected for possessing the knowledge and skill required to facilitate breakthrough-level improvements in the most complex of processes. Black Belts typically comprise 1 to 2 percent of the organization and work full-time leading Six Sigma projects. The Black Belt

- Implements Six Sigma projects that historically are advertised to return a bottom-line value of $150,000 or more to the organization. A Six Sigma Black Belt may implement as many as four such projects a year.
- Mentors and coaches others in applying Six Sigma methods and tools.
- Leads complex departmental, business unit, or cross-functional process improvement projects that require significant data and analytical skill.
- Disseminates new strategies and tools through training, workshops, case studies, local symposia, and more.
- Discovers internal and external (suppliers and customers) opportunities for new Six Sigma projects.

Green Belts

The Six Sigma Green Belt is trained and skilled to solve the majority of process problems in both transactional and manufacturing environments. Green Belts are process leaders, process owners, professional staff, operational specialists, managers, and executives who have a significant degree of business, leadership, statistical, and problem-solving skills. Green Belts typically make up 5 to 10 percent of the organization and work part-time, either in support of Black Belt projects or leading less-complex projects of their own. The Green Belt

- Implements about two projects per year that historically are advertised to return an average bottom-line value of $35,000
- Teaches local personnel to apply Six Sigma strategies and tools and coaches local personnel through one-on-one support
- Leads departmental, business unit, or cross-functional process improvement projects in environments that don't require complex data or heavy statistical analyses
- Disseminates new strategies and tools via training, workshops, case studies, local symposia, and more
- Discovers internal and external (that is, suppliers and customers) opportunities for Six Sigma projects

Yellow Belts

All members in the organization can apply elements of the Six Sigma methodology and improve their work environments. Everyone can assist Green Belts and Black Belts in completing projects. But not everyone needs to be immersed in the details or challenges at a Green or Black Belt level.

The Six Sigma *Yellow Belt* is this "everyone else." Yellow Belts are staff members, administrators, operations personnel, project team members, or any other technical or nontechnical position. Nearly anyone can identify measurement scales, define critical process factors, collect some data, characterize a process, make easy improvements, and cultivate opportunities.

The goal of Yellow Belts is to think in a data-driven, cause-and-effect process manner and apply this thinking to their areas of work. Yellow Belts support Black Belt and Green Belt projects and can even take on small projects of their own.

Following the Five Stages of a Six Sigma Initiative

You don't start a Six Sigma program by launching right into a bunch of projects. Six Sigma is strong stuff; you move deliberately and prescriptively through distinct phases. A Six Sigma initiative occurs in five major stages (see Figure 4-4):

1. You initialize Six Sigma by establishing goals and installing infrastructure.
2. You deploy the initiative by assigning, training, and equipping the staff.

3. You implement projects and improve performance, yielding financial results.
4. You expand the scope of the initiative to include additional organizational units.
5. You sustain the initiative through realignment, retraining, and evolution.

The following sections discuss these phases in detail.

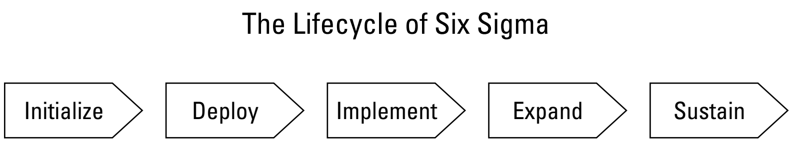


Figure 4-4: Six Sigma progresses in distinct stages.

Initializing: Ready, aim . . .

Six Sigma initiatives are programs. They require programmatic-type preparation and planning, beginning with a prescriptive set of readiness tasks. The initialization stage includes selecting the core team, preparing the supporting infrastructure, and enabling the processes; Table 4-1 spells out the elements you have to have in place to facilitate the deployment activities of the next stage, which we cover in the following section.

Table 4-1 Elements of Six Sigma Initialization

Element	*Details*
Launch planning	A fully documented Six Sigma leadership system, implementation plans, schedules, and activity tracking/reporting techniques
Human resource guidelines	Competency models and participant selection, position and role descriptions, compensation, reporting relationships, career planning
Communications plan	Overall strategy (who, what, and when), message content as a function of time, methods, and mediums
Financial guidelines	Savings definitions, project forecasting, methods of evaluation, realization tracking, integration of initiative metrics with project tracking and management software
Project selection guidelines	Definition criteria, project type categorizations, problem statement, targeted savings values, approval process, completion requirements

(continued)

Table 4-1 *(continued)*

Project tracking and reporting	Organization structure definition, user manuals and training, report generation
Management dashboards	Visualizations and presentations of process and project performance with key operational and strategic indicators
Information technology support	Software installations, computer needs, intranet development, databases for final reports

As part of initialization, executive training prepares the executive staff and senior leaders by providing a comprehensive overview of the Six Sigma deployment process and what to expect. The executives also agree on macro items including scope, time frames, goals, and objectives, and they issue a formal commitment statement to all employees and constituents.

Keep the scope of the first deployments in check. The most successful Six Sigma initiatives begin with the deployment scope limited to a selected line of business or division of activity.

Deploying: Setting the infrastructure in motion

With a supporting infrastructure, corporate goals, and metrics established, the deployment stage begins with selecting the Champions and the first candidate Black Belts, Green Belts, and Yellow Belts. Champions are trained in the Six Sigma methodology, the principles, of implementing Six Sigma, and in project selection, practices, and tools, and begin the critical work of selecting the first Six Sigma projects.

The core team then deploys the infrastructure outlined in Table 4-1. According to the deployment plan, the first waves of Black Belts, Green Belts, and Yellow Belts are trained and assigned to projects. All types of Belt training include defining, characterizing, and improving a work process as part of the training regimen. Although this setup extends the training period, trainees deliver results to the bottom line as they complete their initial training. The training has immediate-term return on investment.

Implementing: Forging first successes

Upon completion of the first waves of Belt training, the early successes create momentum, and the Six Sigma initiative begins to gather traction. As successes continue, the initiative can become infectious and turn around even the skeptics.

In the implementation stage, the practitioners are defining and mapping processes, identifying critical-to-quality indicators, collecting performance data, and characterizing process performance. They're conducting statistical analyses, discovering the root causes of problems, and improving performance levels. Your company has begun to root out waste, increase productivity, lower costs, and decrease cycle time. Six Sigma is working!

REMEMBER

Watch the first implementations closely to ensure success and to generate positive program momentum. Black Belts must be assigned full time to their projects and given leverage to perform their jobs with backing from top management, or they won't get the job done. Green Belts and even Yellow Belts must be supported in their projects. Technical issues must be addressed head-on with appropriate skill to ensure success.

WARNING!

Not all first projects go well — for a variety of reasons. Having early high-profile projects sputter can threaten the success of the initiative. For this reason, be sure to implement early projects that have a manageable scope, moderate risk, and the promise of reasonable returns. Leave the big risk/high reward projects for a little later.

Expanding: Taking it everywhere

Following the first successful waves of implementation, the organization expands Six Sigma into new locations, functional areas, and lines of business.

REMEMBER

Introducing Six Sigma into each new line of business is an initiative unto itself and includes the stages of initialization, deployment, and implementation. The lessons learned from the first deployment are included in revisions to the implementation plans going forward.

Deploying Six Sigma into each new business or functional area requires some form of tailoring or customization. Examples include

- Six Sigma in engineering and design areas employs methods and tools of a subfield known as Design for Six Sigma (DFSS — see the "Designing for breakthrough" section) and tools like Axiomatic Design.
- Six Sigma in manufacturing includes Lean practices, which focus on elimination of waste, like high scrap rates, inflexible manufacturing systems, poorly documented processes, or large lot production scheduling leading to high inventory levels. (You can read more about Lean in the latest edition of *Lean For Dummies* by Natalie Sayer and Bruce Williams [Wiley].)
- Highly computerized environments may incorporate automated process execution management tools.
- Deployment into foreign countries requires internationalization and localization of materials and tools.

Also remember that as the portfolio of projects grows and diversifies, applying enterprise-class tracking and management tools is important. Read more about these tools in Chapter 23.

The first few waves of projects in any given function or business area harvest what is known as the *low-hanging fruit* — the obvious opportunities with big returns. As the Six Sigma initiative matures, two phenomena occur:

- The biggest projects have all been completed.
- The Yellow-Belt culture is curing little problems before they become big problems.

At this point, the project-oriented Six Sigma culture begins to give way to the sustaining culture.

Sustaining: The self-healing culture

The Six Sigma initiative changes character after the low-hanging fruit has been harvested. The deployment leader and Champion shift the sustaining direction away from a project orientation into a process-management approach, where the tools of Six Sigma move to a supporting role as part of how business and work processes execute most efficiently and effectively. The Six Sigma tools take their places in the organization's methodological toolbox, along with other selected tools of business performance operations.

In the sustain phase, the culture is *self-healing;* the Six Sigma project becomes a tool for addressing flare-up issues that emerge from new initiatives and outside forces. Six Sigma training supports these project needs and is also integrated with other methods to support process needs. Training is used as a refresher for existing staff and to enable new hires, contractors, and acquisitions to get up to speed in the Six Sigma culture of the organization.

Part II

DMAIC: Defining and Measuring

"I understand you've found a system to reduce the number of complaints we receive by 50 percent."

In this part . . .

Six Sigma's DMAIC problem-solving road map starts with defining an improvement project, measuring its current performance, and identifying all the possible factors contributing to the situation. This part shows you the tools for beginning an improvement project.

Chapter 5

Identifying and Right-Sizing Projects

In This Chapter

- Defining projects to improve your processes
- Aligning Six Sigma projects with business needs
- Realizing the benefits of a Six Sigma project

The essence of Six Sigma is to solve problems that are impacting business performance. But before you can solve a problem or improve performance, you have to properly define and scope your goal or objective and chart your course — the Six Sigma project. In fact, defining a project is 50 percent of the improvement game, and framing problems the right way is critical to the success of your organization.

The Define stage of the breakthrough strategy (DMAIC) requires you to identify problems to be solved, but to solve them, you must construct Six Sigma projects. To get the most out of your Six Sigma initiative, Six Sigma practitioners and management alike address these problems in a strategic way.

Defining projects for success requires you to recognize problematic areas of the business and subsequently create a clear direction for resolving these problematic areas. The key is to constrain project scope to a manageable and achievable size. Remember the metaphorical question, "How do you eat an elephant?" The answer: One bite at a time. It's the same with Six Sigma projects. Problematic areas of the business (such as warranty returns, accounts receivable, product yield, and customer satisfaction issues) are the elephant-sized issues. Address these large concerns by engaging in more than one Six Sigma project, thereby eating the elephant one bite at a time. This chapter shows you how to take those bites.

Launching a Six Sigma Project

In Six Sigma, you make progress the old-fashioned way — one project at a time. That's not to say progress is serial; it's often accomplished in parallel as many Black Belts, Green Belts, and Yellow Belts apply the breakthrough strategy throughout an organization (see Chapter 4 for more on Belts). In essence, projects are the unit of change; they define the collective effort by which most Six Sigma progress is accomplished. Projects represent — and in fact are — the level of granularity expressed to manage Six Sigma change, from a single process improvement to a large-scale business improvement effort. In the following sections, we walk you through each of the steps to initiating a Six Sigma project, from framing the problem to figuring out your goals and needs.

Scoping the perfect project

A Six Sigma project starts as a practical problem that adversely impacts the business and ends as a practical solution that improves business performance. The focus of a project is to solve a problem that is hurting key performance elements, such as the following:

- Organizational viability
- Employee or customer satisfaction
- Costs
- Process capability
- Output capacity
- Cycle time
- Revenue potential

Begin your project by stating performance problems in quantifiable terms that define expectations related to desired levels of performance and timing, as described in Figure 5-1.

As you define your Six Sigma project, pay attention to issues that warrant a Six Sigma level of effort. Consider problems that

- Have a financial impact to EBIT (Earnings Before Income Tax) or NPBIT (Net Profit Before Income Tax) or have a significant strategic value
- Produce results that significantly exceed the amount of effort required to obtain the improvement
- Aren't easily or quickly solvable with traditional methods
- Improve performance of a specified metric or Key Performance Indicator (KPI) by greater than 70 percent over existing performance levels

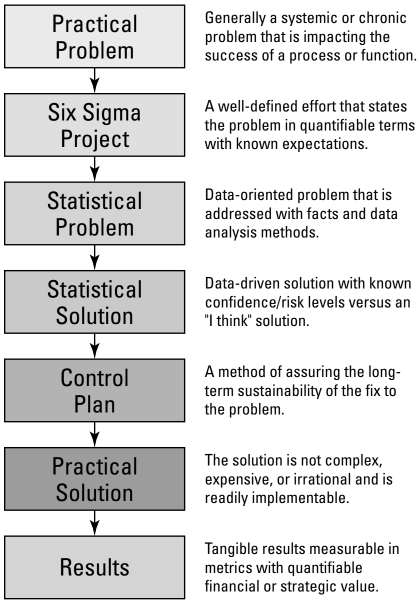


Figure 5-1: Project life-cycle.

Transforming the problem

After you've framed a particular problem to become a potential Six Sigma project, the problem goes through a critical metamorphosis — it transforms from a practical business problem into a statistical problem. This way, you can identify a statistical solution, which you'll later transform back into a practical solution. In defining the project, you therefore state your problem in statistical language to ensure that you use data, and only data, to solve it. Using only data forces you to abandon gut feelings, intuition, and best guesses as ways to address your problems.

TIP

You can't solve real problems just by throwing time and money at them. You need practical solutions. Six Sigma projects provide practical solutions that aren't complex, aren't too difficult to implement, and don't require extensive resources to affect the improvement.

Knowing your goals and needs

To obtain the maximum benefit from your Six Sigma projects, you must be aware of the strategic needs, goals, and objectives of the business. You should keep those key goals and objectives in mind when you decide which problems you need to solve as part of your Six Sigma projects. Figure 5-2 illustrates this process.

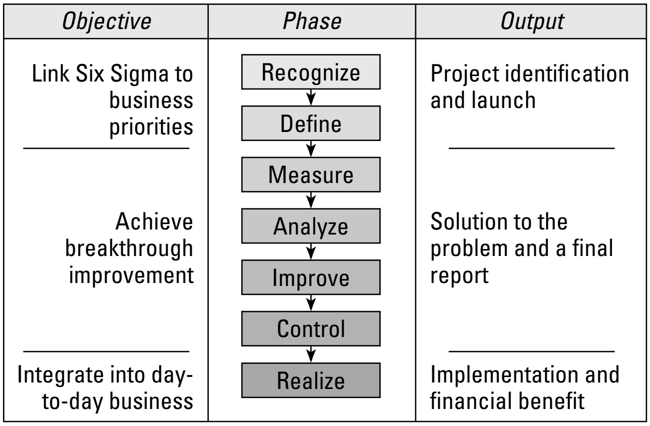


Figure 5-2: Project alignment to business needs.

Figure 5-2 is an expanded view of the breakthrough strategy that includes a Recognize step in the beginning and a Realize step at the end. You begin by finding areas of the business that need improvement to meet business goals (Recognize). This approach leads you to determine the specific problems you need to solve to improve performance. Then you determine a statistical solution to your problem, implement the solution, and obtain the subsequent benefits.

TIP

Where to begin? Start by assessing the higher level needs of your organization, using any knowledge obtained from the voice of the customer (VOC) and the voice of the business (VOB). The VOC is all the needs and expectations your customers have for your products and services. The VOB represents all the needs and expectations of the business. The basic idea is to assess both the VOC and VOB to identify gaps — areas where the expectations of the business and expectations of the customer are misaligned. See Chapter 13 for further details on VOC.

To help zero in on problem areas, look for themes, such as the following:

- Accounts receivable and invoicing issues
- Capacity constraints
- Customer complaints
- Cycle time or responsiveness
- Excessive inventory levels
- Ineffective or defective services
- Product returns or warranty costs
- Yield and subsequent rework or scrap

Determining project responsibilities

In addition to transforming the problem from the practical domain to the statistical domain (see the earlier section "Transforming the problem"), Six Sigma projects also transform the ownership structure. Problems that begin in functional areas transform from line managers through Belts and finally on to process owner, as Figure 5-3 demonstrates.

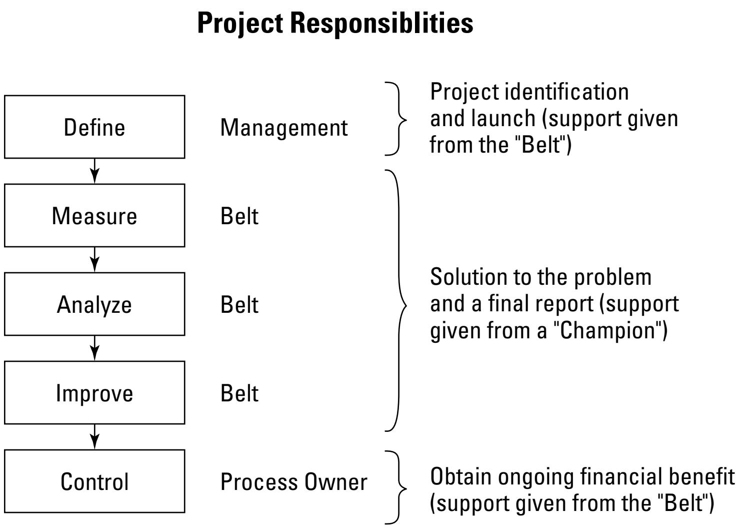


Figure 5-3: Project responsibility and ownership.

Project responsibilities, accountabilities, and deliverables are divided between managers and the various Belts who perform problem-solving activities. Managers, including the process owner, are responsible for determining priorities and focus, while non-management personnel are responsible for implementing the solution and realizing the benefits. These project lifecycle relationships prevent Six Sigma deliverables from falling into the cracks.

Six Sigma is a team effort. Even in the Define phase, where managers are responsible for project identification and launch, the Belts assist. Generally speaking, Belts have only 20 percent of the responsibility for defining and managing improvement, while the managers have 80 percent. Later, during implementation — the MAIC portion of the breakthrough strategy — these percentages are reversed.

Writing the Business Case

After you've homed in on the problem area, you need to define the business case for the project approach you're considering. Writing the business case helps you describe or characterize the issues and estimate the potential value of improvement projects. Don't worry: We provide a writing template and help you with the process in the following sections. At this stage, you aren't looking to define the project but rather to identify the value.

Starting with candidate business-case statements

Completing a business-case writing exercise can be an eye-opening and exhilarating experience. Perform the exercise as a team and have each member use 15 to 20 sticky notes to fill in the business-case writing template (described in this section).

TIP

Describing a business problem at the high level doesn't have to be very detailed. The details come when you define the project itself, just prior to beginning the Measure phase of the DMAIC methodology. At this stage, you're describing the problem at a business level such as the following:

- Excessive warranty returns
- High accounts receivable levels
- Lack of customer sales order responsiveness
- Noncompetitive product yields and cost

Make your best estimate of the potential financial benefit from improvements, based on the data or knowledge you have at the time. In the beginning, just get a number in the ballpark.

Here's the structure of the business case statement. Use it as a template for your own organization:

> As a company, our *(insert specific type of)* performance for the *(name specific area)* area isn't meeting *(define goal, target, or other measure).* Overall, this is causing *(name type of)* problems that are costing us as much as $ *(list specific amount)* per *(insert time frame)*.

Here are some examples:

- As a company, our accounts receivable performance for the finance invoicing area isn't meeting the goal of 47 days sales outstanding. Overall, this is causing cash flow and budget problems that are costing us as much as $4 million per year.
- As a company, our final process yield performance for the paint and polish area isn't meeting the targeted 97 percent yield. Overall, this is causing floor space, shipment, and resource problems that are costing us as much as $900,000 per year.
- As a company, our on-time delivery performance for our healthcare products area isn't meeting the scheduling and delivery cost requirements. Overall, this is causing delivery issues and customer dissatisfaction problems that are costing us as much as $3 million in lost revenues and $1.5 million in expenses per year.

Ask each member of your team to brainstorm in silence, thinking of as many business cases as he or she can and writing the case idea titles on the sticky notes. Each written business case is a stand-alone idea that identifies problem areas of the business. When a team member has exhausted all ideas, he or she sticks those notes on the wall. Each member of the team performs a similar action until all members have posted their ideas.

Selecting the business case

After you've drafted a set of candidate business case statements, your next step is to select the business case that will define the basis for your Six Sigma project. Sort through the candidates iteratively, with each member of the team reading all business case ideas and moving them into common clusters. Feel free to move the ideas from cluster to cluster; after about 10 to 15 minutes, you'll have them sorted into categories.

Usually, you see a natural emergence of five to ten problem areas, or clusters. Have the team leader for the exercise write a title for each of the clusters, such as "warranty returns," "accounts receivable," and so on. Generally, some ideas will be duplicated, but that's okay; duplication indicates the strength of an idea.

After this initial phase, the fun begins. With five to ten different problem areas in hand, your team can now begin adding more data and detail, and even redefine some of the categories if necessary, to help you take the ideas to the actionable level. Next, identify the person most likely to be responsible for each identified area. Because the group makes the decision and the choice is usually obvious, this step goes pretty fast.

Because everyone has been actively involved in this process, each person has a sense of belief in and ownership for the issues and selections. Another important benefit comes from each person having to read and move the notes from one cluster to another; folks process information and become knowledgeable about the broader issues facing the organization instead of only understanding what's going on in their own respective departments. This exercise is a great way to create a common platform of knowledge and cooperation, which leads to widespread involvement in improvement actions.

The business-case selection exercise uses the Six Sigma tool known as an *affinity diagram,* which you can read about in Chapter 8. This modified brainstorming technique has the advantage of gathering inputs from all team members without the inhibition of criticism. It also fosters the natural emergence of important groupings or categories of ideas.

You now have a valuable set of data and a knowledgeable team to develop an improvement plan, using Six Sigma. You know the most critical improvements needed, have an insight into the type and scope of needed improvements, know who has responsibility for each improvement idea, and have a sense of the value that can be created by effectively addressing the problems. This process prepares you to define specific projects to solve elephant-sized problems. You're now ready to enter the Define phase of DMAIC.

The business-case writing tool is a general-purpose tool that can also be used at the local process levels — and even at a personal level to address value and performance challenges in your own life.

When You're Ready: Defining a Six Sigma Project

When defining a project, you get into the nuts and bolts of Six Sigma. Doing this step right is well worth your time because 50 percent of your project's success depends on how well it's defined!

Different people can be part of defining a potential project, including the following (see Chapter 4 for the lowdown on these roles):

- Champions
- Belts
- Process leaders
- Functional managers or process owners

Note: Any employee can suggest a Six Sigma improvement project, but have one of the people in this list consider and sponsor the project.

The most common mistakes people make in defining a potential project are

- Making the scope too broad (solving world hunger or boiling the ocean). Symptoms include considering too many *Y*s (outputs) for improvement (see Chapter 3 for more on what *Y* means), multiple goals, numerous process owners, and multiple departments.
- Picking a problem that's too easy to solve with a Six Sigma project.
- Selecting a problem for which the solution is known or for which a specific solution is mandated.
- Defining a "just do it" solution, where no formal project and problem analysis is required.
- Trying to make a problem out of a management issue.

In the following sections, we provide the steps for defining a project and selecting the key outcomes. We also help you determine the magnitude of the problem and whether forging ahead with a Six Sigma project for that problem is worth the time and effort.

Following the steps of the project definition process

To ensure that a project is well defined, go through a specified sequence of events. Generally, you can expect to perform the following eight specific steps in this process:

1. **Determine the *Y* — what specifically needs to be improved.**
2. **Identify the associated processes and their physical locations.**
3. **Determine the baseline performance for each *Y* chosen.**
4. **Identify the cost and impact of the problem.**
5. **Write the problem statement.**
6. **Write the objective statement.**
7. **Identify and recruit candidates for the project team.**
8. **Obtain approvals and launch.**

These steps are a combination of gathering data and organizing that data into a well-articulated project. Having a worksheet similar to Figure 5-4 can guide you through this process.

Figure 5-4: Project definition worksheet.

Step	Action	Information Elements for Defining a Project	Definition/Explanation	Enter Actual Project Information Here (Examples Indicated)
1. Identify the specific problem that needs to be solved per the business case or other source.	1A	What is the actual problem?	A business condition or impediment to success, stated as the high-level effect that the problem is having on the business. This is usually in terms of cost, revenue, quality, and delivery.	*High inventory levels are consuming space, asset management time, and creating cash flow issues.*
	1B	Where is the problem occurring?	Define where the problem is occurring. This should include a geographic name, such as city, facility, and the high-level name for the business area (accounts receivable, purchasing, manufacturing, human relations).	*Materials control organization*
	1C	Over what timeframe has this problem existed?	Define when the problem first began or the period over which it has existed. For example: The problem began in February 2004; it has existed for the last 15 months; it has always existed.	*Since January 2005*
	1D	Who is the customer(s) most affected by this problem?	Identify the customer who is most affected by this business problem. This could be an external or internal customer.	*Product resellers*
2. Determine the outputs (*Y*s or CTQs), what specifically needs to be improved, and the baseline performance levels.	2A	Determine the characteristics or process outputs (*Y*s) that will be improved if this problem is solved.	This is the name for the outcome (*Y*) that you intend to improve by solving the problem. This should be described by a specific name, such as product test yield, customer complaints, invoice errors, inventory levels, response time.	*Raw material inventory levels*
	2B	Identify the primary metric for each *Y*. The metric describes the problem and is used to measure and track the improvement.	The primary metric is a combination of the name for the outcome (*Y*) and the unit of measure associated with it. For example, motor torque percent defective, daily number of customer complaints, defects per invoice, call-back response time in minutes.	*Days of inventory on hand*
	2C	Estimate the magnitude of the problem using the primary metric (baseline performance).	Data is gathered to determine the performance or behavior of the primary metric assure the data is long term and not short term. An Excel macro may be used to plot the data as a function of time and then used to monitor the improvement as a function of time. These data establish the base from which to calculate the potential financial benefits of the project, as a function of the improvements.	*Inventory levels average 31.2 days, with a high of 37.1 and a low of 28.0 days*
	2D	Identify a consequential metric(s).	This is any other characteristic or process output you want to monitor to assure there is no negative impact on another area from solving the problem.	*Percent of order requests not billed due to inadequate inventory on hand*
3. Identify the associated process and generate a macro process map.	3A	Indicate the major high level process(es) by names that are associated with the problem.	High-level process steps generally contain sub-processes. At this point, you are interested in identifying the process steps in order to demonstrate the overall scope of the project and to later identify process owners. Think of where the problem starts and ends as a guide and then name the major steps	*Purchasing, order replenishment, inventory reconciliation, production control, and planning*
	3B	Develop a high level business process map to indicate the scope of the project.	Using the data from the above steps, draw the high level process, including as much other pertinent information as possible, such as the flow of the work, process performance data, names.	*See example in Fig. 4-6*
4. Identify the cost and impact of the problem.	4A	Identify the most likely cost centers that will experience a cost benefit from this project.	Who is currently experiencing additional cost because of this problem? These same cost centers will experience improved operating costs as a result of the improvement. Generally, this means some action will be taken in these areas.	*Inventory control department 5422*
	4B	Estimate the annual financial impact of the project. Usually, this forecast is at an 80 percent confidence level.	With the support of the financial representative, develop a reasonable estimate or targeted savings for this project. You may need to refer to your Objective Statement to identify the targeted improvement; for example, costs may be expressed as cost of labor, inventory, productivity, or material.	*We could save $250,000 per year if we met industry best-in-class levels of 13.5 inventory turns.*

Identifying the significant Y

So you know you want to improve the performance of some process, but how do you figure out which characteristics or outputs of the process need to be improved? You have to identify which process output variables (*Y*s) need improvement to solve the business problem (see Figure 5-5 for an illustration of this process). The *Y*s in need of improvement must be easily identifiable and quantifiable.

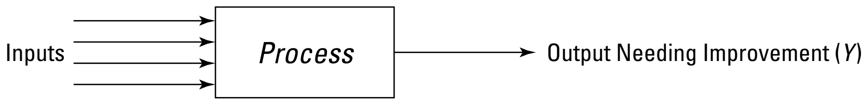


Figure 5-5: Selecting a process output for improvement.

If more than two *Y*s exist, your project is quite likely too large in scope. You may have to break the project into two or more projects to be successful.

You probably now have to get a better sense of the process steps that are involved in the performance of your *Y*. Doing so allows you to better understand who will be involved in the project and its scope and complexity.

At this point, you need a macro process map, which concerns the high-level flow that generates the output of interest. (The good news is that Six Sigma practitioners use several software tools, such as Visio, iGrafx, and ARIS, to ease the drawing of these maps.) Such a map shows the full scope of the process and includes all major areas being affected.

Figure 5-6 is an example of a pizza restaurant that is taking excess time to make pizzas. The macro process map illustrates the major steps in making the pizza.

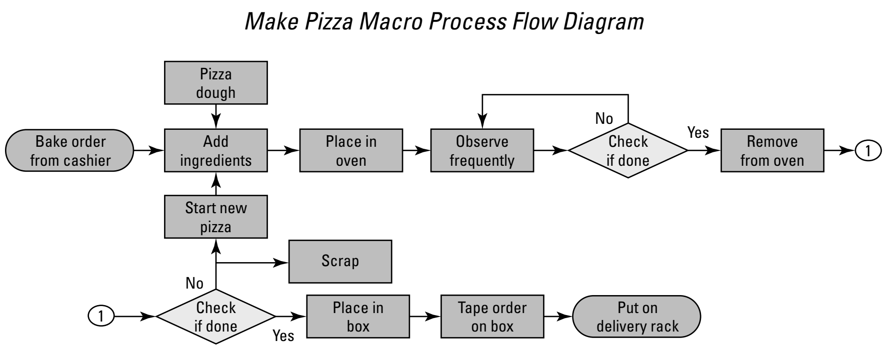


Figure 5-6: A macro process map.

Understanding how bad it actually is

You may already have a sense of the magnitude of the problem you want to solve, but that's not enough. Under the Six Sigma methodology, you must be able to express the magnitude of the problem (defect level) in some unit of measure (for example, hours, inches, percent late, and so on).

TIP

At this phase of your improvement effort, you may not have abundant and accurate data. Although having data of high integrity to quantify the severity of your problem is handy, don't be discouraged if your data aren't perfect at this time. Because you significantly improve the amount and integrity of your data in the Measure phase, plan to update the quality of your data at that time.

Improving your data is essential because you have to demonstrate your current performance (the *baseline*), your desired performance (the *objective*), and monitor the actual data resulting from your project.

The comparison of these data is demonstrated in *a time-series chart* — a graphical method employed by Six Sigma practitioners to track the progress of improvement (see Figure 5-7). In this case, the figure tracks the number of pizzas that exceeded the make time established by the restaurant in order to meet customer demands.

WARNING!

Verify that your data are long term, not short term, when estimating the baseline performance. Short-term data are a snapshot of what's happening and can mislead you; they also don't represent all the potential sources of variation that contribute to your problem over the long term, such as seasonal effects.

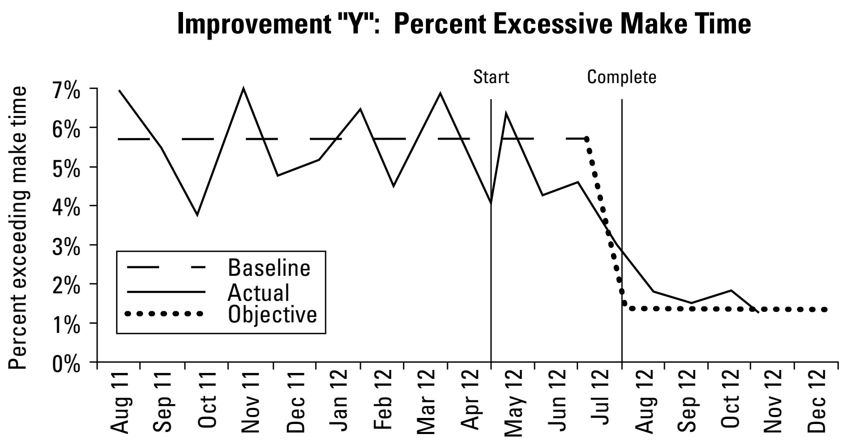


Figure 5-7: Time-series chart tracking your improvement.

Knowing the baseline level of performance allows you to calculate the potential financial benefits when you target a level of improvement.

Deciding whether a project is worthwhile

You've done well if you've gotten to this point. You've identified what needs to be improved, you know which processes are involved in creating your problem, and you've determined your current level of performance. You also may have a good estimate of how much this problem is costing you.

After you set the targeted level of improvement, you can then determine the financial benefit of doing the project and decide whether the project is worth your time. The Six Sigma effort is often aimed at cost reductions by eliminating waste (scrap, inefficiencies, excess materials, rework, and so on) that are increasing costs but not adding value. As a general rule, you want all your Six Sigma projects to produce a financial benefit, either directly or indirectly, through cost reductions, revenue growth, balance sheet improvements, or accomplishing strategic goals.

Look for a savings category for each Six Sigma project: hard, soft, or potential. We define these three categories as the following:

- *Hard savings* reduce expenses and result in a financial improvement.
- *Soft savings* are financial benefits that may occur as a result of a Six Sigma project but aren't accountable as a direct result of the project. Soft savings are calculated by using a rational assessment of the expected benefits and a probability analysis of their likelihood.

  For example, because of a Six Sigma project, your customers may become more satisfied and place more orders. Because many factors affect order rates, you can't necessarily calculate a change caused by the project. But you just know the project helped. Because these changes aren't traceable directly to the project, they're considered soft savings.
- *Potential savings* are a form of hard savings but require some action or decision to be realized. An example is a project that optimizes the design of an existing product. Until the redesign is implemented, the savings are only potential.

Generally speaking, cost improvements come from reductions in labor, inventory, material, cost of money, scrap, excess equipment, space, and so on.

Cost avoidance isn't an appropriate metric for determining Six Sigma savings. If a process has been improved, you can't make a projection into the future about what may have happened if the project hadn't been done. The vast majority of Six Sigma projects are straightforward reductions of costs, resulting in hard savings. A good way to estimate the potential value of a project is to imagine how much you could save if the problem was completely eliminated.

WARNING!

Be careful not to make generalizations about the average value of a Black Belt, Green Belt, or Yellow Belt project. Projects have a broad distribution of returns. Small projects can escalate, while high-value projects may never reach their potential.

Chapter 6

Launching a Project

In This Chapter

- Isolating the problem with a problem statement
- Identifying your entitled level of improvement
- Setting project goals with an objective statement
- Starting your DMAIC project

The scope and goal of your DMAIC project is summarized in two short statements — a problem statement and an objective statement. They represent the North Star for your project. This chapter helps you devise and link both of these statements so you can start your project off on precisely the right foot. We also help you decide how much improvement you should aim for and give you more tips on how to get your Six Sigma project off the ground and running.

Describing the Problem with a Problem Statement

The *problem statement* serves several purposes. First, it significantly clarifies the current situation by specifically identifying the problem and its severity, location, and financial impact. It also serves as a great communication tool, helping to get buy-in and support from others. When problem statements are well written, people readily grasp and understand what you're trying to accomplish.

TIP

Write the problem statement with the audience in mind. Keep in mind that you probably have to both convince management to provide resources to solve the problem and enlist team members to assist you; you don't want to spend your precious time explaining over and over what you're trying to accomplish.

REMEMBER

A problem statement should be concise and include the following:

- A brief description of the problem and the metric used to describe the problem
- Where the problem is occurring by process name and location
- The time frame over which the problem has been occurring
- The size or magnitude of the problem

WARNING!

You must be careful to avoid under-writing a problem statement. A natural tendency is to write a problem statement too simplistically because you're already familiar with the problem. If you're going to recruit support and resources to solve your problem, others have to understand the context and the significance in order to support you.

Following are examples highlighting the depth and quantification of a Six Sigma project definition. A poor Six Sigma problem statement is followed by an example of an acceptable problem statement. First up: a statement with too little information:

> **Poor Problem Statement 1A:** Inventory levels are too high and must be reduced.

How many times have you heard a problem statement like this one before? Yes, having high inventory levels is a problem, but a problem statement containing so little information significantly reduces your ability to take specific action, enlist support, and obtain improvement.

WARNING!

The problem statement must not include any indication or speculation about the cause of the problem or what actions will be taken to solve the problem. Never attempt to solve the problem or steer the solution at this stage. For example, the following problem statement is more detailed than Poor Problem Statement 1A, but it's still, well, problematic:

> **Poor Problem Statement 1B:** Having too few forklifts is making inventory levels too high.

By saying "Having too few forklifts" in Poor Problem Statement 1B, you're purporting that you know what the solution is. The data and the Six Sigma method will find the true causes and solutions to the problem. Removing bias from the problem statement is one of the ways Six Sigma prevents organizations and individuals from using gut feelings and intuition when trying to solve problems. Problem statements such as the following are effective at enlisting peoples' attention, energy, and support:

> **Better Problem Statement 1:** Inventory levels at the West Metro inventory storage process in Scottsdale are consuming space, taking up asset management time, and creating cash flow issues. Inventory levels are

averaging 31.2 days, with a high of 45 days. These levels have exceeded the target of 25 days 95 percent of the time since January 2012. We could save $250,000 per year if inventories were at the targeted level.

Look at the amount of information that is available in this example. You know where the problem is occurring, you know how long it has occurred, you know the magnitude of the problem, and you know how much it's costing. Here's another example of a problem statement with insufficient information, along with a rewritten Six Sigma alternative:

Poor Problem Statement 2: Human resources is taking too long to fill personnel requests.

Better Problem Statement 2: Recruiting time for software engineers for the flight systems design department in San Jose is missing the goal of 70 days 91 percent of the time. The average time to fill a request is 155 days in the human resources employee recruitment process over the past 15 months. This delay is adding costs of $145,000 per month in overtime, contractor labor, and rework costs.

And one more:

Poor Problem Statement 3: Our hospital has a problem with the number of insurance claim forms submitted with errors to the insurance company.

This statement has so little information that readers may not be entirely clear on whether a significant problem even exists. Of course, nobody thinks that having claim forms with errors is good. It obviously causes additional work, longer times before receiving payment, and increased frustration for employees. But is this problem worthy of being worked on as stated? Maybe; maybe not. Other problems may be giving you worse headaches than this one.

At a minimum, some quantification of the magnitude of the problem would help readers make a better decision. Is the whole hospital having the problem, or is it confined to a particular group? Writing the problem statement to the standards of Six Sigma provides the level of information needed to make an informed decision:

Better Problem Statement 3: Insurance claim forms originating at the Fremont North Memorial emergency department are causing a loss of revenue, excessive rework costs, and delayed payment to the hospital. Forty-five percent of the claim forms have errors, with an average of 2.3 defects per form. This problem has existed since claims processing was moved to Kansas City in March 2012. Billings could increase by $3.5 million per month, rework cost could be reduced by 50 percent, and an additional 1.3 percent of revenue could be recovered if errors were occurring less than 5 percent of the time. Achieving this level of performance would increase profits by $395,000 per year.

Deciding How Much Improvement Is Enough

Perhaps you've now convinced yourself that you have a viable project — a problem worthy of being worked — and that you can convince others to help. You know specifically what must be improved to make life better for everyone. Now the questions are "How much improvement do we need?" and "How much improvement can we make?" You need to answer these questions before you can create your objective statement (see the following section).

You want to target the amount of improvement for the project by looking simultaneously at how much improvement you need to satisfy business requirements and how much improvement you can make given the opportunity and the power of Six Sigma. Sound confusing? Don't worry; some simple guidelines can assist you here.

Setting the objective for the project's level of improvement is a prioritizing activity with several key inputs:

- Defining your own opinion of what success is
- Considering entitlement (which we discuss in the section "Asking 'How much am I entitled to?'")
- Benchmarking
- Finding the hidden operation
- Striving for breakthrough levels of improvement
- Listening to the needs of your customer

Some people like to go right to the cash. They establish some threshold of savings and try to configure the amount of improvement required to achieve those savings. Although this approach is okay in some cases, the best strategy is to strive for an aggressive but rational level of improvement and to let the dollars flow later. The following sections show you how to do just that.

Asking "How much am I entitled to?"

Entitlement is an extremely powerful, eye-opening Six Sigma concept used to determine the potential level of improvement; when understood, it can change the way you think about everything. *Entitlement* is the best performance that a process, as currently designed, has demonstrated in actual operation.

Suppose you have a business process that has a 90-percent average yield over a long-term period. In other words, 90 percent of the time, it delivers to requirements. Now imagine that you observe the same process delivering at a 98-percent level for a few weeks or some other short period. You may consider the uptick to be incidental or just plain lucky — an alignment of the stars.

In Six Sigma–speak, however, you would say that the conditions or inputs to this process (the *X*s) all combined in such a way that they delivered the observed improved performance (the *Y*). (If you need help with the equation $Y = f(X) + \varepsilon$, flip to Chapter 3.) Therefore, if you can determine the right alignment (settings or values) for the inputs that have led to this improved performance, you're entitled to operate at this performance level all the time! This alignment is the *entitlement level of performance* for the process.

As the Six Sigma saying goes, "You can't unscramble scrambled eggs, but you can unscramble entitlement!" When determining the amount of improvement, always take entitlement into consideration.

Acknowledging that other hidden opportunities exist

The hidden factory (see Chapter 2) is another Six Sigma concept that can change the way you think about the work in your company. The *hidden factory* or *hidden operation* is work that is done above and beyond what is required to produce a product or a service, such as rework or repair. The hidden factory is also the work that creeps into the organization when you forget to ask yourself, "Why are we doing this activity, because it isn't adding any value?"

So where do hidden factory effects come from? You may have experienced something like the following: "Over a year ago, we did this quick fix on a problem, followed by an additional inspection to make sure the problem was contained." That quick fix may well have become part of normal procedures. If you've ever heard the saying, "That's the way we've always done it," you probably have a hidden operation opportunity to find.

Figure 6-1 shows a view of the hidden factory. At some point in almost every process, you find a sequence of steps that are very similar to these steps. Work is done on the product or service during one of the process steps called Op *i,* which is a form of shorthand for naming this process step. You also see the next work step in the process is operation $i + 1$, which in shorthand means the next work step in the process.

Between these two work steps in the process is an inspection or verification step. When there is a verification step in a process, you have a high potential for a hidden factory to exist. Refer to the area below the dashed line in Figure 6-1 — it's the extra analysis, repair, scrap, and so on that occur when a product or service has been deemed to not meet requirements.

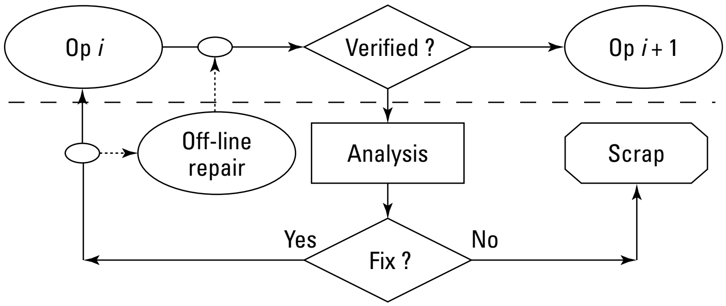


Figure 6-1: The hidden factory.

All these steps add cost because the product or service wasn't correct the first time. Most organizations just accept these types of additional steps as "That's the way we do things here; that's the way we've always done it." When this rationalization occurs, you have mentally hidden this operation.

TIP

Finding the hidden factory and quantifying its effect helps you further understand your potential level of improvement when writing your objective statement.

Going for breakthrough improvement

Another important approach is to estimate a breakthrough level of improvement that may be possible by carrying out your project. This estimation helps you avoid setting your sights too low, which can often happen when you don't have a lot of experience with the problem-solving power of Six Sigma. Your current thinking is probably influenced by your sense of how much improvement you can achieve by using *traditional methods* (the methods with which you're already familiar).

TIP

So what constitutes *breakthrough improvement?* Always consider a 70-percent improvement over baseline performance as a starting point for the target improvement in your objective statement. For example, if you have a process step with a 10-percent problem for a particular characteristic, a Six Sigma project should be able to lower the defect rate to less than a 3-percent problem. Remember that this rate of improvement is an average that doesn't necessarily hold true for all projects; most actual projects will be somewhat higher or lower.

Figure 6-2 shows the difference between breakthrough improvement and the more traditional incremental rates of improvement that you're probably used to.

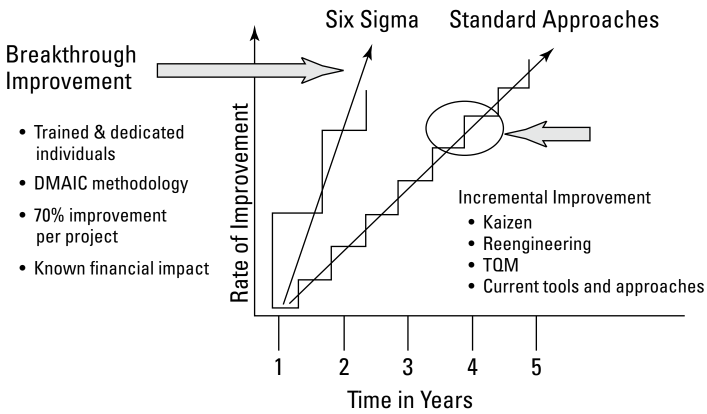


Figure 6-2: Breakthrough improvement.

Setting an Improvement Target with Your Objective Statement

After you know what your problem statement is and how much improvement you're aiming for (head to the two preceding sections if you're not quite there yet), you're ready to craft your objective statement. Your *objective statement* spells out the specific, quantifiable amount of improvement planned above the baseline performance that was indicated in the problem statement. You also need to determine how long completing this project and achieving your goal will take.

TIP

The objective statement directly addresses the information in the problem statement. Just like the problem statement, the objective statement must contain certain information in order to be effective. A good objective statement contains all the following elements: metric, baseline, goal, amount of time, impact, and corporate goal/objective. That is, you want to improve some metric from some baseline to some goal in some amount of time with some impact against some corporate goal or objective. This timeline should be aggressive but realistic.

To begin crafting your objective statement, start with the baseline performance you established in the problem statement. After you've set your improvement goal, you can estimate the financial benefit of achieving this goal. This estimate should be aggressive but reasonable, and you shouldn't worry about being accurate to the nearest penny.

You estimate the financial benefit by assessing what will be different at the new operating level versus what it is today. Your task, with the assistance of the financial organization, is to identify the differences and to estimate the annual benefit.

Linking Six Sigma projects to the key goals and objectives of the organization is always a good idea. Aside from the common sense benefits, this strategy is a good way to roll up all projects and the accumulated benefits related to the company's goals and objectives. In some businesses, Six Sigma has created, for the first time, the ability to quantitatively link improvement effort to strategy.

The following are several Six Sigma–style objective statements that you can adapt for your projects, along with some painful examples of how not to craft your objective statement. (You can find the related problem statements in the earlier section "Describing the Problem with a Problem Statement.")

> **Poor Objective Statement 1A:** Reduce inventory levels as soon as possible.

Can you succeed at this goal? Can you get excited about working on this project? Well, those answers may depend more on the mood of your boss than anything else! Consider your attitude and the enthusiasm of your boss if the statement looked something like this:

> **Better Objective Statement 1A:** Reduce raw material inventory levels from 31.2 days average to 23 days average with a maximum of 27 days by August 1, 2012. This project will save $235,000 per year for interest, space, and personnel in support of our corporate goal to improve asset management and ROI.

Now management and team members know where the goal line is, how long they have to get there, and how much benefit their efforts will create, and they have the reassurance that their efforts will be for a good cause. With this more specific objective, everyone involved is more likely to be chomping at the bit to get started.

If you were a manager needing software engineers to complete a design, would you sign up for an aggressive schedule and put your career on the line based on the following objective statement?

> **Poor Objective Statement 2:** Improve how long human resources takes to fill personnel requests.

Unless you have nothing better to do, you probably should look the other way when volunteers are being recruited to take on this project. But your adrenaline may get flowing if the objective was worded like this:

> **Better Objective Statement 2:** Reduce the software engineer recruiting time from an average of 155 days to 51 days, with an upper limit of 65 days. This change will meet the current maximum goal of 70 days greater

> than 99 percent of the time. The new goal will be achieved by June 1, 2012. It will support our Employer of Choice goal and achieve an annualized savings of $145,000 per month.

Finally, one more example:

> **Poor Objective Statement 3:** Retrain employees to eliminate inaccurate claims forms.

In addition to being another poor objective statement, this example has an additional no-no: the inclusion of the solution "retrain employees." If you already know the solution, why bother with the project in the first place? The following example includes all the necessary information but doesn't undercut the project with a proposed solution:

> **Better Objective Statement 3:** Reduce the defects per form from 2.3 DPU to less than 0.1 DPU by September 15, 2012. This change will increase revenue collection by $3.2 million per month, resulting in an additional $25,000 profit per month at an 8-percent profit margin. This project supports the corporate goal to increase revenue by 15 percent per year.

Objective statements like the "better" examples here are part of the reason Six Sigma projects are effective and can generate breakthrough levels of improvement.

Getting a Project Approved and Assigned

Your final step in getting your project started is to identify who has to approve the project. Although this task seems like an easy step that requires little effort, don't take it lightly — it's vitally important! You've probably been involved in task force teams in the past where things were pushed through without enough thought given to who should be involved, provide support, or provide resources. Are any of these efforts really successful?

Six Sigma treats this process differently than the aforementioned ill-planned task force team. Because you know so much about the problem, where it's occurring, how long it has existed, its impact, and the benefits of eliminating it, you're the best person to know who should approve your effort and, more importantly, why. You're always better off getting buy-in at the front of the effort than waiting until the last minute; any effort you expend on the project before approval may be for naught if the powers that be want changes to your proposal or deny it outright.

The key individual to identify — the person who will get your project off the ground — is the *process owner,* the person who has the primary responsibility for the results of the process associated with the problem you're solving.

If additional approvals are required, those entities will become obvious when you know the process owners. If you're assigning this project to another Six Sigma practitioner, don't forget to ask him if he accepts the assignment to lead the project.

TIP

Refer to the macro process map in Chapter 7 to help you identify the process owners and others you may need to approve your project.

You must now decide what skill levels, in the form of Six Sigma Belts, are required to solve this problem. Figure 6-3 assists you in making this decision. From experience, we can tell you that for any organization a large number of smaller "fruit on the ground" and "low hanging fruit" problems exist, followed by fewer "process optimization" problems, and then finally a few "world hunger" issues that aren't really process problems but more likely management problems.

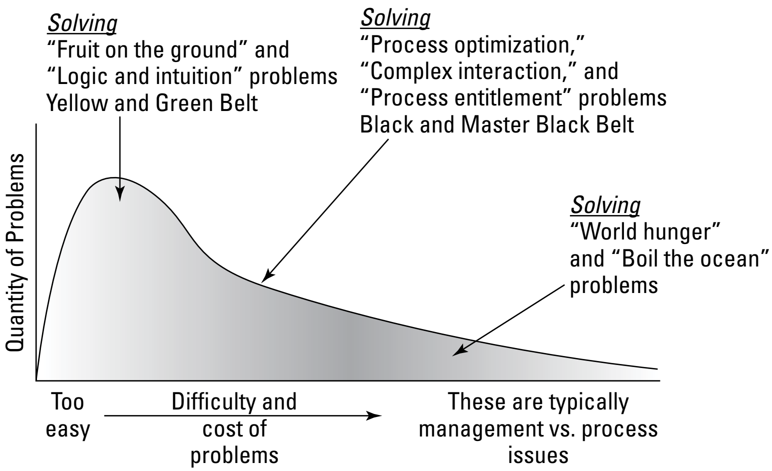


Figure 6-3: Problem difficulty distribution.

Finally, you have to identify which project team will be associated with the improvement, unless you believe you can accomplish the improvement goal by yourself. Be wary of going it alone: Very few people have all the skills necessary to take on process improvement projects. Usually, three to six team members, all of whom have expertise from the areas associated with the project, are sufficient. If you've enlisted the process owners into your project, identifying these individuals will be easy.

Chapter 7

Mapping to Identify Possible Factors

In This Chapter

- Characterizing a process by mapping its flow, sequence, and steps
- Getting a high-level view with a SIPOC
- Gaining perspective with value stream mapping

A map of your location and your surroundings is invaluable, whether you're looking for a store at the mall, navigating your way across a busy city, or trekking on a mountaineering expedition. In the same way, a view of the current state of your processes — whether in traditional flowcharts or as value stream maps — is invaluable, if not essential, in your Six Sigma improvement efforts. It captures the current state of how work is accomplished, what resources are used, what equipment and materials come into play, and so on.

Without a map, you may think you know what goes on in your process, but you'd almost always be wrong. You may be surprised how often managers lose track of things such as invoices, production capacities, inventory levels, rework, and bottlenecks. This type information must be accurate and current in order to make good decisions about improving a process.

In this chapter, we show you how to define a process and create a SIPOC, a helpful tool for getting a high-level view of a process. We show you how to use a process map to capture and document the current, as-is state of a process. This tool guides you in knowing what subsequent work your process needs and where you need to allocate resources. We also introduce value steam maps, which capture the overall end-to-end process.

REMEMBER

Keep your process maps current and accurate. As your processes change, your maps must change. If you don't keep the process maps up to date, you don't have a reference definition of what's happening in your organization.

Breaking Down Process Flow

In Six Sigma, you want to define a process very precisely — down to the last detail of activity, resource, decision, dependency, and value. Sometimes, this level of definition is the only way you can sufficiently measure and analyze a process, leading to breakthrough improvements and, ultimately, effective controls. Mapping or modeling the process is a representation of this precise process definition, and the practice of process modeling is therefore fundamental to Six Sigma.

A *process map* looks like a flowchart, and, at the top level, that's exactly what it is. A process map is a picture of the activities and events in a process. Figure 7-1 is an example process map.

Map your processes as rigorously as you need to in order to see the big picture as well as the tiny details. Take the time to build your maps properly. They cross boundaries and borders, and sometimes the act of creating a map causes you to uncover issues and even step (or stomp!) on a few toes.

But don't despair; process maps speak the truth! They form the basis for increased levels of understanding and breakthrough improvement. The time you spend building the map reaps its rewards in performance and satisfaction.

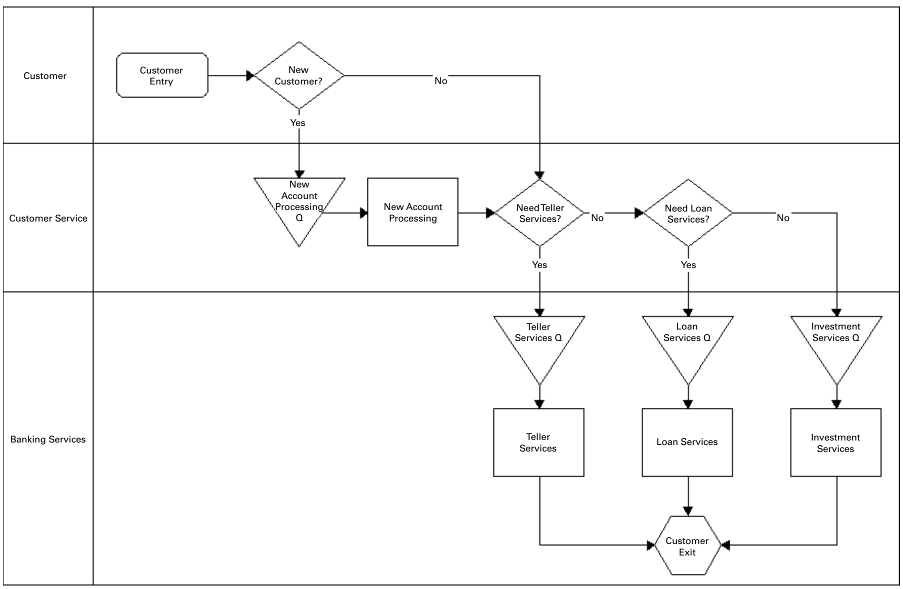


Figure 7-1: A process map.

Six Sigma process mapping begins with building flowcharts. You then annotate and define the paths, encounters, decisions, and destinations on these charts in quantitative terms, including such measures as value, time, resources, yields, and the statistical distributions around each. In this section, you discover how to create the perfect Six Sigma process map.

Drawing a process map

Process mapping has been practiced for decades, and the fundamental concepts around process maps are nothing new. The Six Sigma style of process mapping has a few different aspects, however, so you utilize a few new features from its flowchart ancestors. In the world of Six Sigma, you characterize the process map in mathematical terms so you can perform a plethora of statistical analyses on its various parts and pieces. You back each step, function, and activity with numerical descriptions and quantifiable attributes, enabling you to see the process in all its exacting glory.

In Six Sigma process mapping, you characterize a practical situation in ways that let you describe it in statistical terms, allowing you to develop statistical solutions that you then apply back into your practical environment. On the surface, a Six Sigma process map can look like a simple flowchart, but underneath, it's detailed, complicated, and mathematical.

You can draw a process map with a pencil and paper or with a drawing tool like Microsoft Visio. But these creations are just drawings. Only with more advanced tools such as ARIS (see Chapter 21 for details) can you capture the details that enable Six Sigma–class analysis, simulation, execution, and management.

Regardless of what kind of tools you use to create your map, following a consistent set of conventions when using shapes, connectors, and other drawing elements is important. Figure 7-2 is an example set of some drawing conventions used in process mapping. Although these icons are typical, the exact shape may vary slightly from one tool to another or from one company to another. Most of the process mapping software applications use the Business Process Modeling Notation (BPMN) standard.

As you begin, don't worry about the details of what happens inside each of these boxes. Your goal at this stage is to capture each of the steps, identify its basic function, and connect all the steps in the manner that represents the existing process.

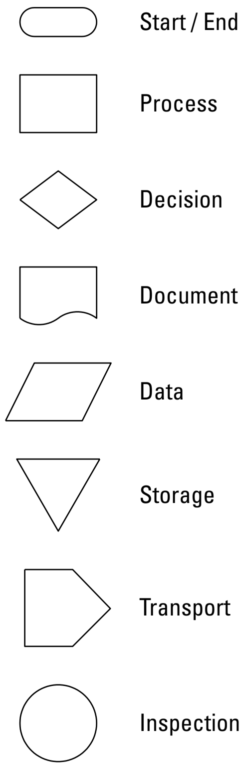


Figure 7-2: Mapping icons.

Defining and visualizing the process points

After you've drawn a process map (see the preceding section), your next step is to define each of the map's objects. You must be precise and quantitative; the accuracy of your process model depends on it. If you're using a process mapping technology tool (such as those we discuss in Chapter 21), your tool includes prompts for the numerous definitions and attributes at each *node* (step) in the map. The categories of process element definitions include the following:

- **Operation cycle time of the process element,** including its average time to complete, the variation in time called the *standard deviation,* and perhaps a distribution curve to represent all the possible completion times as well. Head to Chapters 9 and 12 for more on standard deviation and distribution, respectively.

- **Resources used in the process element,** including human, capital, and natural resources. The better tools let you identify resources by name and type and then later track their utilization during simulation.
- **Value added by the process step,** in the units of measure that mean the most to your organization. At a minimum, you must be able to define whether the process step is value add (VA) or non-value add (NVA). Chapter 11 gives you the lowdown on these designations.
- **Costs of the resources consumed,** including the costs of personnel, facilities, direct material, and sometimes even indirect costs.

TIP

The closer you can come to defining costs in the same terms as your accounting system, the better. Ultimately, you have to reconcile cost and claim value that your accounting department can verify. Get the bean counters involved upfront and make them your partners by counting your beans the same way they count theirs.

A common practice in process modeling is to employ a visualization technique called *swim lanes.* As we note earlier in the chapter, processes cross functional boundaries and borders, and swim lanes helps you see that movement. In a swim lane process map, time flows from left to right; the process crosses lanes as it traverses departments on its journey from start to finish. Imagine you're the customer in the process map in Figure 7-1: You're in lane 1. As you work your way through customer service and then the banking services, you cross over into lanes 2 and 3. Figure 7-3 shows this action.

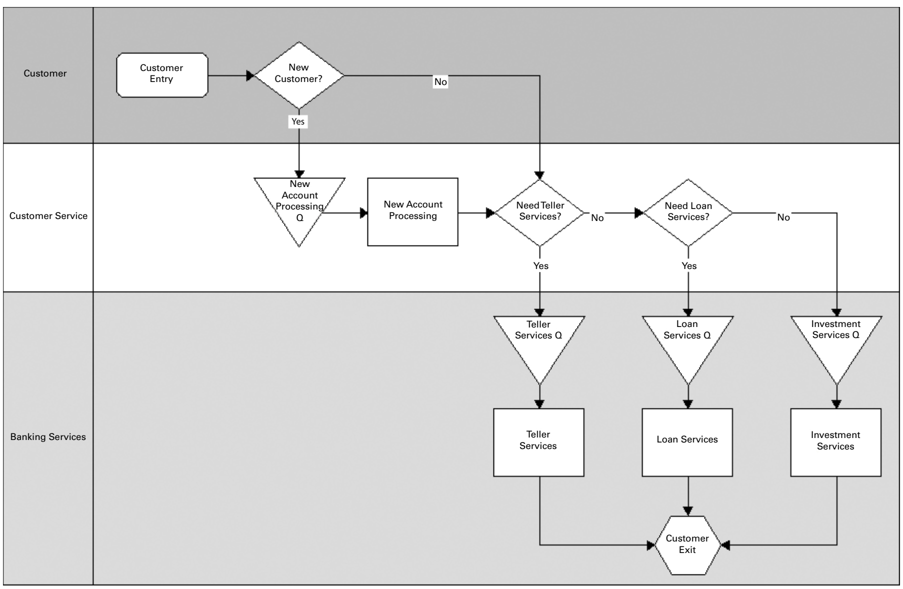


Figure 7-3: Swim lanes.

Swim lanes are an effective visualization technique that lets each functional contributor to a process understand his role while giving everyone a chance to see just how complicated the process may be within your organization. Remember, each time you cross a lane, you have in essence created a supplier-customer interaction that implies needs, wants, and desires that must be met.

Acknowledging the as-is state

One way to think about process mapping is as an exercise in defining a better process — how you envision your process can work sometime in the future, after implementing the changes that would enable your new concepts. It's the *to-be* state of affairs. And mapping the future in this way provides you the opportunity to examine your plans in detail and consider your options before implementing the changes. You wouldn't dream of making changes without first modeling them.

But first, you must create a map of today's reality: the so-called *as-is* state. Many organizations skip this kind of mapping. They're so eager to dismiss today's problematic world that they leapfrog straight to the dream of tomorrow's possibilities. Big mistake! The only excuse for not modeling the as-is process is if you're implementing something brand new and there's no existing process. Otherwise, if a process exists today, model it first. Doing so accomplishes three important tasks:

- **Sets the baseline:** Before you can measure the effects of your sweeping changes, you must first characterize the present conditions. By using the same process mapping techniques to characterize today's as-is state as well as the future to-be state, you have the basis for measuring the effectiveness of your process improvement effort.
- **Sees the process:** Seeing the process involves recognizing that three different perspectives exist:
  - What you think is going on
  - What's really going on
  - What should be going on

  These views are distinctly different, but characterizing the differences is precisely what you're trying to achieve with Six Sigma. You must replace what you think is going on with what is really going on, and only then can you understand what moving to the third view requires.
- **Stimulates closed-loop behavior:** Your investment in mapping primes the pump for breakthrough performance improvement. To continue the cycle of improvement, your model should be a dynamic, living entity such that your model is in sync with reality at any point in time. Modeling the as-is condition from the beginning promotes this closed-loop behavior.

Developing a SIPOC

SIPOC, pronounced *sy-pok*, is an acronym that stands for Suppliers-Inputs-Process-Outputs-Controls. The SIPOC is a powerful companion to a process map (see the preceding section if you haven't delved into process maps). With this tool, you build your first controlled and organized view of your work process and set the foundation for applying the breakthrough DMAIC strategy.

TIP

SIPOC is one of those handy reminder acronyms that contains the terms in their proper order, helping you remember not only the five high-level elements of a process map but also their order. Here's the breakdown:

- **S: Suppliers:** *Suppliers* are systems, people, organizations, or other sources of the materials, information, or other resources that are consumed or transformed in the process.
- **I: Inputs:** *Inputs* are materials, information, and other resources the suppliers provide that are consumed or transformed in the process.
- **P: Process:** The *process* is the set of actions and activities that transform the inputs into the outputs.
- **O: Outputs:** *Outputs* are the products or services that the process produces and the customer uses.
- **C: Customer:** *Customers* are people, groups of people, companies, systems, and downstream processes that receive the output of the process.

Hearing voices yet?

If you've developed a successful SIPOC, you should be hearing voices by now. Who's talking?

- **Voice of the customer (VOC):** These voices are the needs, wants, and desires of the customer, generally spoken as the customer requirements. VOC is the loudest voice you should hear, and it's the voice calling back at your process from beyond the output that offers you compensation in return for satisfaction of its needs and wants. Flip to Chapter 11 for more on the VOC.
- **Voice of the process (VOP):** The process must meet the requirements of the customer, and its ability to do so is called the *VOP.* VOP is a construct for examining what the process is telling you about its inputs and outputs and the resources required to complete the functional transformation. You can read about the VOP in Chapter 13.
- **Voice of the business (VOB):** *VOB* is the voice of profit and return on investment. At the end of the day, every endeavor has to enable the business to survive, grow, and meet the needs of its employees, investors, and the community. Chapter 5 has more info on VOB.

You build a SIPOC from the inside-out, beginning at the center, with the process map — of course! It's a six-step approach:

1. **Identify the process you want to map and define its scope and boundary points.**

   Using action verbs, describe what the process is supposed to do and in how much time. Define its starting and ending points.

2. **Identify the outputs.**

   What are the products and the services that the process produces?

3. **Define the recipients (the customers) of the outputs by name, title, system, or organizational entity.**

4. **Define the customer requirements.**

   What do the customers expect? What do they demand? What are they entitled to in their fair exchange of value?

5. **Define the inputs to the process.**

   Identify the human, capital, information, materials, and natural resources the process requires to produce the identified outputs.

6. **Identify the sources (suppliers) of the inputs.**

With this information in hand, you now have a fully-contained, high-level view of any process. This result alone is one of the most powerful tools you can use because it sets the conditions for the DMAIC of Six Sigma. With the SIPOC, you have the basis for defining and characterizing the process itself; the context for measurement; and the basis for analyzing, identifying areas of improvement, and homing in on your targets of control. SIPOC software tools, such as ARIS, iGrafx, and SigmaFlow, help you capture, organize, and display this information.

VSM: Charting the Value Stream

Traditional process mapping (see the section "Breaking Down Process Flow" earlier in this chapter) is a powerful way to capture the detailed, step-by-step flow, sequence, roles, and resources of a process. But that very detail can sometimes cloud the larger picture.

Originating from Japanese manufacturing, another format of process mapping has its advantages. It's called a value stream map and often is abbreviated simply as VSM. A properly constructed VSM provides insight into the end-to-end process in ways that no other method does.

Introducing a stream of resources, information, and value

The end-to-end chain of activities, events, and processes — which begins with the customer's requirements and includes everything needed to provide the customer your product or service — is called the *value stream.* It embodies the flow of all material and information through the process steps that come together to create the product or service that has value to the customer. A value stream map comprehensively captures the cross-functional, end-to-end entirety of a process.

Figure 7-4 is an example of a value stream map for a manufacturing process. Imagine you're in your customer's shoes and can view how the product or service comes into being. Working from the right, you (through the customer's eyes) receive the item. Before that, it's configured and prepared for shipping. Even earlier, steps are performed that create or assemble the item from raw materials. Raw materials are ordered and received from various suppliers. The earliest event is your actual order or request (either direct or anticipated) for the item.

The primary advantage of capturing a process with a VSM rather than using the traditional flowchart approach is that you see the entire end-to-end process. Too often traditional flowcharts allow you to review and improve only a part of the process (the *subprocess*). This localized improvement often leads to unintended problems that crop up in other areas of the value stream or simply shift upstream or downstream instead of being eliminated altogether.

A value stream map forces you to see the entire end-to-end translation of resources and materials into a valuable result. That way, you're less likely to improve one section of a process at the expense of other areas.

VSMs aren't the be-all and end-all, though. A VSM by itself doesn't provide the level of internal details needed to isolate and improve the root cause of poor process performance. A VSM's focus is on flow — flow of materials, flow of information, the capacity and reliability of each individual process, and so forth — not on the internal goings-on at each stop.

Supplement your VSM with detailed process maps where they are needed. Doing so gives you the best of both worlds: an end-to-end, customer-centric view of the process and the level of focus and detail afforded by traditional process maps.

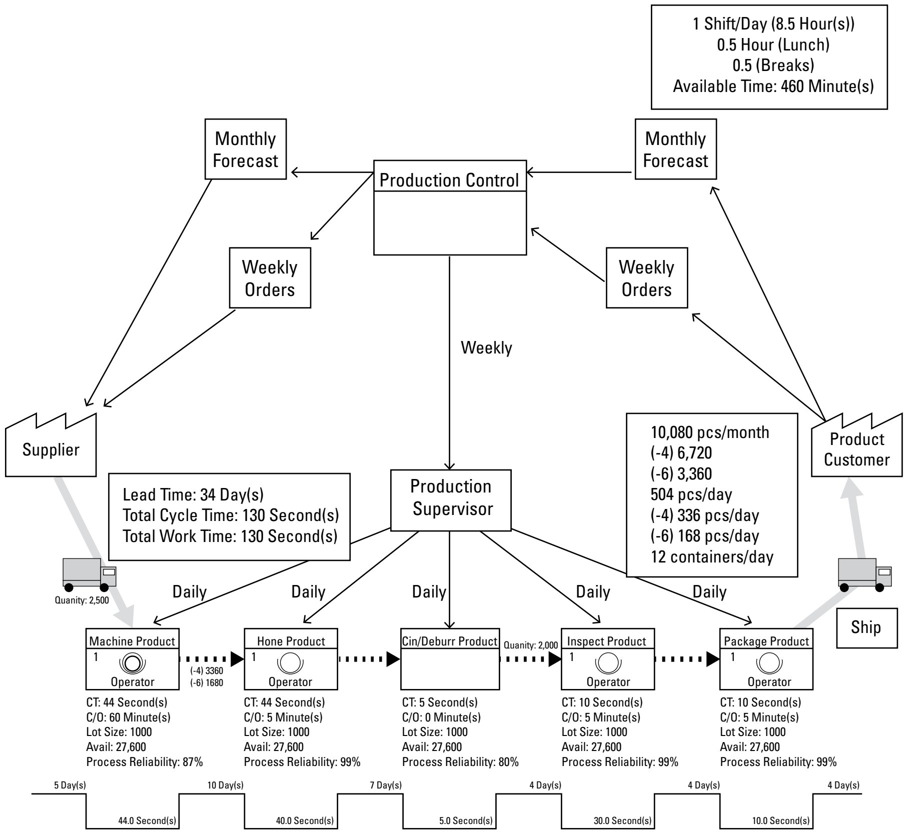


Figure 7-4: A value stream map (VSM) for a manufacturing process.

Creating a VSM for your process

In this section, we provide a quick guide on how to create a VSM for your process. (You can find a lengthier treatment of creating and analyzing value stream maps in the latest edition of *Lean For Dummies* by Natalie Sayer and Bruce Williams [Wiley].)

Here's a quick rundown of the creation process; the following sections cover the blow-by-blow details.

1. **Assemble a cross-functional team that has representatives from all areas of your process.**
2. **Consider the customer.**
3. **Draw the customer near the top right of your VSM and capture the events or signals that trigger the start of the process.**
4. **Capture the process steps.**

5. **Add the process time line.**
6. **Summarize the key operational metrics for your process on the VSM.**
7. **Identify improvement opportunities.**

Getting team input

Because of a VSM's end-to-end scope, you need to gather input from a wide set of domains: production planning, supply chain, inventory/stores, manufacturing, shipping, and so on. Including all these inputs is critical to creating an accurate and useful VSM.

Starting with the customer

After gathering inputs, consider the customer. In the example shown in Figure 7-4 earlier in the chapter, you can see the "product customer" drawn toward the upper right. Ask yourself what the customer does to signal the need to start the process. Does it place an order? Does the signal come from a forecasted customer demand? Whatever the impetus is, the customer always does something to start the ball rolling.

Draw the customer near the top right of your VSM and begin by capturing the events or signals that trigger the start of the process.

TECHNICAL STUFF

To follow typical VSM conventions, use thin, solid lines to indicate signals or the flow of information in your process. Use thick solid lines to designate external material flow, like from a supplier. And use thick dotted lines to document material or flow that occurs within your organization.

In the example shown in Figure 7-4, you can see a customer order being first routed to production control. Production control, in turn, sends out forecasts and weekly material orders to suppliers. In a parallel path of the value stream, the production supervisor also receives a signal from production control and sends out daily production instructions to each of the process steps.

Capturing the process steps

Next, you want to capture the process steps. Usually, you place the as-is internal process steps at the bottom of the VSM in a horizontal layout. These steps are designated by blocks with characteristic measures for each step. Capture as much information as possible about each step, including cycle time, changeover time, number of operators, number of pieces, work in process, inventory quantities, reliability, yield, and so on. The more information you capture, the more insight you gain.

In Figure 7-4, you can see the internal process steps along the main horizontal of the diagram, starting with machining and proceeding to honing, deburring, inspecting, and packaging.

Process mapping and VSM aren't armchair activities! You must physically go to where the process is conducted to gain the greatest insight regarding the as-is process. Never neglect this important effort. *Genchi genbutsu* is a Japanese improvement term that means "go and see." The phrase reminds you that, to truly understand a situation, you must go to *gemba* (another Japanese term meaning the "real place" where work is done).

Adding the process timeline

Value stream maps contain a unique feature — a highly insightful timeline — beneath the horizontal line of main process steps. As you can see in Figure 7-4, the timeline captures not only the time required for each step but also the time spent waiting between steps. In this way, you document how long the entire process takes to be completed from end to end (the *cycle time*).

The timeline also includes a vertical component. To highlight waste, any segment of process time that doesn't add value (see Chapter 11) is drawn in the timeline with an elevated step. So in a glance, you can see what portion of overall process time is spent adding real value and how much isn't.

You'll almost always be surprised to discover how much elapsed time in an as-is process is non-value add. Often, it's over 95 percent! Use the timeline component of your value stream map to capture and communicate this waste and improvement opportunity.

Don't confuse takt time with cycle time. Cycle time is a measure of how long a process takes to complete. *Takt time* is the pace needed to exactly meet customer demand. (*Takt* is a German word that means "beat.") It's calculated by dividing the available production time by the number of parts needed to meet customer demand during that available time. To minimize waste, a process should produce its output no faster or slower than the customer-determined takt time. Otherwise, waste occurs (see Chapter 11).

When you compute takt time, take into account your current production efficiency. A realistic takt time is multiplied by your efficiency number (for 80-perent efficiency, multiply the takt time by 0.8). This step means you build in enough capacity that you can meet customer demand while sustaining production losses of 20 percent. Of course, you shouldn't be satisfied with an 80-percent performance; find the root causes for your production losses and work to improve your performance. When you realize efficiency improvements, adjust your takt time accordingly; this adjustment will have an impact on your production schedule as you strive to meet customer demand.

Supplying the box score

Place a summary of the key operational metrics — known as the *box score* — right on the VSM, usually near the top. Be sure to include the total lead time, including the value add and non-value add times. You may also include information like the total distance traveled, total parts per shift, scrap, pieces produced per labor hour, changeover time, inventory turns, uptime, downtime — whatever is critical in your situation.

Identifying improvement opportunities

With your VSM in hand, you immediately begin to see opportunities for improvement. A few of our favorite improvements include the following:

- **Reducing or eliminating waste:** Anything in the process that doesn't contribute value to the customer should be a candidate for improvement.
- **Matching/balancing cycle time with takt time:** Ideally, each step of the process should match the pace needed to meet customer demand.
- **Cutting back on bottlenecks and flow:** Think of a smooth, flowing river. Anything that chokes, diverts, or disrupts the flow of your process is a candidate for improvement.
- **Decreasing inventory:** Reduce or eliminate unnecessary inventory (whether that's raw materials, work in process, or finished goods inventory).
- **Speeding up changeover times:** The ability to rapidly switch production from one item to another opens up a new dimension in adding value to the customer. For example, quick changeover times allow you to hold less inventory because you can respond rapidly to changes in customer demand.
- **Improving information flow:** The right information gets to the right people at the right time.
- **Optimizing physical layout:** Reconfigure the layout of the process to eliminate or reduce movement and transportation.
- **Standardizing work:** Deviations from set patterns always lead to an uptick in waste. Which process steps need better or improved standards?
- **Maximizing equipment uptime and availability:** Equipment issues no longer limit the effectiveness of your process.
- **Enhancing process capability:** This category of improvement is what the analytical tools of Six Sigma are geared toward. You can make dramatic breakthrough improvements in how well the output of each process step meets customer requirements.

Chapter 8

Diagramming to Identify Possible Factors

In This Chapter

- Understanding the need for diverse and cross-functional teams in idea generation
- Conducting a brainstorming session
- Developing a fondness for affinity and fishbone diagrams
- Using failure mode effects analysis (FMEA) to identify potential factors

The Six Sigma problem-solving approach requires that you objectively set aside your preconceived ideas about what the root cause of the problem may be. Instead, you explore and capture a list of all the factors that may in some way — large or small — be contributing to the problem you're trying to solve. This chapter explores a few of the diagrams you can add to your toolkit for generating a comprehensive list of possible factors (the *X*s) that may be contributing to the performance of your project's critical output (the *Y*).

Whether you're generating ideas through brainstorming, fishbone diagrams, or failure mode effects analysis (FMEA), you need to be working in a cross-functional team setting to be most effective. It's extremely difficult for one person to come up with several possible ideas or to accurately or thoroughly identify process steps, their requirements, their potential failure modes, associated effects and causes, how often the causes occur, and how well the causes are prevented or detected. Instead, a cross-functional team from all stages and/or perspectives of the process should participate together to effectively capture a viable list of possible inputs (the *X*s).

An added benefit to the team approach is that as stakeholders participate in identifying possible *X*s within a process or product, they naturally invest themselves in the solution. Team-based idea generation builds consensus and removes resistance to change. So while you're considering the different tools in this chapter, make sure you're doing so as a team.

Breaking Down Brainstorming Tools

At this point in your DMAIC project, the intent of your brainstorming is to generate and capture a list of possible factors (the *X*s) that may be influencing the key output (the *Y*) of your project.

The basic format for brainstorming is well known: You bring a group together and ask everyone to offer possible ideas on a topic. Effective brainstorming defers judgment; the goal is to gather as many ideas as possible, even unusual ones, and critiquing suggestions at this point will stifle the group's creativity. Two of the best brainstorming tools are affinity diagrams and fishbone diagrams, which we cover in the following sections.

Affinity diagrams

An *affinity diagram* is a special form of a brainstorming session where team members each write their ideas on sticky notes, one idea per note, and then place the notes on the wall. After everyone's notes are posted, the team members work together to group similar notes into natural categories. The resulting groupings can be insightful and revealing.

Fishbone (Ishikawa) diagrams

One of the most basic yet powerful brainstorming tools for capturing all the potential factors in your system is a *fishbone diagram,* named because of its bony, fish-like shape. Sometimes a fishbone diagram is called an Ishikawa diagram, after Kaoru Ishikawa, who first suggested its use. (If you want to sound clever, we suggest calling it a fishikawa diagram.)

The information documented in your fishbone diagram is invaluable. A properly executed fishbone diagram forms the foundation for the analysis phase of the DMAIC project road map because it effectively captures a large number of potential inputs. A meager fishbone diagram makes the rest of your project that much harder. Figure 8-1 shows an example of a fishbone diagram.

A fishbone diagram is so simple that you can draw it on a whiteboard, a notepad, or even a lunch napkin. Start by placing the *Y* of your project — the key output — at the head of the fish. Then, to jump-start your brainstorming, draw a backbone with six main bones coming off to the sides. These bones represent main categories of captured factors: man, machine, method, measurement, materials, and environment.

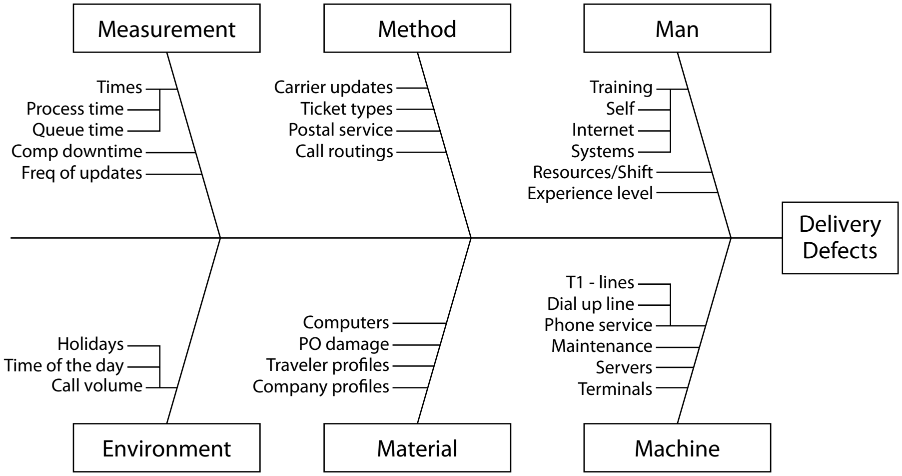


Figure 8-1: A fishbone diagram with the output (*Y*) at the head and the *X*s filling in the bones.

REMEMBER

These six main bone categories are just suggestions. Use whatever categories fit your situation. Some Six Sigma practitioners add the categories of maintenance and management to their diagram. Some in the service industries use the categories of price, place, promotion, people, process, and physical evidence to better help them get started.

Now, with your cross-functional team members, begin to think of any and all factors that may have an influence on the key output. Write each of these factors on a smaller bone on the fish skeleton as an offshoot of the appropriate category (see Figure 8-1). Ideas usually come in bunches as team members leapfrog off the suggestions of others, and pretty soon your team has dozens (if not hundreds) of ideas identifying what factors may be influencing the key output.

Focusing on Failure Mode Effects Analysis (FMEA)

Failure mode effects analysis (FMEA) is a tool you can use to quantify and prioritize risk within a process, product, or system and then track actions to mitigate that risk. Its value in Six Sigma is as a method for identifying and prioritizing which critical few factors you must address in order to improve the process in your DMAIC project. It's also a great tool for developing and carrying out the associated improvement plans.

An FMEA is a tabulated list of the process steps, with each step's potential *failure modes* (ways in which the process step may go wrong or not produce its desired/required outcome); its associated effects and causes; how often the causes occur; and how well the causes are controlled, prevented, or detected. It basically looks like a large table, like the example shown in Figure 8-2 for the process of a pizza shop employee taking a pizza order over the phone.

The rows in the FMEA table correspond to individual steps of the process you're analyzing. As you read from left to right in the table, you transition from listing the process step to that step's potential failure modes, the potential effects, the potential causes, and the current detection or prevention controls.

For each row, you also provide a score for the severity of the effect, the frequency of occurrence of the cause, and the effectiveness of the current controls to detect or prevent the cause. The product of those scores creates the risk priority number (RPN). ***Remember:*** By *you,* we mean your cross-functional team; for best results, all affected parties should have a role in hashing out the FMEA.

For a Six Sigma DMAIC project, you should start an FMEA after you have defined the project and you have an initial understanding of the current process. An efficient FMEA effort doesn't try to start from a blank slate. Instead, it relies heavily on the previous completion of a process map of the current state (see Chapter 7 for info on process mapping).

Other resources that you can feed into an FMEA include compiled performance data from the process, fishbone diagrams listing potential process factors, existing process instructions or standards, and so on. (The preceding section gives you the lowdown on fishbone diagrams.)

Although the overall flow of an FMEA is straightforward, the effectiveness of the method lies in rigorously following the guidelines for each of the detailed elements in order, which we explain step by step in the following sections.

Listing process steps

Using a previously completed process flow map, list each process step or action in the column of the FMEA titled "Process Steps or Product Functions."

To check whether you're on the right track with your process step listing, look at the grammatical construction of the steps; each listed process step description should generally begin with a verb and end with an object: "Machine outside diameter of part," "Enter customer address," and so on. Using the verb-object grammar check helps you make sure that your process steps are granular enough to properly identify risks.

Figure 8-2: A completed FMEA table for an example pizza delivery process.

Process									Actions			Results			
Process Steps or Product Functions	Potential Failure Mode	Potential Effects of Failure	Severity (1-10)	Potential Cause(s) of Failure	Occurrence (1-10)	Current Controls	Detection (1-10)	Risk Priority Number (RPN)	Recommended Action	Responsibility and Target Completion Date	Action Taken	Revised Severity (1-10)	Revised Occurrence (1-10)	Revised Detection (1-10)	Revised Risk Priority Number
Answer phone	Answer on or after fifth ring	Customer hangs up + customer becomes disgruntled + loss of current sale + loss of future sales + interruption to flow of pizza making process	7	Can't hear phone	3	Ringer set to "loud" + music in seating area not to exceed a "4" setting + staff training	5	105	Remove seating area music from order area	Bill, March 17th, 2009	Same	7	3	2	42
			7	Phone too far to reach in time	8	Taped-off spot for phone + end-of-shift area clean-up requirement	7	392	Buy wireless phone headset system	Sarah, March 12, 2009	Too expensive, deferred to next quarter's budget	7	8	7	392
			7	Staff tied up in work that cannot be interrupted	5	One available staff member always assigned to phone duty only	3	105	None	None	None	7	5	3	105
Identify store location															
Determine if pick-up or delivery															

If you're doing an FMEA centered on the function of a finished product rather than on the execution of a process, just list each of the required product functions rather than the process steps.

In the FMEA table shown in Figure 8-2, the initial steps for the pizza order and fulfillment process are listed in the far left column of the FMEA table. Notice that they all follow the recommended verb-object guideline.

Identifying requirements and recording potential failure modes

For each process step, you must first think of its requirements. Identifying the process step's requirements is an intermediate step to accurately and comprehensively identifying the step's potential failure modes. The *requirements* are the additional criteria that determine the success of the step's execution.

In the pizza order taking example, the first step is "Answer the phone." What is the requirement for this step? An employee may answer the phone after it rings for five minutes, but that likely isn't the level of customer service the restaurant is shooting for. The requirement therefore may be to answer the phone before the fifth ring. With the process step's requirement in mind, you then ask yourself what the potential failure modes may be; what constitutes failure to meet the requirement? For the requirement of answering the phone before the fifth ring, the failure mode is "Answer on or after the fifth ring." (***Note:*** This example is relatively simple; most process steps will have multiple requirements.)

WARNING!

Take care not to get sidetracked by failure modes that aren't related to the requirement for your listed process step. For example, a failure mode of "Phone call sound quality is poor" may be legitimate, but it's not at all related to the "Answer within five rings" requirement. These other requirements will be captured properly and detailed in another section of your FMEA. Let the FMEA method do the work for you. If you don't, the FMEA method becomes much more arduous.

Spelling out effects of failures

The next step in the FMEA is to list the potential effects — yes, that's plural *effects* — of each identified failure mode (see the preceding section). Simply list each individual effect in the same cell of the FMEA table, separating each individual effect with a + or an &.

Try to think thoroughly and realistically. What may happen if this failure mode occurs? Figure 8-2 lists the potential effects of not answering the pizza shop phone in time under the "Potential Effects of Failure" column.

TIP

To help think of effects, consider two aspects of the failure mode: First, think of how the failure mode may affect the flow of the process and internal customers; second, think of how the failure mode may affect the end customer of the process. Pretty soon, you get into the groove and can quickly create a comprehensive list of possible effects.

Scoring the severity of the effects

Looking at your list of potential effects, you need to determine how severe of an impact the identified failure mode may have. You use a 1 to 10 scale, with 10 being the most severe impact and 1 being the least severe. Table 8-1 shows a typical FMEA severity scoring scale. The first column shows the numeric scores; the second column is a verbal description of typical industry-standard levels of severity from the Automotive Industry Action Group (AIAG), and the third column translates that AIAG language into more practical, customer-centered terminology. (***Note:*** The AIAG isn't an official authority on FMEA, but it's arguably FMEA's leading proponent. Because of that, most of the industry tries to follow the AIAG's lead when doing FMEA.)

Table 8-1 Sample Severity Scoring Scale for FMEA

Score	*AIAG Description*	*Customer-Centered Description*
10	Hazardous without warning	Injures a customer or an employee
9	Hazardous with warning	Illegal; violates regulatory requirements
8	Very high	Renders product or service unfit for use
7	High	Causes extreme customer dissatisfaction
6	Moderate	Results in partial malfunction or failure
5	Low	Causes a loss of performance which is likely to result in a complaint
4	Very low	Causes a minor performance loss
3	Minor	Causes a minor nuisance but can be overcome with no performance loss
2	Very minor	Is unnoticed and has only minor effect on performance
1	None	Is unnoticed and does not affect performance

For the combined list of effects in the pizza example of Figure 8-2, the FMEA team needs to assign a score to each listed individual effect and then give an overall severity score based on the worst possible individual effect. In the pizza example, you may decide that the "loss of future sales" component of the effect is the worst and should be scored as, say, a *7.* This score is the one that you assign to this grouping of potential effects.

Listing causes of failure modes

After scoring the severity of the possible effects as we discuss in the preceding section, your cross-functional FMEA team brainstorms potential causes of the identified failure mode.

REMEMBER

Think of causes for the failure mode, not for the *effect*. In the pizza example, you need to think of causes for why the phone is answered on or after the fifth ring, not causes for why a customer hangs up or why a customer becomes disgruntled.

Be sure to list potential causes of the failure mode in separate rows of the FMEA table, which usually means you have to insert new rows into your FMEA table as shown in Figure 8-2.

Scoring the occurrence of the cause

The next important task is determining how often each listed cause occurs with a 1 to 10 occurrence score; 10 represents a very frequent occurrence and 1 a very rare occurrence. Table 8-2 is a typical FMEA occurrence scoring scale; the second column includes information from the AIAG on the consequences of the frequency, and the last column gives information on a yield level associated with the frequency of occurence. (P_{PK} is a measure of long-term process capability that we cover in Chapter 13.)

Table 8-2 Sample Occurrence Scoring Scale for FMEA

Score	*AIAG Description*	*Frequency*	*Yield*
10	Very high; persistent failures; $P_{PK} < 0.55$	More than once a day	> 30%
9	Very high; persistent failures; $P_{PK} \geq 0.55$	Once every 3–4 days	< 30%
8	High; frequent failures; $P_{PK} \geq 0.78$	Once every week	< 5%
7	High; frequent failures; $P_{PK} \geq 0.86$	Once per month	< 1%
6	Moderate; occasional failures; $P_{PK} \geq 0.94$	Once every 3 months	< 0.03%

Score	AIAG Description	Frequency	Yield
5	Moderate; occasional failures; $P_{PK} \geq 1.00$	Once every 6 months	< 1 per 10,000
4	Moderate; occasional failures; $P_{PK} \geq 1.10$	Once per year	< 6 per 100,000
3	Low; relatively few failures; $P_{PK} \geq 1.20$	Once every 1–3 years	< 6 per million
2	Low; relatively few failures; $P_{PK} \geq 1.30$	Once every 3–6 years	< 3 per 10 million
1	Rare; failure is unlikely; $P_{PK} \geq 1.67$	Once every 6–9 years	< 2 per billion

REMEMBER

This stage is one where the participation of the cross-functional team is critical. Members of the team from different aspects of the process will have a good idea of how often each listed cause occurs. Has the listed cause ever happened before? About how many times over the last month? The last year? In the unlikely event that no one on the team knows how often a particular cause occurs, the team should go to *gemba* (that is, the place where the work occurs) and measure for themselves how often the cause is occurring.

Figure 8-2 shows occurrence scores for each listed cause in the pizza order example.

Identifying current controls

The next step in the FMEA process is for the team to identify what controls or protections are in place within the current configuration of the process to prevent the cause from happening or at least to detect and provide an alarm when the cause does happen. Typical controls include operator training, process instructions, automated in-process inspection, and so on.

TIP

Causes often have more than one control. In this case, list all the controls in one table cell and separate them with a + or &.

The controls for the example pizza order process are listed in Figure 8-2 under the “Current Controls” column.

Scoring the detection of the controls

Just as with the severity and occurrence scores we discuss earlier in the chapter, the cross-functional team now gives each listing of controls a score for the controls' effectiveness at preventing or detecting the associated cause. This scale utilizes scores from 1 to 10, with 10 indicating no ability to prevent or detect and 1 signifying perfect ability to prevent or detect. Table 8-3 lays out a typical detection scoring scale, with detection descriptions from the AIAG and associated inspection types typical of that detection score.

TIP

SPC refers to *statistical process control,* which is the method of using specialized statistical probability calculations to monitor and detect external influences on a system's performance. You can read more about SPC in Chapter 20.

Table 8-3 Sample Detection Scoring Scale for FMEA

Score	*AIAG Description*	*Inspection*
10	Almost impossible; absolute certainty of non-detection.	Defect caused by failure isn't detectable.
9	Very remote; controls probably won't detect.	Occasional units are checked for defect.
8	Remote; controls have poor chance of detection.	Units are systematically sampled and inspected.
7	Very low; controls have poor chance of detection.	All units are manually inspected.
6	Low; controls may detect.	Manual inspection with mistake-proofing modifications.
5	Moderate; controls may detect.	Process is monitored (SPC) and manually inspected.
4	Moderately high; controls have a good chance to detect.	SPC is used with immediate reaction to out-of-control conditions.
3	High; controls have a good chance to detect.	SPC, with 100% inspection around out-of-control conditions.
2	Very high; controls almost certain to detect.	All units are automatically inspected.
1	Very high; controls certain to detect.	Defect is obvious and can be kept from affecting the customer.

WARNING!

Be careful not to accidentally flip the numbers of the detection scale. Remember, a detection score of 10 is bad and means you have no detection, while a score of 1 is good and indicates that you have perfect control.

When giving detection scores, keep in mind that training, reminders, or even formal discipline of employees aren't effective means of preventing or detecting causes of failure. When training or operator awareness is the only or the best available control, the detection score is usually given a fairly high score — maybe a *7* or an *8*.

Figure 8-2 lists the detection scores for the pizza order process.

Calculating and reviewing RPN scores

With severity, occurrence, and detection scores for each row (see the preceding sections), you can calculate an overall composite *risk priority number,* or RPN. An RPN is simply the severity score multiplied by the occurrence score multiplied by the detection score. The lowest possible RPN is 1 ($1 \times 1 \times 1$), while the highest is 1,000 ($10 \times 10 \times 10$). With the FMEA filled out for each process step and with an RPN for each row, the cross-functional team can quickly identify where risk currently resides within the process.

Because the RPN is a composite score, rows in the FMEA table that have same or similar RPNs may need to be addressed very differently. Be intelligent in your review; one process step with a particular score may require action to reduce the occurrence, while another with the same score may require improved detection.

Devising and assigning improvement actions

The far right-hand column of the FMEA table is for coming up with improvement actions that will improve the current risk situation. These actions may include taking additional data or measurements to more accurately understand an occurrence of a specific cause or implementing improved detection actions. You can record these assignments and target completion dates directly into the FMEA with revised severity, occurrence, and detection scores.

The right side of Figure 8-2 shows assigned improvement actions and revised severity, occurrence, and detection scores to reflect the improved situation.

Chapter 9

Describing Performance with Numbers

In This Chapter

- Recognizing different types of data
- Understanding the basics of statistics
- Seeing the difference between short-term and long-term variation

Although the idea of data, numbers, and measurements may not be exciting to some, it should be very exciting to you, a Six Sigma practitioner who is tasked with improving a process, an operational unit, or an entire organization.

In this chapter, you find out about different types of data and understand how to characterize data in a critical, scientific way. The nitty-gritty information in the following sections can help you use tried-and-true statistical tools to explain how your processes are performing.

Recognizing Different Types of Data

All data aren't created equal. As you begin your quest to organize your data, you first need to know what type of performance data you have. Just as knowing what the fish are biting tells you which lure to use, knowing what kind of data you're dealing with tells you which tools to use. This section defines two important data categories: attribute (also known as category) and continuous (also called variable); take a look at them in Table 9-1 and the following sections.

Table 9-1 Characterizing Data Types

Data Type	*Description*	*Examples*
Attribute/ category	Data observations fall into discrete, named value categories.	Eye color: brown, blue, green
		Location: Factory 1, Factory 2, Factory 3
	No mathematical operations can be performed on the raw data.	Inspection result: pass, fail
		Size: large, medium, small
		Fit check: go, no-go
		Questionnaire response: yes, no
	You can count the number of occurrences you see of each category.	Attendance: present, absent
		Employee: Fred, Suzanne, Holly
		Processing: Treatment A, Treatment B
Continuous	Data observations can take on numerical value and aren't confined to nominal categories.	Bank account balance: dollars
		Length: meters
		Time: seconds
		Electrical current: amps
	Any two data values can be meaningfully added and subtracted.	Survey response: 1 = disagree, 2 = neutral, 3 = agree

Identifying attribute (category) data

Some data consist of measurements that describe an attribute of the characteristic or process. These data are called *attribute* or *category* data.

Attribute data are all around you:

- Telephone area codes
- S, M, L, XL, XXL clothing sizes

- "Pass" or "fail" judgments pronounced on just-assembled products
- "Good" or "bad" assessments of the output from a process

How do you know whether you're working with attribute data? The telltale test is to ask yourself, "Can I meaningfully add or subtract values of this data?"

If the answer is "no," what you have is attribute data. For example, what do you get when you add a S-sized shirt to a M-sized shirt? Nothing meaningful. Or, if you subtract telephone area code 213 from area code 415, does the resulting area code of 202 mean something? Of course not! And so you know that you're dealing with attribute data.

What you can do with attribute data is count how many times each category or attribute appears. For example, you may find that a process produces 152 "good" items and 28 "bad" items over a given period of time. You use the results of these types of category counting studies as the starting point for many Six Sigma analyses.

A subset category of attribute data that provides a little more horsepower is called *ordinal data* (also known as *rank order data*). Ordinal data are attribute data that can be logically placed in an order from smallest to greatest or in an order of time, such as the months of the year: January, February, March, and so on. If you have "month" data on a set of last year's invoices, you can sort them into buckets of occurrence starting with January and then move on through the year. Or you may not have actual completion times, but you may have data about which employees finished a task first, second, third, and so on. In this case, you have a powerful set of ordinal data that you can use to begin analysis and improvement.

Classifying continuous (variable) data

If you find that you can meaningfully add or subtract any two values of your data, you're working with *continuous* (or *variable*) data rather than attribute data. (See the preceding section for more on attribute data.)

When testing whether data is attribute or continuous, be sure to apply the "meaningfully add or subtract the values" question to the raw data and not to any summarized counts of the data. For example, the fact that you can subtract five M-sized shirts from seven L-sized shirts to get a two-shirt difference doesn't indicate that you have continuous data. You have to apply the question to the raw data: a L-sized shirt minus a M-sized shirt has no meaningful answer.

Both *continuous* and *variable* are poor names for this type of data, but for whatever reason, these are the names that have stuck. The name "continuous" is meant to convey the idea that this data type can have any value from a continuous scale, like the reading on a mercury thermometer. "Variable" is an attempt to say the same thing — that the measured values can vary anywhere along a given scale. You can get 98.23 degrees Fahrenheit or 98.25 degrees Fahrenheit or 98.37 degrees Fahrenheit. The problem is that no matter how continuous or variable you think your measurement scale is, as soon as you record a measurement, you always truncate its reading to some fixed length, making it no longer continuous. But the powers that be want you to use the names *continuous* and *variable,* so go ahead and use them anyway.

A few more examples of continuous data include

- A numbered GPA scale representing letter grades at school
- The temperature in your oven
- The amount of money you spend on groceries
- The time it takes to complete a process task
- The gas mileage of your car

Any two values of continuous or variable data can always be meaningfully added or subtracted. For example, a count of the number of children in each household can only occur in integer values — you can't physically have 2.3 children — so the scale of measure of children in a household isn't continuous at all. But you can take the integer measurement from each household and perform mathematical operations to calculate a meaningful average or standard deviation. Being able to mathematically operate on any two values of continuous data is what sets it apart from attribute data.

Using Statistics to Make Sense of Data

In 1891, the famous scientist Lord Kelvin provided valuable insight for future Six Sigma practitioners:

> When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the state of science.

In other words, if you want to make big performance gains, you need to harness the power of statistics and data analysis to take you out of the realm of intuition and estimation and into the realm of objective truth. Statistics — and its embodiment in Six Sigma — is like vegetables: It's not always what you want to have, but you know it's good for you.

Statistics is the branch of mathematics that distills raw numbers, data, and measurements into knowledge and insight. If you understand a little bit about statistics, you can create a data-leveraging environment that you can use to understand or improve something. You don't have to have a PhD in statistics to be a Six Sigma practitioner, but you should have a grasp of the statistical concepts that we cover in this section. Armed with two quantities — a measure of location and a measure of spread — you can describe any type of distribution in scientific terms. Lord Kelvin would be proud!

Beginning with measurement 101: Distribution

Suppose you need to find out how long filling out a certain purchase order form takes. Each time you fill out the form, you record the elapsed time to the nearest second and plot the result as a dot along a horizontal time scale. Figure 9-1 shows the first three times you fill out the form, with times of 41, 50, and 47 seconds.

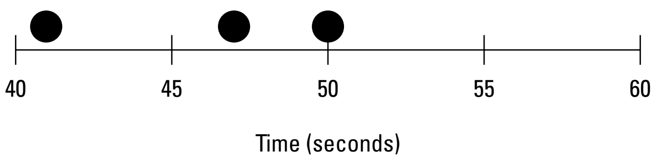


Figure 9-1: First three measurements for filling out a purchase order form.

See how your data reveals that variation is inherent in the process? Continuing the study, you take a total of 100 purchase order time measurements. Whenever you encounter a measurement that already has a recording (such as 47 seconds), you simply stack another dot on top of the previous dot. Figure 9-2 has the completed chart with all 100 measurements.

Notice in Figure 9-2 that the output values that occur often pile up with multiple dots. For example, 50 seconds is the purchase order completion time that occurs more frequently than any other. Consequently, it has the highest peak in the chart (15 occurrences). Output values that happen less frequently have lower heights, and output values that were never observed have no dots at all.

Figure 9-2 graphically describes how the measured output is *distributed* along its scale of measure: time. Looking at the chart, you can predict that if you were to measure another cycle of the purchase order process, the elapsed time would most likely be around 50 seconds. A completion time of 30 seconds or 80 seconds, for example, is just not likely to happen.

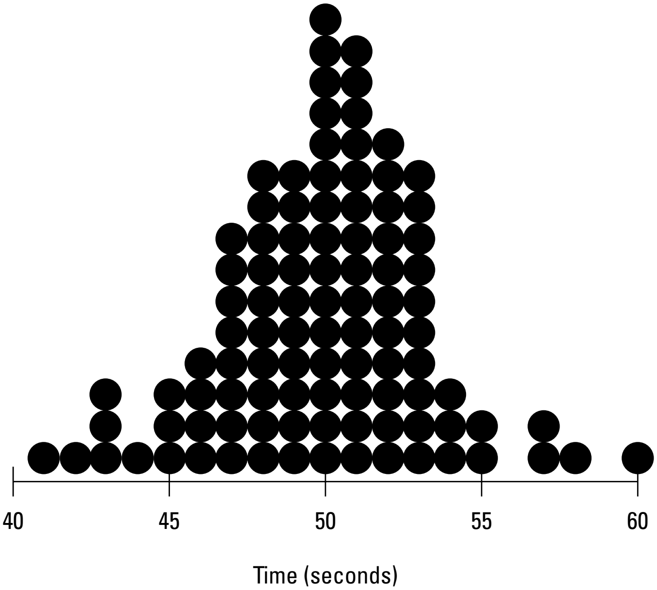


Figure 9-2: 100 measurements of elapsed time for filling out a purchase order form.

Distribution is the statistical term that describes the relative likelihood of observing values for a variable factor. (You may also see it referred to as *probability distribution* or *probability density function.*) When you think of the critical performance characteristics of a product or service — either output *Y*s or input *X*s — you should begin thinking of them as distributions. Variation is inherent in all *X*s and *Y*s, so you will see distributions in your measurements.

Measuring distribution location

When you have a distribution for some data you're working with (check out the preceding section for an example), you can then ask yourself, "How can I describe this distribution with numbers?" Or, "Where is the distribution's center located along the scale of measure?"

A distribution can have infinitely many points, and fixing a location for the distribution is important so that you can then understand the variation around that location. To determine this location, statisticians have developed three different measures of *central tendency* to describe a distribution's location: the mode, the mean, and the median. Table-9-2 gives you an overview of these measures, and we discuss them more fully in the following sections.

Table 9-2 Statistical Measures of Variation Location

Measure of Variation Location	*Definition*	*Comment*
Mode	Peak of distribution	Problematic, seldom used
Mean (average)	$\bar{x} = \frac{\Sigma x_i}{n}$	Most common and familiar
Median	Point where half of data are below and half are above	Used when data contains outliers

Evaluating peaks a la mode

The *mode* is the value observed most frequently in a distribution and is associated with the distribution's highest peak. If ten students take an exam and three score 60, three score 90, and four score 80, you peg 80 as the mode because it occurs more frequently than any other value.

Although using the mode as the measure of variation location is simple and intuitive, doing so has a drawback: Many distributions don't have a single clear peak, and some have more than one peak of roughly the same height. In these cases, presenting a single mode metric by itself does little to deepen your knowledge of the location of the variation.

Making nice with the mean

The most common measure of central tendency is the *mean* — widely called the *average.* Examples of averages are everywhere — the Dow Jones industrial average, grade-point average, the average temperature in your hometown, and the list goes on.

Understand that the mean is theoretical rather than real; although the mean may not have actually occurred within your measurements, it's the value most likely to occur next in a sequence or population of data. The mean, therefore, is a mental model by which the Six Sigma practitioner (that's you) can make comparisons, forecast predictions, interpret data, and anchor much of the analytical work that is done in order to save money in operations, make customers more satisfied, and improve products and services.

Calculating the mean is simple. Imagine having ten paper cups, each holding a different amount of water. What is the average amount of water in the cups? Consider combining the contents of each of the ten cups into a large bowl. You'd simply measure the collected amount and divide it by the number of paper cups. This tells you how much water would be in each paper cup if the amounts were forced to be equal — or *average.*

Mathematically, the process for calculating the mean is written as

$$\bar{x} = \frac{\Sigma x_i}{n}$$

where

- $\bar{x}$ (pronounced "ex bar") is the symbol representing the calculated mean.
- Σ is the Greek capital letter sigma. In the shorthand of math, it tells you to sum up (add) all the individual measurements.
- x_i represents each of the individual measurement values.
- n is the number of individual measurements in your data set.

So for the purchase order form example in Figure 9-2, you find the mean ($\bar{x}$) by adding up each of the $n = 100$ time measurements and dividing the result by $n = 100$. The result is an $\bar{x}$ of 49.9 seconds. Computing the mean for any distribution is never any harder than that.

Finding the median

The *median* is the point along the scale of measure where half the collected data is below and half is above. The median is the preferred measure of variation location when your collected data contain *outliers* (recorded observations that are well outside the range of variation of the rest of the data).

For example, the median is often used when communicating home prices because it's usually more reflective of the central tendency of the distribution of all prices. Suppose you have a set of homes with prices of $158,000, $200,000, $178,000, $125,000, and $535,000. The average price is $239,200. The median, however, is $178,000. Figure 9-3 shows the raw data of home prices with the mean and median specified. Note that the median represents the central location of the distributed home prices better than the mean does. That's because the calculated value of the mean is pulled up away from the more accurate location value by the presence of the outlier — the $535,000 home.

WARNING!

Beware when someone communicates only the average of a measured characteristic to you when describing its performance. Without your knowing, he or she may have included an outlier (accidentally or on purpose) that has biased the calculated mean value.

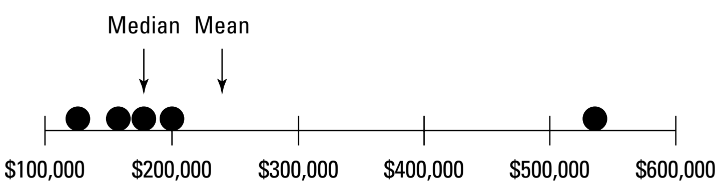


Figure 9-3: Graphical comparison of the mean and median.

Calculating the width of variation

Measures of mean, median, and mode don't tell the whole story. They fail to communicate exactly how spread out or widely dispersed the variation really is around its central location point. For example, two sets of measurements with identical means may contain raw data values that are distributed very differently. You need a second measure to quantify how widely or narrowly dispersed the data are around their central location. In this section, you find out how to do that with the range and standard deviation. Check out Table 9-3 to get an idea of these measurements.

Table 9-3 Summary of Statistical Measures of Variation Spread

Measure of Variation Spread	***Definition***	***Comments***
Range	$R = x_{MAX} - x_{MIN}$	Simple. Preferred metric for sets of data with few (2 to 5) members. Drawback: Greatly influenced by outliers.
Variance	$\sigma^2 = \frac{\Sigma(x_i - \bar{x})^2}{n-1}$	Theoretically useful, but lacks direct tie to reality.
Standard deviation	$\sigma = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n-1}}$	Most commonly used.

Working with the range

The simplest measure of the spread of your data is its range. The *range* of a distribution is defined as the difference between the largest and the smallest observed data values. Mathematically, you write this quantity as

$$R = x_{MAX} - x_{MIN}$$

where

- R is the calculated range.
- x_{MAX} is the largest observed measurement.
- x_{MIN} is the smallest observed measurement.

In the Figure 9-2 form example (see the section "Beginning with measurement 101: Distribution" for the full example), the range is simply the longest recorded time to fill out the form (60 seconds) minus the shortest time (41 seconds), or R = 19 seconds. Calculating the range works just as well when you only have two recorded measurements as it does when you have 1,000. But obviously, outliers directly affect its calculated value. (By their very nature, outliers end up being the x_{MAX} or x_{MIN} used to calculate the range.)

Determining the standard deviation

So can you quantify a distribution's degree of dispersion in a way that avoids the problem of outliers? Look at any single recorded measurement. How far is it from the central location of the data set? Mathematically, you represent this problem as

$$x_i - \bar{x}$$

where

- x_i represents any single recorded measurement from your set of data.
- $\bar{x}$ is the calculated mean of your collected observations.

$x_i - \bar{x}$ then acts as a numerical "score" for each data point. Like in golf, the lower the magnitude of the score, the better (the less it varies from the central location).

You've probably played around with numbers enough, however, to recognize a problem with this scoring system. When x_i is less than the mean ($\bar{x}$), the score ($x_i - \bar{x}$) ends up being less than zero. That won't work as a way to fairly score the distance of each point from the average! Being above or below the central location doesn't matter; it's how far away it is that counts. And negative scores make things too complicated. You need a way to score each data point that looks only at the data point's distance from the central location and disregards the direction of the distance.

Luckily, you can get around this problem by using the following formula:

$$\left(x_i - \bar{x}\right)^2$$

The parentheses and the exponent *2* tell you to square the entire quantity $x_i - \bar{x}$ (multiply it by itself). No matter whether the quantity you're squaring is positive or negative, the resulting answer is always positive: $2 \times 2 = 4$ and $-3 \times -3 = 9$. Thus, you've taken care of the negative number issue.

A side benefit of squaring each individual score is that it penalizes points that are farther away from the central location disproportionately more than those that are closer. Figure 9-4 shows a plot of $\left(x_i - \bar{x}\right)^2$ output values versus input values for $x_i - \bar{x}$.

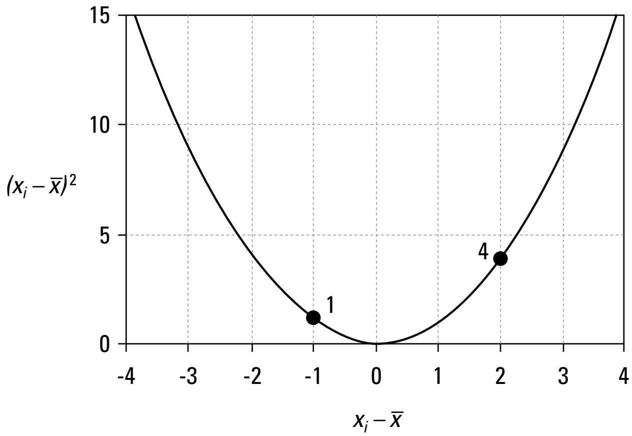


Figure 9-4: Squaring as a way of scoring individual deviations from the central location.

If an individual data point is one unit away from the central location (on either side), $x_i - \bar{x} = 1$ and $(x_i - \bar{x})^2 = 1$. If a different point is two units away, however, $(x_i - \bar{x})^2 = 4$, resulting in a score that isn't twice as bad but *four times* as bad.

To create an overall, combined score for the entire data set, simply add all the individual squared scores together. Mathematicians write this operation as

$$\Sigma(x_i - \bar{x})^2$$

Statisticians call this result the *summed squared error,* or SSE for short.

In the field of statistics, *error* doesn't mean something is wrong. The term simply means a calculated deviation from a comparison value. In this case, error is the difference between the mean and the individual observations.

To find the average squared score, you divide the summed squared error by the number of independent data points in your collection, like this:

$$\sigma^2 = \frac{\Sigma(x_i - \bar{x})^2}{n-1}$$

where

- n is the total number of data points you have collected.
- σ^2 is the averaged squared error score — what statisticians call the *variance.*

Right now, one of two things has happened. Either your eyes have glazed over, or you're saying, "Hold on a minute. Why did you divide by one less than the number of measurements I collected ($n - 1$) rather than by the total I collected (n)? That doesn't seem right."

If you're in the latter camp, you've asked an outstanding question. (And if you're in the former camp, don't worry; statistics does that to the best of us.) Notice that the equation for the variance includes the mean ($\bar{x}$). This point is where you lose the *independence* of one of your collected measurements.

It's like having a full five gallon bucket and dividing the contents completely into ten new buckets. Even though the amounts you pour into the first nine buckets can vary independently from each other, when you get to the tenth bucket, you have no more freedom — what you have is exactly what remains. In the same way, using the mean ($\bar{x}$) reduces the number of independent measurements available to compute the variance.

Finding the standard deviation

A final problem lingers with the development of a measure of how widely or narrowly your collected data are distributed: What are the units associated with the computed variance? In the Figure 9-2 purchase order example, your measurements have been in seconds. That means the variance comes out as seconds^2. In the real world, no one knows what seconds^2 are (and anyone who thinks they do ought to be avoided!)

The person who originally solved this last issue must have known the answer from the beginning. Notice that the symbol for the variance is σ^2. And as you've likely guessed, the solution is simply to reverse the squaring done previously to your measurements. Mathematicians call this reverse-squaring operation the *square root* and give it a special operator symbol ($\sqrt{\ }$).

Applying it to the variance introduces the measurement you're after — namely, the standard deviation (σ):

$$\sigma = \sqrt{\frac{\Sigma\left(x_i - \bar{x}\right)^2}{n-1}}$$

The standard deviation is by far the most commonly used measure of dispersion. It occurs throughout statistics and Six Sigma — that's where this whole quality initiative gets its name.

The standard deviation represents the typical (average) distance from the central location you expect to observe. Its units are exactly the same as your original measurements. So for the purchase order example, its units are seconds.

The Long and Short of Variation

In the earlier section "Using Statistics to Make Sense of Data," we introduce the various measures of variation. This section continues the topic by peeling back the layers of the onion to reveal another aspect of variation you need to know about: the difference between long- and short-term variation. For quick reference, Table 9-4 presents the formulas for both of these types of variation. The following sections cover deviation in detail.

Table 9-4 Formulas for Calculating Short-Term and Long-Term Standard Deviation

Variation Type	*Formula*
Short-term	$\sigma_{ST} = \frac{\overline{R}}{1.128}$
Long-term	$\sigma_{LT} = \sqrt{\frac{\Sigma\left(x_i - \overline{x}\right)^2}{n-1}}$

Sizing up short-term variation

Suppose you monitor a characteristic of a product or process — say, the volume of inbound calls per hour at a customer call center — over an extended period. After each hour, you measure and record the number of calls received. To review what you've observed, you graph your collected measurements as a sequence of connected points along an axis representing time, as shown in Figure 9-5.

Although the points graphed in Figure 9-5 represent the number of incoming calls per hour, recognize that they can also represent any process characteristic in any type of company. All process characteristics vary from cycle to cycle: the exact length of newly manufactured pencils, the time required to fill out an invoice, the number of calls per hour, and so on.

If you zoom in on a narrow portion of the graph, as shown in Figure 9-6, you can see from the scattered points that the output certainly does vary for each measurement cycle. But you can also notice that the variation isn't limitless. It lies within upper and lower boundary limits — represented by the dashed, horizontal lines.

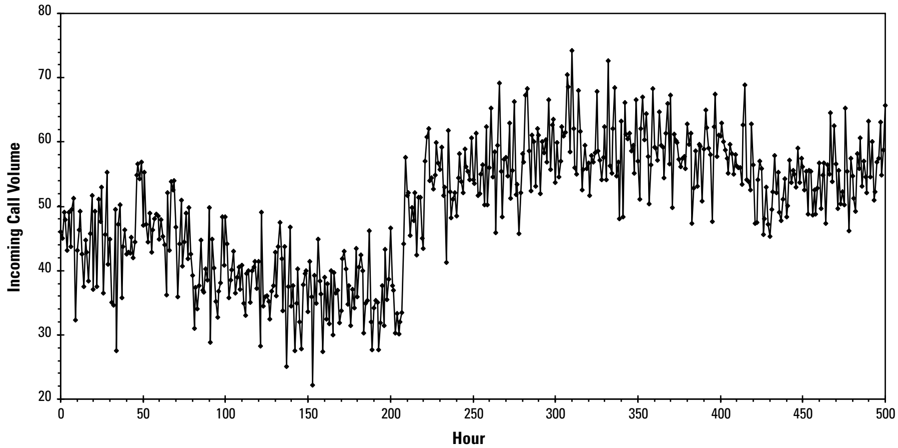


Figure 9-5: The observed output behavior of a process over an extended period.

In fact, for any selected short period of time, the process essentially varies within the same rough limits. (Try it for yourself. Pick any short time segment of Figure 9-5 and eyeball the vertical variation limits with your thumb and index finger. Now, keeping the distance between your fingers fixed, move to a different time section of the graph. Do your eyeballed limits capture the output variation for other short-time segments?) This natural level of variation is called the *short-term* variation of a process. Often, it's designated with a simple *ST* notation.

Short-term variation is purely random. Like rolling a pair of dice, you can't predict what the next output value will be. If you could, Las Vegas would be bankrupt in a week!

REMEMBER

Short-term variation (sometimes called *entitlement variation*) is what you use to compare the inherent capability of different processes to meet a specified goal. For example, creating a shaped plastic part by using an injection mold machine may have an entitlement variation of ±0.002 inches. The process of cutting plastic with a milling machine, on the other hand, may have an entitlement variation of ±0.0005 inches. In this case, the milling machine process has the better level of entitlement. It has less inherent, short-term variation.

Considering the many mini-causes of short-term variation

Short-term variation is caused by the combined effect of all the little things that are too hard to include in your understanding of the process. Even Einstein would find it too difficult to determine exactly how the microscopic textures of the dice contribute to their spin as they contact the felt surface of the table, or how the drag of the swirling air on the corners of the airborne dice alters their tumble. Yet these factors — and many more — are real and do add up to affect the outcome of the roll.

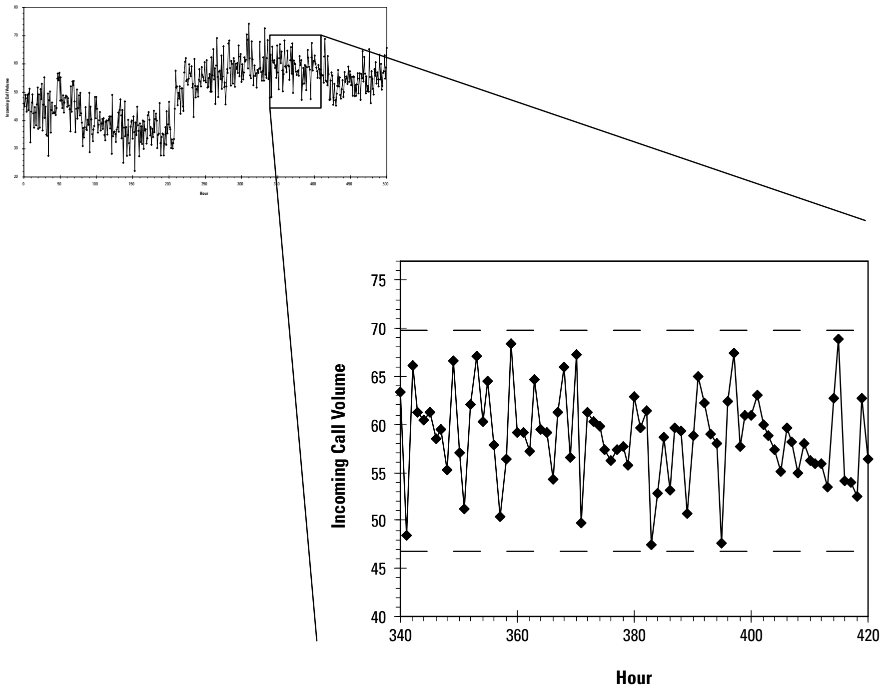


Figure 9-6: Detailed view of a narrow segment of the extended process behavior graph.

The reality of short-term variation in any and all processes, from rolling dice to preparing a meal to writing a memo to launching a rocket, is that the complete chain of causation is unknown and unknowable. Like rolling dice, your ability to understand the full depth of causation for any process is ultimately limited. Because these small forces are present to some degree in all processes, they're referred to as *common.* Consequently, the short-term variation they cause is sometimes called *common cause variation.*

Calculating short-term variation

After you know what short-term variation is, you need to know how to quantify it. The formula in the earlier section "Finding the standard deviation" for calculating the standard deviation doesn't account for any short- or long-term effects. It just looks at the overall variation in all the measurements. But never fear; hard-working statisticians have developed a way to extract the level of the short-term variation out from the overall variation.

The quickest way to get to the short-term variation is to analyze the separation or differences between sequential measurements of a critical characteristic. The difference between any two sequential measurements can be thought of as a kind of range. For a sequence of measurements

$$x_1, x_2, \ldots x_{n-1}, x_n$$

where n is the total number of collected data points, you can write the difference or range between the first and second measurements as

$$R_1 = |x_1 - x_2|$$

In general, the difference between any two sequential measurements is

$$R_i = |x_i - x_{i+1}|$$

The vertical parentheses-like bars in the equation are called an *absolute value.* They signal you to take the positive magnitude of the calculated difference inside the absolute value symbols, regardless of whether it is a positive or negative value. And the average range or difference between sequential points is

$$\bar{R} = \frac{1}{n-1}\sum_{i=1}^{n-1} R_i$$

The way to calculate the short-term standard deviation from these sequential, between-point ranges is to multiply their average by a special correction factor based on the range between two sequential measurements:

$$\sigma_{ST} = \frac{\bar{R}}{1.128}$$

Never try to calculate a characteristic's short-term standard deviation on anything other than a sequential set of measurements. That is, only perform this calculation on a set of measurements that are in the exact order that the measurements were taken. The calculation of the short-term standard deviation is based on the natural ranges that occur between the characteristic's measurements; altering the order of the measurements in any way directly affects the calculated value of the short-term standard deviation.

Shift happens: Looking at long-term variation

Take another look at the extended process behavior graph in Figure 9-5 earlier in the chapter. Something besides pure random variation is going on here. Notice that the range of short-term variation doesn't stay locked at a single level. Instead, it shifts and drifts up and down over time. These bumps and currents — called *disturbances to the process* — are emphasized with overlaid lines in Figure 9-7.

When these underlying disturbances are added to the natural short-term variation, the overall combination is called the *long-term variation* of the process. In many cases, it's written with a simple LT notation.

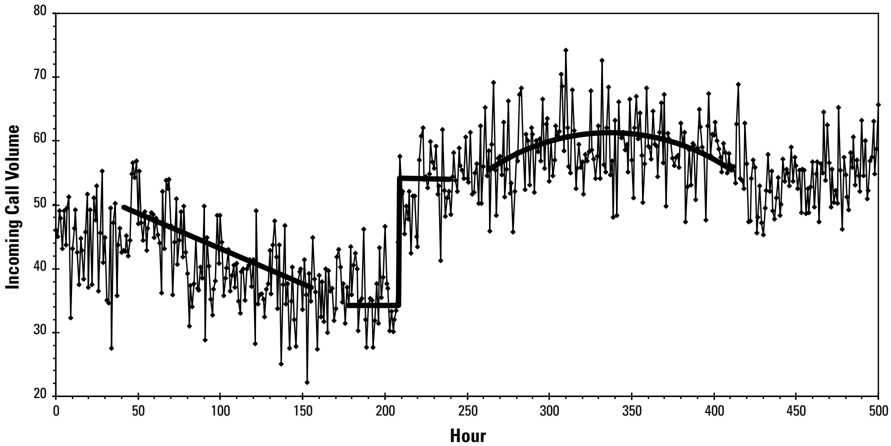


Figure 9-7: Non-random disturbances overlaid on the extended process behavior graph.

Pinpointing long-term variation's non-random behavior

As opposed to random, short-term variation, these underlying disturbances are *non-random* over the long term. You can approximate them with a line, a step, a curve, or a repeated pattern.

The great thing about long-term variation is that you don't have to be Einstein to figure it out. With the proper detection techniques and tools, you can see what part of your process is affected by non-random forces. If the process is to assemble a proposal, and if the critical output of that process is how long it takes to create the proposal, you want to look at the variation patterns in the output of the process.

Figure 9-7 shows just the *output variation,* or changes in the number of incoming calls at a call center per hour. If the output metric varies in a non-random way, you can safely say that some combination of special cause factors has affected the volume of incoming calls.

REMEMBER

When we say "special cause," we mean that the output has varied to an extent that is inconsistent with what you would expect from purely normal, short-term, natural — or random — influences. You know that something non-random has occurred, and, therefore, you know that you can find the cause and solve the problem.

TIP

A good way of depicting the difference between short-term and long-term variation in a process is by using two probability distributions, as shown in Figure 9-8. Notice that, over time, the long-term variation is wider than the inherent, short-term variation.

Non-random variation is caused by special forces whose effects on the process are readily observed and understood. Consequently, this non-random variation is also called *special cause variation* or *assignable cause variation.*

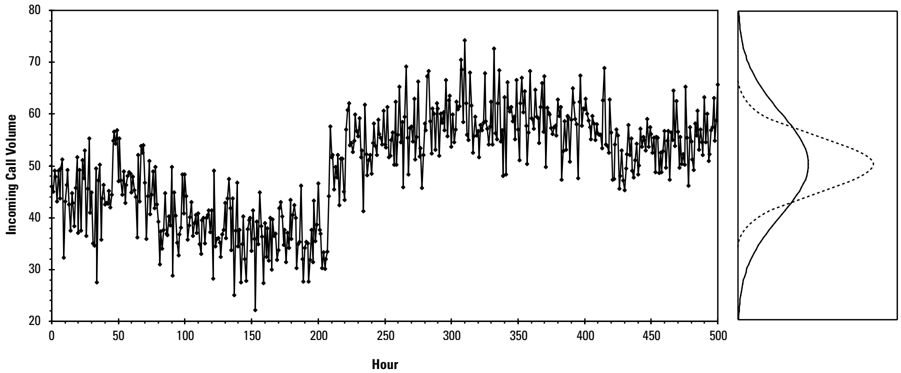


Figure 9-8: Long-term (LT) and short-term (ST) process variation summarized as probability distributions.

Computing long-term variation

Calculating the long-term variation of a characteristic is identical to calculating its overall variation. Therefore, the overall standard deviation is the formula you use to quantify the level of long-term variation in a characteristic.

The calculated long-term variation should always be greater than or equal to the calculated short-term variation.

For any long-term variation you find, you can immediately create solutions to solve the problem, whether that's conducting routine preventive maintenance on your drills, making the maintenance procedure so easy that anyone can understand and adhere to it, creating redundant systems in case equipment breaks down or a contingency plan in the event of losing a principal leader, or whatever.

Being all you can be: Entitlement

Every process involves a combination of short- and long-term variation. The short-term component comes from the unaccounted-for common causes rooted within the process. The long-term component is the result of factors you can detect — special causes. Suppose that you want to reduce the overall level of variation in your process. What do you do? How should your new understanding of short-term and long-term variation guide your approach?

Imagine you identify and remove all of the non-random, special causes affecting your process. You're left, then, with a process that is influenced by only random, short-term variation. Further shrinking the output variation is difficult — very, very difficult. That's because further shrinking requires discovering what previously was unknown about the inner workings of your process. You need to identify, understand, prioritize, and fix the myriad of embedded, common factors jiggling the process output.

What's the difference between short-term and long-term variation?

How do you know when short-term variation is no longer short-term? No set time period creates a concrete boundary where short-term variation transitions into long-term variation for every process characteristic. The transition point depends totally on the process and the time required for long-term, special causes to exert themselves on the process.

Some long-term things can go wrong (assignable causes) in a manufacturing environment:

- **Tool wear:** The bit that drilled holes in your new assemble-it-yourself desk was too worn down at the time it was employed during the manufacturing process. You, and 500 other people who bought desks from the same production batch, now struggle to assemble your pieces while muttering unkind words about the manufacturer.
- **Changes in machine operator:** Jack replaces Jill on the printing press but doesn't do his required maintenance. Print quality suffers, customers are unhappy, and the finger-pointing begins.
- **Differences between raw materials:** Print quality also suffers non-randomly when Jill is on her shift, because the quality of the ink is sometimes compromised by the supplier, and at other times the ink is slightly off its target color value.

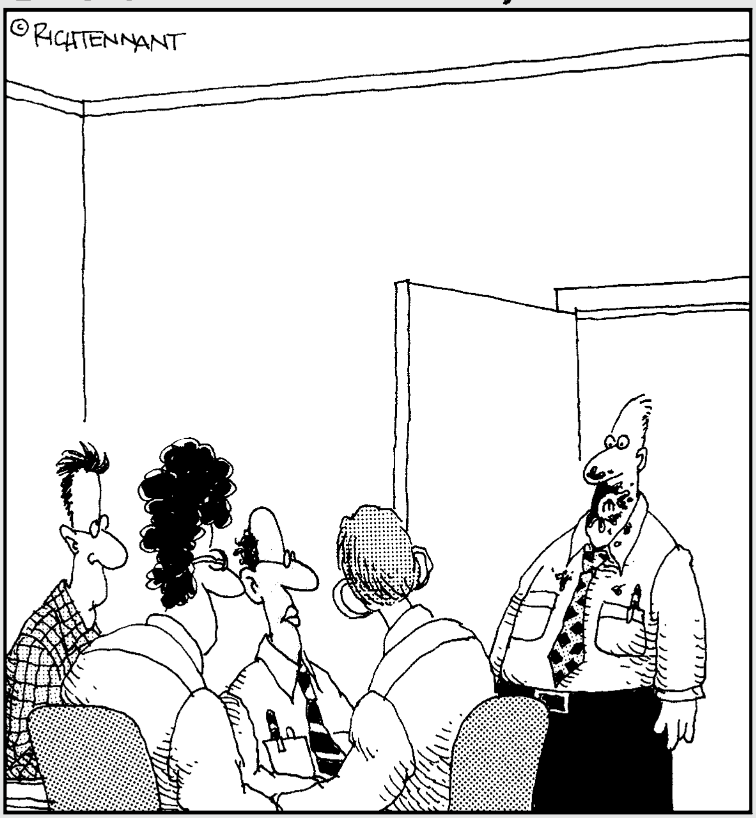
Some long-term things can also go wrong (also assignable causes) in a service environment:

- **Equipment breakdown:** Your computer crashes, preventing you from providing great customer service at the call center. The jet carrying the express mail needs unscheduled maintenance at the airport, thus making the deliveries late.
- **External forces:** Traffic jam patterns in certain geographical areas negatively impact the productivity of a trucking company. Inventory gets backlogged, and deliveries are late.
- **Health of service provider:** The lead litigator in a very important case becomes ill and can't perform his duties. His colleagues don't have the depth of knowledge and experience to maintain the momentum created.

This hard wall in the improvement path leads to the idea of entitlement. *Entitlement* is the level of variation that is naturally built into a process — the amount of variation you can expect from a process under the best conditions, when all the special causes are identified and eliminated. (Of course, you can see that this is just another name for short-term variation.)

Part III
DMAIC: Analyzing

The 5th Wave By Rich Tennant



"I ran an evaluation of our last pie chart. Apparently it's boysenberry."

In this part . . .

With a comprehensive collection of possible factors in hand, you can use the chapters of this part to objectively eliminate the factors that aren't important and to isolate those variables that are critical.

Chapter 10

Depicting and Analyzing Data through Charts and Graphs

In This Chapter

- Understanding the power inherent in basic charts and graphs
- Creating and analyzing variation and distributions through histograms or dot plots
- Comparing distributions with box and whisker plots
- Exploring variable relationships with scatter plots
- Using process behavior charts to see true performance

Data are the medium in which you, as a Six Sigma practitioner, work. Therefore, how you depict and analyze your data is critical.

The most important — and often the most powerful — tools for analyzing and communicating data are graphical; they display the nitty-gritty of what's going on in the company through pictures, charts, and graphs. These basic graphical tools, called *graphs* or *plots,* are much simpler to use than their strictly numeric counterparts (such as a table of raw data). Pictures of data often serve as a more intuitive way of gaining the same insights that you would from crunching numbers, and pictures make communicating your gained insight to others easy.

The chief purpose of plotting and charting data is to graphically show the central tendency and the spread of variation in a measured item of interest. You can accomplish this task in a couple of different ways; each has its advantages and disadvantages. In this chapter, we show you how to visually display your data through histograms or dot plots, box and whisker plots, scatter plots, and process behavior charts. You also figure out how to pick up on the signs and clues that the data give you when they're portrayed graphically.

REMEMBER

Using visual materials to communicate data is your best way of getting improvement team members to be integral parts of the Six Sigma breakthrough process. When team members can see the reality of performance for themselves, they're more motivated to contribute and participate in measurement and improvement efforts. Also, your visual pictures are an effective and essential prop for communicating your project details to management.

Checking Out Dot Plots and Histograms

Both dot plots and histograms give you lots of information about the variation of a critical characteristic in a process. A *dot plot* shows the scatter and grouping of a data from a single characteristic using (no surprise here) dots. A *histogram* takes the data from the dot plot and replaces the dots with bars. The following sections show you how to generate these helpful graphics and understand what the graphs are telling you.

Creating your own dot plots and histograms

After collecting measurements or data for a characteristic, create a *dot plot* for it by using the following steps:

1. **Create a horizontal line that represents the scale of measure for the characteristic.**

   This scale should be in whatever measure best quantifies the aspect of the characteristic you're interested in — for example, millimeters for length, pounds for weight, minutes for time, or number of defects found on an inspected part.

2. **Divide the horizontal scale of measure into equal chunks or "buckets" along its length.**

   Select a bucket width that creates about 10 to 20 equal divisions between the largest and smallest observed values for the characteristic.

3. **For each observed measurement of the characteristic, locate its value along the horizontal scale and place a dot for it in its corresponding bucket.**

   If another observed measurement falls into the same "bucket," stack the second (or third, or fourth) dot above the previous one.

4. **Repeat Step 3 until you've placed all the observed measurements onto the plot.**

To create a histogram (so that you can impress your peers with a graph that has a much more complicated-sounding name), replace each of the stacks of dots with a solid vertical bar of the same height as its corresponding stack of dots. ***Note:*** The vertical dimension on a dot plot or histogram is sometimes called *frequency* or *count* (refer to the following section). Because it's pretty straightforward, the label of the vertical scale is often left off the plot, which is why we don't include it in the process here.

Interpreting dot plots and histograms

A dot plot and its fancy cousin, the histogram, offer ready access to a wealth of information about the variation of a characteristic's performance. The following points are a few aspects of a dot plot or histogram to note:

- **Plot height**: The frequency — the height of dots or the bar — in a dot plot or histogram indicates how often the corresponding value on the horizontal axis was observed.
- **Variation shape:** The shape of the variation on a histogram comes in three basic flavors: normal, uniform, and skewed. Figure 10-1 shows a variation shape that is *normally* distributed, or bell-shaped. For a normal distribution, most of the observed values of the characteristic are close to a central point, with fewer and fewer values appearing as you get farther away from the central tendency.

  Figure 10-2 shows a uniformly distributed variation for a characteristic. With *uniform* distribution, the variation is evenly spread out across a bounded range. That is, you're just as likely to observe a value for a characteristic at one end of the interval as you are at the other, or anywhere in between. Figure 10-3 shows a skewed distribution shape. A *skewed* distribution is a variation shape that isn't symmetrical; one side of the distribution extends out farther than the other side.

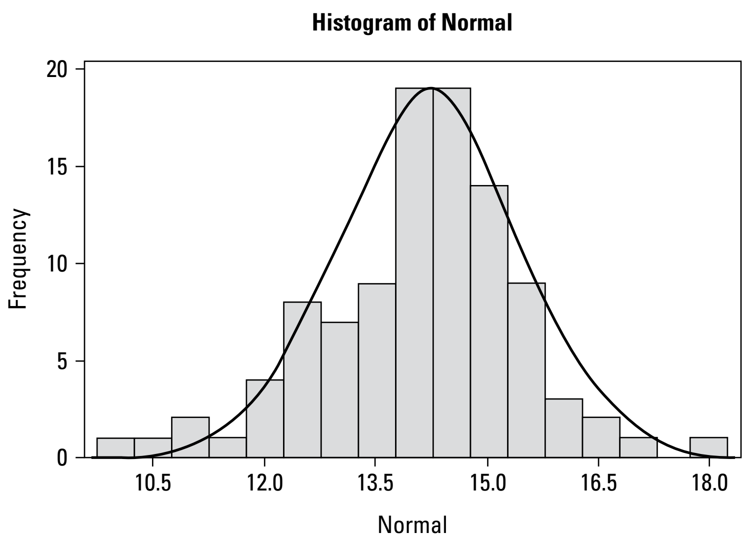


Figure 10-1: Histogram showing normally distributed variation.

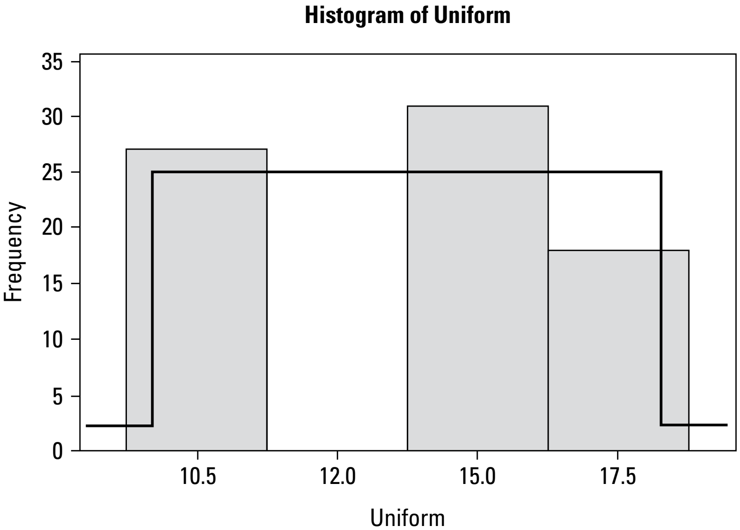


Figure 10-2: Histogram showing a uniformly distributed variation of a characteristic.

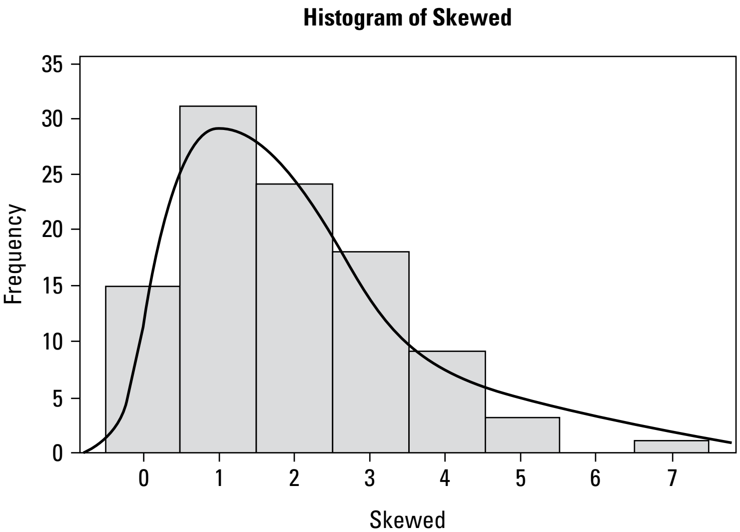
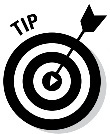


Figure 10-3: Histogram showing a skewed distribution.

- **Variation mode:** The *mode* of a distribution is its most often repeated value, or in other words, its peak. Usually, the variation in a characteristic has a single peak, as seen in Figure 10-4.

  But sometimes, a characteristic displays two or more modes, as shown in Figure 10-5, because two or more values dominate the variation. A histogram showing two or more distinct peaks is *multi-modal.* Multiple major peaks aren't usual; this situation typically means that a factor affecting the characteristic's performance is causing the entire system to behave schizophrenically.



When you encounter a multi-modal distribution, always dig deeper to discover what factor or factors are causing the characteristic's schizophrenic behavior.

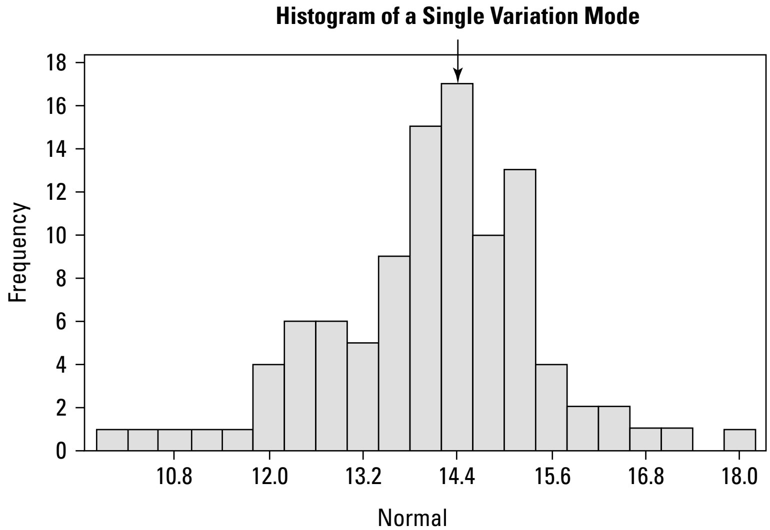


Figure 10-4: Histogram showing a single variation mode.

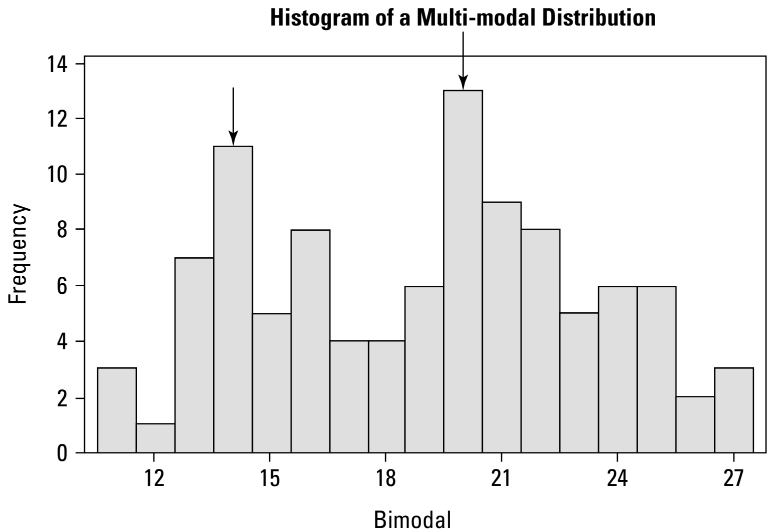


Figure 10-5: Histogram showing a multi-modal distribution.

- **Variation average:** A dot plot or histogram lets you visually estimate a characteristic's *mean,* or average value, without your having to crunch any numbers.

  Hold your index finger up against the horizontal axis of the dot plot or histogram and move the finger back and forth across the horizontal axis until you find the point where the middle knuckle balances your distribution equally on each side. Voila! This point is the approximate average value of the variation.

- **Variation range:** The extent or width of variation present in a characteristic is immediately recognized in a dot plot or histogram. The difference between the greatest observed value x_{MAX} and the smallest observed value x_{MIN} creates the *range* of the distribution. The symbol R always represents the range, which you calculate with the following equation:

  $$R = x_{MAX} - x_{MIN}$$

- **Outliers:** *Outliers* are measured observations that don't seem to fit the grouping of the rest of the observations. They're either too far to the right or too far to the left of the rest of the data for you to conclude that they come from the same set of circumstances that created all the other points.

  When you see an outlier or outliers on a dot plot or histogram, you immediately know that something is probably different about the conditions that created those points, whether it's the process's setup or execution or the way you measured the process.

  Investigate all outliers! Find out what caused their values to be so different from all the other observed values. Isolating the cause almost always leads you to discover which factors are abruptly changing the performance of the characteristic.

If you want to get more quantitative with your dot plots and histograms, you can use them to calculate the proportion of observations you've measured within an interval of interest or to predict the likelihood of observing certain values in the future. (Seeing into the future is definitely powerful stuff!)

Suppose you measure a characteristic 50 times. Counting and adding up what's in each of the buckets of your dot plot or histogram, you observe 17 measurements that occur between the values of 5 and 6. You can conclude, then, that 17 out of 50, or 34 percent, of your measurements ended up between 5 and 6. Now, peering into the future, you can predict that if the characteristic continues to operate as it did during the time of your measurements, 34 percent of future observations will end up being between 5 and 6! The casinos of Las Vegas thrive in business because they use statistics this way to know what will happen when you sit down for, say, a game of craps.

Comparing Distributions in Box and Whisker Plots

The problem with dot plots and histograms (see the earlier section "Checking Out Dot Plots and Histograms") is that they only allow you to effectively look at one characteristic's performance at a time. Like putting two people back-to-back to see who's taller, *box and whisker plots* (or just *box plots*) allow you to directly compare two or more variation distributions. When you need to compare value distributions for multiple characteristics, few things are quicker to make or easier to interpret than a box and whisker plot.

A box and whisker plot is made up of a *box,* which represents the central mass of the variation, and thin lines, called *whiskers,* that extend out on either side and represent the thinning tails of the distribution. Figure 10-6 shows an example of a box plot.

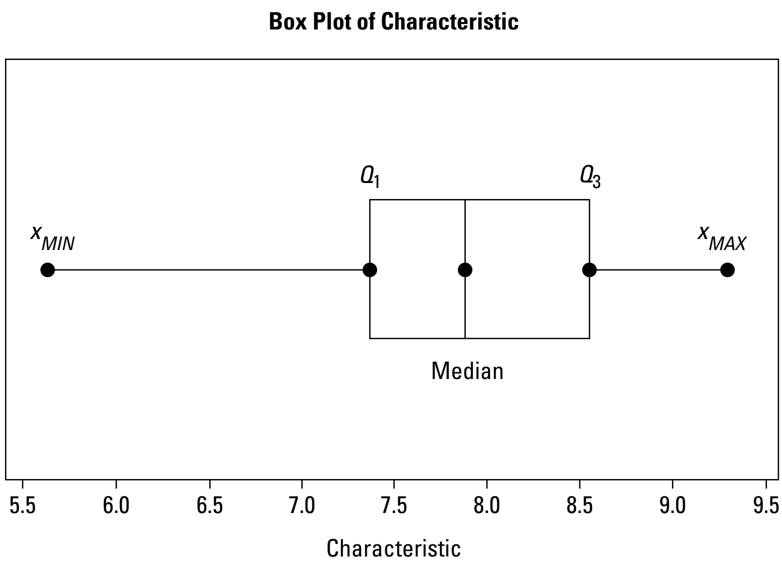


Figure 10-6: Box and whisker plot example.

Making your own box and whisker plot

To create a box and whisker plot, just follow these steps (and refer to Figure 10-6 for a visual):

1. **Rank the data measurements in order from least to greatest.**
2. **Determine the median of the data.**

   Find the observed value in the rank-ordered data where half of the data lies above and half lies below.

   - When the number of observed points (n) in your data set is odd, take

     $$\left[\frac{n+1}{2}\right]$$

     That value in the rank-ordered sequence is your median. For example, if n equals 99, take 99 + 1 = 100 and then divide that result by 2 to get 50. The 50th number in your list is the median.

   - When n is even, the median is the average of the

     $$\left[\frac{n}{2}\right]$$

     and the

     $$\left[\frac{n}{2}+1\right]$$

     values in the rank-ordered sequence. If n = 100, you'd find 100 ÷ 2 and (100 ÷ 2) + 1. Those expressions give you 50 and 51, so you'd find the 50th and 51st values and average them to find the median.

3. **Find the first quartile, Q1.**

   The *first quartile* marks the 25-percent point in your rank-ordered sequence; three-quarters of the data are yet to come.

4. **Find the third quartile, Q3.**

   The *third quartile* is the 75-percent point in your rank-ordered sequence; one-quarter of the data is left.

5. **Find the largest observed value, x_{MAX}, and the smallest observed value, x_{MIN}.**
6. **Draw a horizontal line, representing the scale of measure for the characteristic.**

   This scale can be in millimeters for length, pounds for weight, minutes for time, number of defects found on an inspected part, or anything else that quantifies what aspect of the characteristic you're interested in.

7. **Mark your median and quartile values from Steps 2 through 4 and construct the box.**

   Make points for your median and quartile values. Draw a box spanning from the first quartile (Q_1) to the third quartile (Q_3) and draw a vertical line in the box corresponding to the median value.

8. **Add the minimum and maximum values from Step 5 and construct the whiskers.**

   Draw two horizontal lines, one extending out from the Q_1 value to the smallest observed observation, x_{MIN}, and another extending out from the Q_3 value to the greatest observed value, x_{MAX}.

9. **Repeat Steps 1 through 8 for each additional characteristic to be plotted and compared against the same horizontal scale.**

   Figure 10-7 in the following section shows a scale with multiple box plots.

TIP

When you have a large set of data for a characteristic, you may want to extend the whiskers out to only the 10th and 90th percentiles, or to the 5th and 95th percentiles and so on, rather than to the maximum and minimum values. Then when outlier data points fall beyond these ends of the whiskers, you can draw them as disconnected dots or stars. This method is a great way of graphically identifying and communicating the presence of outliers in your data.

Making sense of box and whisker plots

Box and whisker plots are ideal for comparing two or more variation distributions, such as before-and-after views of a process or characteristic or alternative ways of conducting an operation. Essentially, when you want to quickly find out whether two or more variation distributions are different (or the same), you create a box plot. Figure 10-7 is an example of using box plots to compare distributions *A, B,* and *C.*

In Figure 10-7, distribution *B* clearly has the lowest level. But it still overlaps the performance of distribution *A*, indicating that it may not be that different. Distribution *C*, on the other hand, has a much higher value and no overlap with distributions *A* and *B*. It also has a much broader spread to its variation.

Other things to look for in comparative box plots include the following:

- Differences or similarities in location of the median
- Differences or similarities in box widths
- Differences or similarities in whisker-to-whisker spread
- Overlap or gaps between distributions
- Skewed or asymmetrical variation in distributions
- The presence of outliers

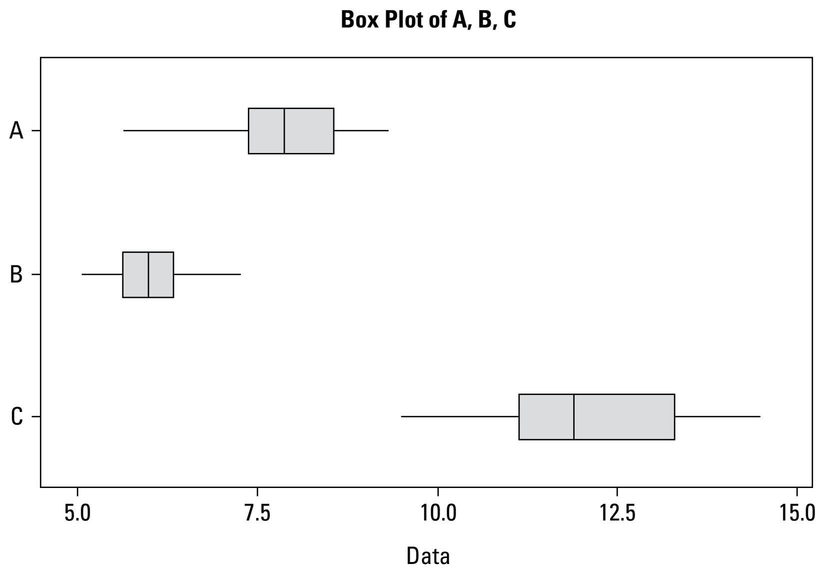


Figure 10-7: Graphical comparison of three variation distributions, using box and whisker plots.

Making Connections with Scatter Plots

Dot plots, histograms, and box plots (see the preceding sections) chart only one characteristic at a time. Often, you need to explore the relationship between two characteristics. To do so, you use a scatter plot. Scatter plots get their name from their appearance — a scattered cluster of dots on a graph.

Scatter plots are a simple yet extremely powerful tool you can use to explore and quantify the relationship between two or more characteristics. Scatter plots start to get to the root of how certain variables impact other variables — how certain inputs either inhibit or enhance your ability to create your desired outcomes. This analysis is really the start of getting to the fundamental $Y = f(X) + \varepsilon$ relationship at the heart of Six Sigma improvement.

Developing a scatter plot

The key to creating a scatter plot is in capturing the measurement data. To investigate the relationship between two characteristics, you need to capture measurements from the two characteristics simultaneously. If you're interested in exploring the relationship between characteristics *X* and *Y*, at each point of measurement, you have to collect and record values for *X* and *Y*.

REMEMBER

The two characteristics you're plotting can be two inputs; one can be an input and the other can be an output; or they can be two outputs. As long as you make your measurements simultaneously, whether they're inputs or outputs doesn't matter.

With this simultaneous data collected, you're now ready to create a scatter plot:

1. **Form points from the collected data.**

   At each of the measurement times, pair the simultaneously measured values for the two characteristics together to form an (*x, y*) point that can be plotted on a two-axis graph.

2. **Create a two-axis plotting framework.**

   Create two axes, one horizontal and the other vertical, with each being assigned to one of the two characteristics under investigation.

   The scale for each axis can be in millimeters for length, pounds for weight, minutes for time, number of defects found on an inspected part, or anything else that quantifies what aspect of the characteristics you're interested in.

3. **Plot each formed point on the two-axis framework.**

Figure 10-8 shows a sample set of simultaneous measurement data and a corresponding scatter plot.

Scatter plots can also be created when one of the characteristic data types isn't measured on a continuous scale but fits into discrete categories. For example, the characteristic of sales volume (measured on the continuous dollar scale) can be plotted against marketing plans 1 and 2 (measured by two discrete categories). Figure 10-9 shows an example of this type of category data scatter plot.

Time	X_3	Y
1	2.02	5.75
2	1.97	6.16
3	1.67	7.21
4	1.99	5.85
5	2.04	5.79
6	2.19	5.11
7	2.16	5.00
8	2.04	5.58
9	2.05	6.04
10	2.06	5.82
11	1.88	6.78
12	2.01	5.89
13	1.96	6.28
14	2.22	5.36
15	2.12	5.40
16	2.05	5.84
17	1.80	6.76
18	1.83	6.91
19	1.94	6.70
20	1.96	6.13
21	1.96	5.71
22	2.31	4.50
23	1.85	6.83
24	2.34	4.46
25	1.83	6.96
26	1.64	7.87
27	2.21	4.96
28	1.98	6.25
29	1.56	7.65
30	2.30	4.59

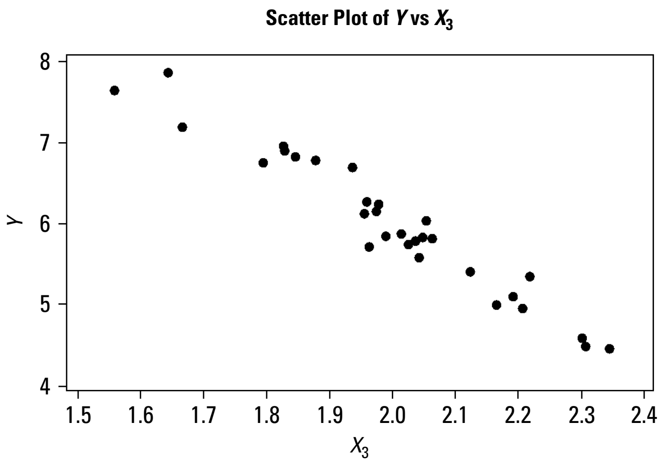


Figure 10-8: Scatter plot with output characteristic *Y* plotted against input characteristic X_3.

Drawing correlations from a scatter plot

A scatter plot tells you graphically how two characteristics are related, or *correlated.* You can then use this correlation information to explore which factors and outputs affect each other and in what way. The following sections detail the correlation factors you should be on the lookout for in a scatter plot.

Assessing the amount of correlation

The *amount of correlation* in a scatter plot is determined by how closely or tightly the plotted points fit a drawn line. If two characteristics aren't related, the scatter plot of the two should appear as a random cloud or scattering of points like the one in Figure 10-10. Unrelated characteristics show no pattern, trend, or grouping among the plotted points.

On the other hand, when two characteristics are related, a pattern, trend, shape, or grouping in the plotted points emerges in the scatter plot. When you can naturally fit a drawn line to a set of plotted points, as in Figure 10-11, you know that the characteristics are correlated. For example, Figure 10-11 shows the earlier scatter plot of Figure 10-8 with an overlaid line to highlight the trend.

If a line can only loosely fit the plotted points, the characteristics have only a slight relationship. However, if the plotted points are tightly clustered around a line, the characteristics are highly correlated.

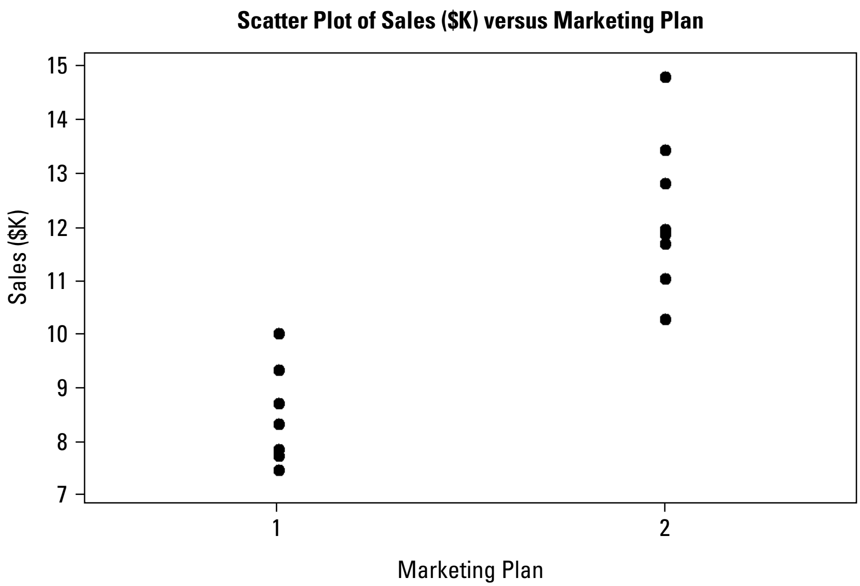


Figure 10-9: Scatter plot sample for category data.

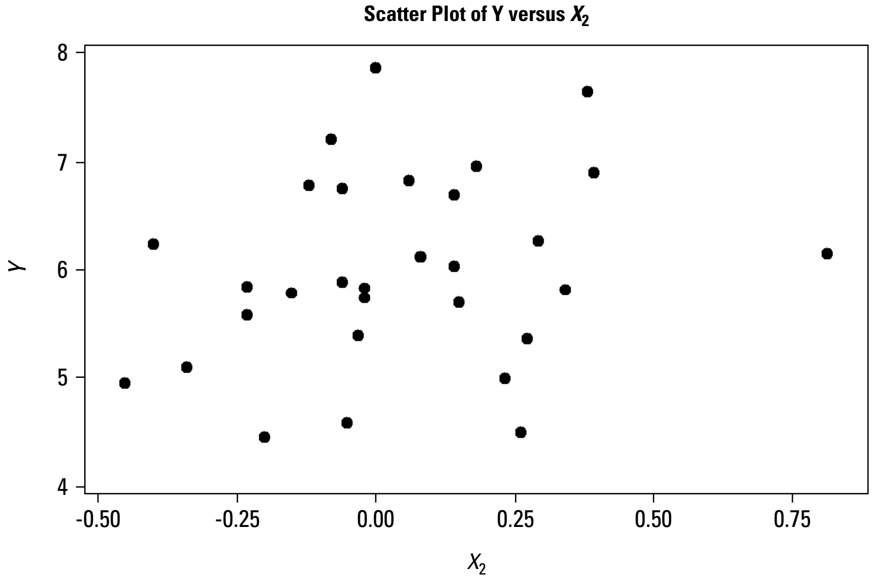


Figure 10-10: Scatter plot example of two characteristics *Y* and X_2 that aren't related.

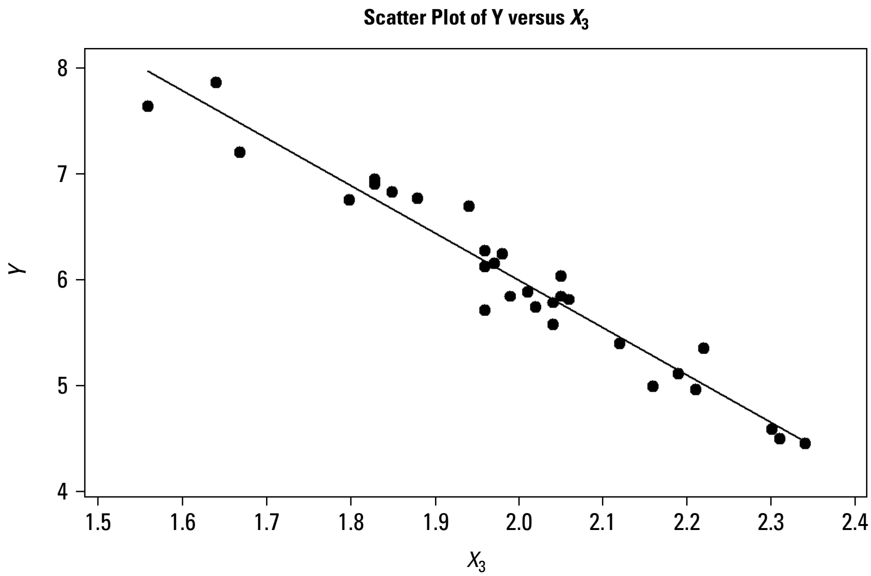


Figure 10-11: Scatter plot showing correlation between characteristics *Y* and X_3.

REMEMBER

Of course, the reason you should be concerned with how closely certain input and output characteristics are related is that you're trying to find operational leverage (which we discuss in Chapters 3 and 17.) You're looking for the factors or variables that can positively influence your desired performance improvement outcome as defined by your project objective statement, and the amount of correlation is a key indicator of this relationship.

TIP

How closely clustered do the scatter plot's points need to be before you have evidence of significant correlation? A good rule of thumb is the *fat pencil test.* Imagine laying a fat pencil on top of the drawn line fitting the plotted points. If the pencil body covers up the plotted points, it passes the test, and you can conclude that the correlation between the two characteristics is enough to call it significant.

Dealing with direction of correlation

Direction of correlation comes in two types: positive and negative. Two characteristics are *positively correlated* if the relationship indicates that an increase in one characteristic translates into an increase in the other. Figure 10-12 shows a scatter plot with a positive correlation between two characteristics.

Two characteristics are *negatively correlated* if the relationship indicates that an increase in one characteristic translates into a decrease in the other, and vice versa. The earlier Figure 10-11 shows a scatter plot with a negative correlation between two characteristics.

Surveying strength of effect

Scatter plots also graphically show the strength or magnitude of the effect one characteristic has on the other. Two characteristics may be strongly correlated (see the earlier section "Assessing the amount of correlation"), but a large change in one characteristic may still lead to only a small change in the other. Alternatively, a small change in one characteristic can be magnified as a large change in the other.

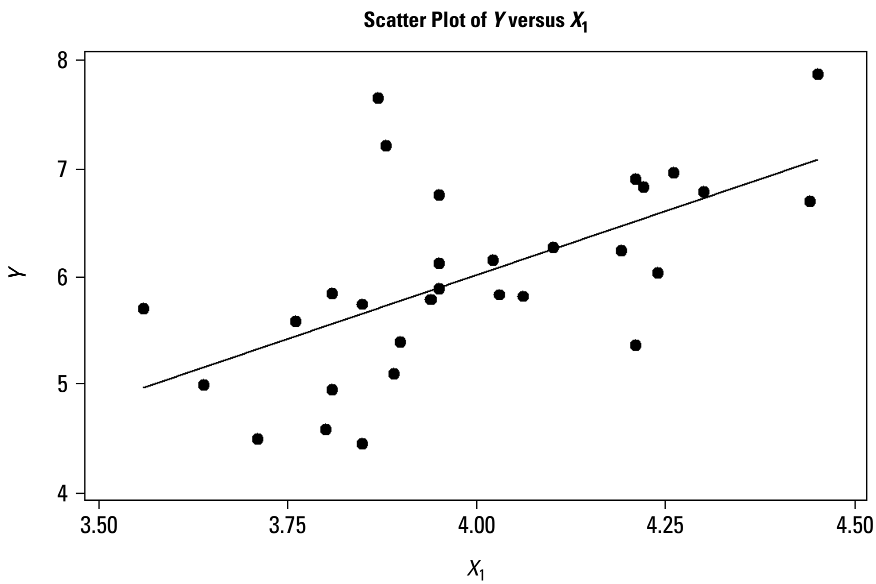


Figure 10-12: Scatter plot showing positive correlation between two characteristics.

The way to visualize this strength of effect between two characteristics is to look at the slope of the line fitted to the scatter plot points. Figure 10-13 shows three scatter plots, one for each of three input characteristics' effects on an output characteristic *Y*. The steepness of the slope of the fitted lines determines how strong an effect the input has on the output. (Hint: Steep slopes mean strong effect.)

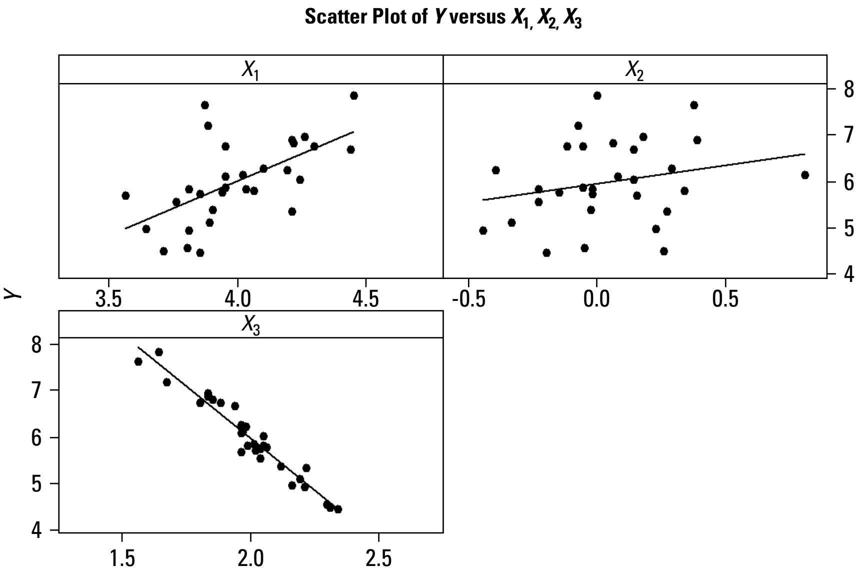


Figure 10-13: Showing the strength of effect for each input characteristic X_1, X_2, and X_3 against a single output characteristic *Y*.

The *slope* of a line is how steep it is. The slope is quantified mathematically by comparing how much the line climbs to how much it runs across between two points. This comparison is formed from a ratio of *rise* to *run*. For example, given two points on a line (x_1, y_1) and (x_2, y_2), you calculate the slope with the following equation:

$$\frac{rise}{run} = \frac{y_2 - y_1}{x_2 - x_1}$$

If the calculated slope is zero, the line is horizontal or flat. A negative slope means that the line slopes down from left to right, and a positive slope indicates a line that slopes up from left to right.

As the calculated slope value gets farther away from zero (either positively or negatively), the steepness of the line increases. When you get to a slope of positive infinity or negative infinity, you have yourself a vertical, straight up-and-down line.

In Figure 10-13, you can compare the slopes of the fitted lines for each input characteristic X_1, X_2, and X_3 to the output characteristic *Y*. The scatter plot showing a correlation with the greatest slope indicates the greatest impact or effect on the output. So in Figure 10-13, characteristic X_3 has the greatest effect on the output *Y*. In other words, you'd have to modify input characteristic X_3 the least to get a one-unit change in the output *Y*. X_3 is the largest point of leverage among the input characteristics. When you use a scatter plot to determine the strength of effect one characteristic has on another, the graph is often called a *main effects plot*. You can read a lot more about main effects plots in Chapter 18.

Hindsight Is 20/20: Observing Process Behavior Charts

The dot plots, histograms, box plots, and scatter plots we discuss earlier in the chapter all ignore a critical element: time. None of these graphical methods takes into account the order in which the measured data are observed. Time/order can be a critical factor, especially when you're trying to figure out the causes behind variation and changes in process behavior.

Under *normal* conditions, a process or characteristic should behave *normally*. This statement is more profound than it sounds. The performance of every process or characteristic has natural variation. A *behavior chart* graphically shows how that variation plays out over time. The following sections help you build and analyze these charts.

Creating a characteristic or process behavior chart

To investigate the behavior of a characteristic or process, plot your observed measurements one at a time along an axis representing time or order, in the exact sequence the measurements occurred in real life.

To create a characteristic or process behavior chart, follow these steps:

1. **Create a horizontal scale representing time or order.**

   You usually do so by creating an axis for the order in which the measurements occurred, called their *run order*.

2. **Create a vertical axis representing the scale of measure for the characteristic.**

   This scale can be in millimeters for length, pounds for weight, minutes for time, number of defects found on an inspected part, or anything else that quantifies what aspect of the characteristic you're interested in.

   Set the maximum and minimum values on this vertical scale just slightly larger and slightly lower than the maximum and minimum observed data values, respectively. That way, you won't have some of your process data disappearing off the edge of your chart.

3. **Plot each observation as a dot, using its order and measurement.**
4. **Connect the dots.**

   Draw a line between each sequential point to emphasize the change that occurs between observations.

Figure 10-14 shows an example of a behavior chart for the completion time of an assembly process.

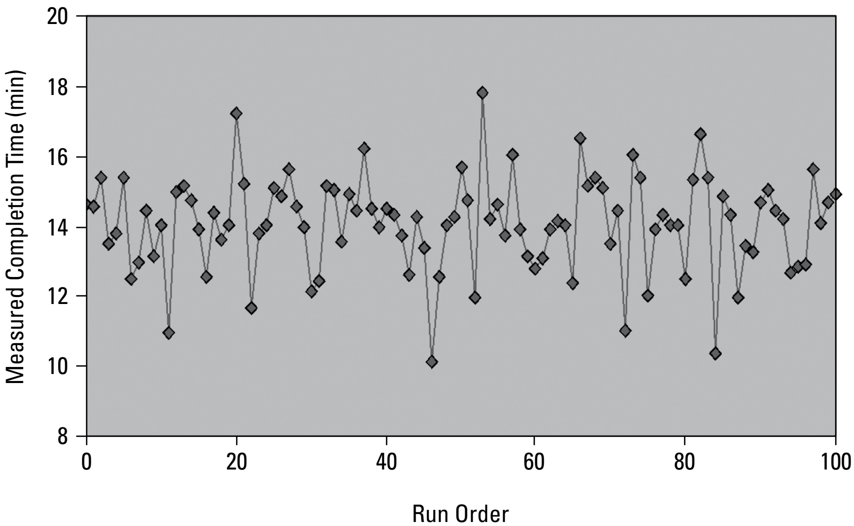


Figure 10-14: Characteristic or process behavior chart example.

Interpreting characteristic or process behavior charts

A behavior chart not only allows you to see the normal behavior of a process or characteristic but also lets you quickly detect *non-normal* behavior — variation above and beyond the expected normal level. The causes of non-normal behavior are the assignable or special causes that erode and degrade entitlement performance over the long term (more on special cause in Chapter 9). Behavior charts form the foundation of detecting and finding the root cause of non-normal behavior.

Like in Figure 10-14, a process or characteristic has variation that bounces around a central, horizontal level on the behavior chart. Most of the observed variation clusters close to this central level. However, every now and then you see values that are farther away from the center. The variation of these exceptions is completely random over time, without patterns or trends. This type of behavior is the definition of *normal* and is analogous to the entitlement level of variation covered in Chapter 9.

The following sections present important observations for when you're looking at process and characteristic behavior charts.

Variation beyond expected limits

Outliers are measurement observations that occur beyond the limits of the normal short-term variation you expect out of the process or characteristic.

Observing an outlier is like rolling five doubles in a row with a pair of dice. Five doubles in a row is possible but not common; when that roll happens, you suspect that something out of the ordinary is at play, such as maybe a loaded pair of dice. (In this case, "loaded" is just another way of saying the dice are acting non-normally.)

Figure 10-15 shows a behavior chart with variation outside the expected levels.

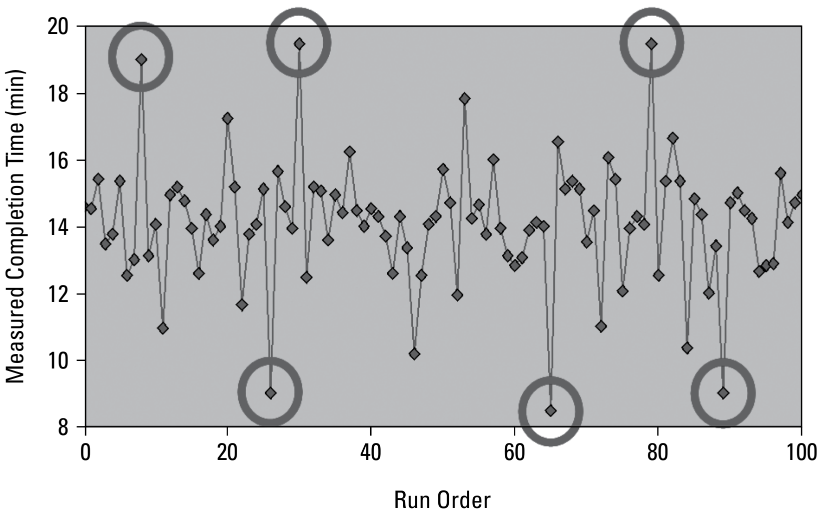


Figure 10-15: Behavior chart showing evidence of variation beyond the expected normal limits.

When you see such excessive, non-normal variation, use the time scale or run order of the behavior chart as a starting point for investigating what conditions or factors are at fault. What was different at that point in time to take the characteristic or process behavior out of its normal course? The answer allows you to identify and manage the factor or factors influencing the process or characteristic performance.

Typical causes of outliers include worker inattention, measurement errors, and other one-time changes to the process's or characteristic's environment. For example, you may have a data outlier for purchase order processing due to an emergency in the office where two workers had to leave at the same time, or a purchase order in the queue for an excessive period of time because no one was around to take care of it.

In Chapter 20, you find out much more about detecting evidence of this type of special-cause variation in the performance of your process or characteristic.

Trends

A *trend* is a steady, gradual increase or decrease in the central tendency of the process or characteristic as it plays out over time. If all the conditions in the system stay constant, the level of performance of the process or characteristic also stays level. The presence of a trend in a graphical behavior plot is evidence that something out of the ordinary has happened to move the location of the process or characteristic behavior. Figure 10-16 shows a sample of a trend in the location of the variation center over time in a process behavior chart.

Just like with any other evidence of non-normal behavior, when you see a trend in a behavior chart, you need to look more closely at the system to uncover what is causing the changed performance.

Trends in performance are almost always caused by system factors that gradually change over time, such as temperature, tool wear, machine maintenance, rising costs, and so on.

Runs

A *run* is a sequence of consecutive observations that are each increasingly larger or smaller than the previous observation. Figure 10-17 shows an example of two runs, one increasing and one decreasing, within a behavior chart. Runs can be caused by faulty equipment, calibration issues, and cumulative effects, among other things.

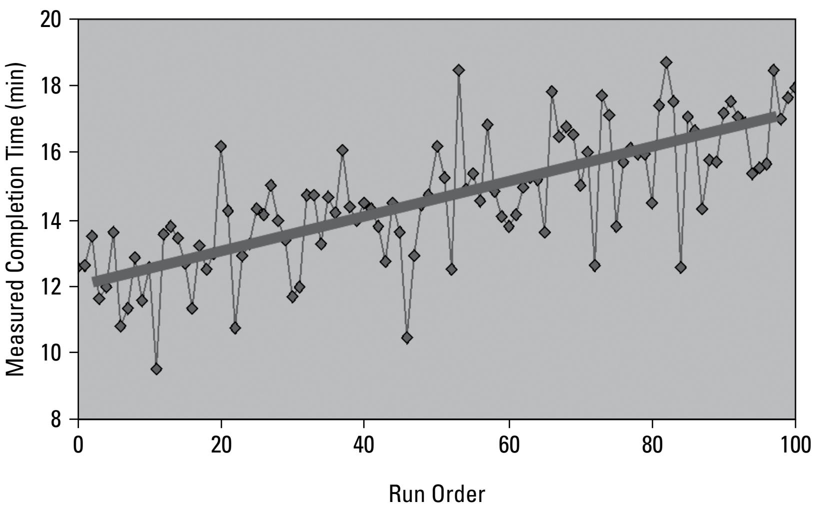


Figure 10-16: Behavior chart with evidence of a trend.

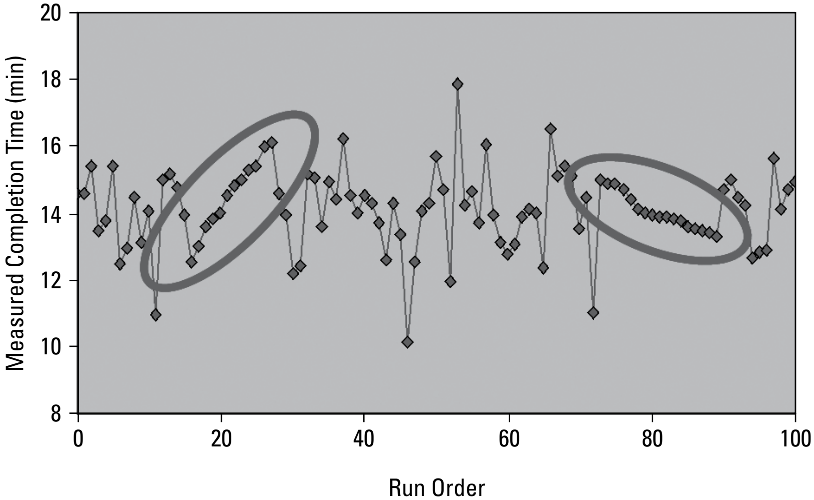


Figure 10-17: Behavior chart with evidence of a run.

Shifts

Shifts are sudden jumps, up or down, in the process's or characteristic's center of variation. Something in the system changes permanently — a piece of equipment, a new operator, a change in material, a new procedure, or whatever — to cause these modifications. Shifts are clearly non-normal behavior.

Figure 10-18 shows an example of a process or characteristic that has experienced a shift in the center level of its variation.

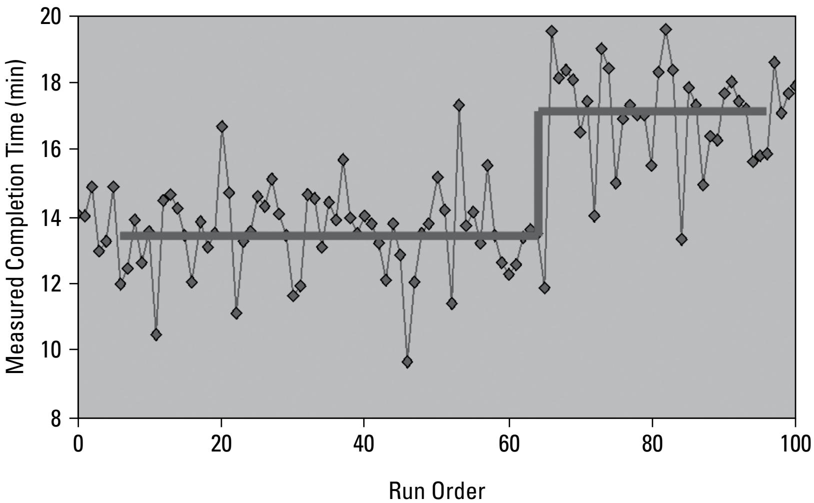


Figure 10-18: Behavior chart with a non-normal shift.

Chapter 11

Analyzing for Value

In This Chapter

- Defining true customer value
- Analyzing customer satisfaction
- Pinpointing waste and its seven forms
- Building cause-and-effect matrices to analyze factors leading to value
- Using Failure Mode Effects Analysis (FMEA) to analyze for value

Every company wants to advertise that it delivers good value. The promise of value is what prompts customers to buy products or services. Yet delivering true value to customers is too often a hit-and-miss proposition for businesses because most people think of value in vague terms, without a precise, fixed definition.

This chapter gives you a working definition of value that's used by the companies that consistently deliver the greatest value to their customers. You also find tools for detecting value and determining what input factors lead to true value for customers.

Understanding and Achieving Value: It's Customer-Driven

Most companies want to meet their customers' needs. They want customers to express both a strong demand for and a great satisfaction with their work.

Don't assume you know what your customers want. That's a dangerous proposition because more often than not, you'll be wrong. Instead, do what the best companies do: Suspend your own ideas and let customers themselves tell you what's valuable to them.

The set of product or service features that customers truly desire — whether they explicitly express them or even consciously know them — is called the voice of the customer (VOC). Customers decide what they want; your job as the producer is to listen to the VOC (if you want to be successful, that is).

In Six Sigma companies, the voice of the customer is captured and cherished as the driving North Star in improvement. In this section, we introduce you to what value really means and give you the how-to on hearing the VOC loud and clear.

Ascertaining value

Your customer is the final authority on what is and isn't valuable, but gauging whether you're on the right track — whether the improvements or changes you're making lead to greater customer value — can be tricky.

In Six Sigma jargon, you classify a feature or process step that truly adds value from the customer's perspective as *value add.* Features or process steps that do not add value are simply called *non-value add* or sometimes NVA.

A set of three simple criteria always reveals whether some feature or task has value:

- Does the process step, task, or feature in question change the form, fit, or function of the item being created for the customer?
- Is the feature created correctly, or is the process step or task performed correctly the first time?
- Is the customer willing to pay for the process step, task, or feature?

Unless the process step, task, or feature in question generates a "yes" answer to all three of these questions, you characterize it as non-value add. And if it's not adding value, it must be waste. For more on waste, head to the following section.

As you begin to analyze your process or product, simply review each process step or feature and ask these three value questions. You quickly find that much, if not most, of what you do is non-value add, or waste.

REMEMBER

Just because you categorize a process step or feature as non-value add doesn't mean you *must* eliminate it. Steps and features identified as non-value add should always be candidates for elimination, but often — because of important regulatory reasons or requirements — you can't actually remove them. For example, if you are a material supplier, some of your customers may require you to hold a certain amount of finished goods inventory as part of your sales agreement. You wouldn't hold that inventory otherwise, and you may feel that doing so is unnecessary and represents waste. But you don't have a choice, so inventory reduction below your customer's requirements wouldn't be a good candidate for a waste reduction project.

Similarly, removing non-value add steps isn't the only place for improvement. Process steps that you've determined add value can always be improved from their current levels of efficiency. That endeavor is the focus of most of this book and of Six Sigma itself.

Waste not: Defining the seven forms of waste

When a step, task, or feature fails to satisfy all three questions in the preceding section, you classify it as waste. All the non-value adding waste in a process or product falls into one or more of seven distinct categories. Knowing these categories is a great help when you're analyzing your process or product and looking for opportunities to make improvements.

TIP

Six Sigma practitioners use various acronyms to help them remember the seven types of waste. Our favorite is TWO-DIME. (Who could ever forget that?) Here's how it breaks down:

- **T: Transportation:** When parts, material, or information must be moved to continue a process, you know waste has entered your system. One of the criteria for adding value is a change in the form, fit, or function of the item; transportation by itself definitely doesn't meet that description, so immediately you know that this activity must be waste.
- **W: Waiting:** Whenever a person, a part, a material, information, or equipment sits idle without something being done to it, it's waiting. (The aging of cheese or wine is an exception because those items are in fact changing molecular form over time.) Waiting doesn't add value, so it's wasteful.
- **O: Overproduction:** *Overproduction* occurs when, in anticipation of a future need, you purposely produce more of an item than is presently needed. The problem with overproduction is that it always creates other waste such as waiting or inventory (see the later bullet). Even though getting ahead is tempting, overproducing typically creates more waste than it's worth.
- **D: Defects:** Producing a defective item means you have to rework or scrap it. Not only is the original effort waste, but you also have to expend extra resources to remake the item.
- **I: Inventory:** Raw materials in storage, items in-process on the production line, backlogs of information, and finished goods waiting to be shipped are all *inventory.* These items do not bring value to the customer by taking up space and consuming resources to maintain. They do not fit the three value criteria questions, so inventory is, by definition, waste.
- **M: Motion:** A process that requires people or equipment to move or walk more than is minimally required to produce a product, feature, and so on is waste.
- **E: Extra processing:** When you perform more work on an item than is needed, you're creating *extra processing,* which is a kind of waste.

Memorize this list. Then, as you carefully watch, analyze, and work within processes, you can begin to recognize waste in all its specific and myriad forms.

Figure 11-1 shows an example of a process flow map for a pizza delivery process. Process steps that do not add true value are labeled NVA.

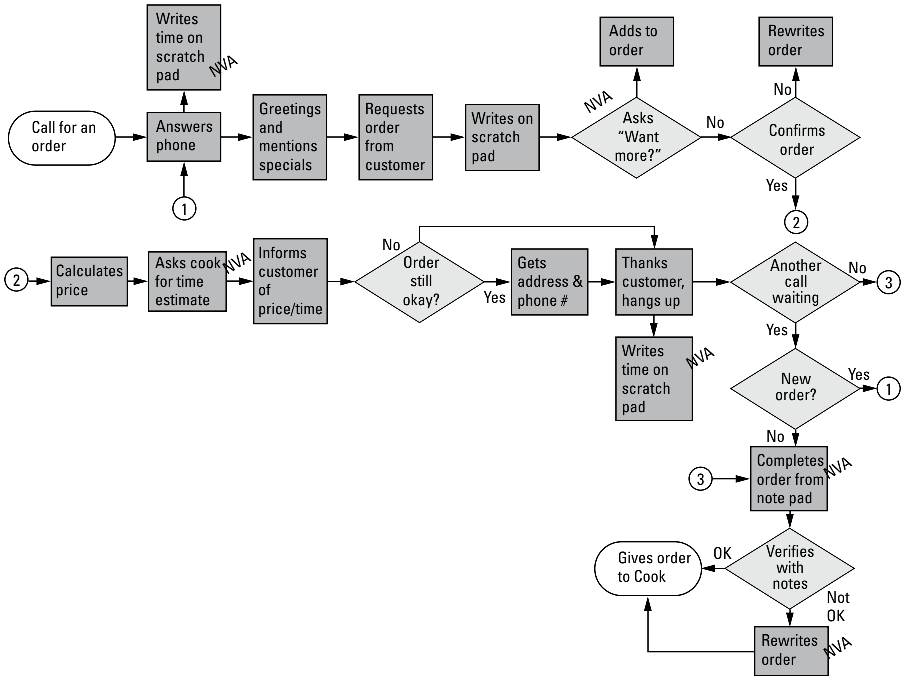


Figure 11-1: A process flow map with NVA highlighted.

Value analysis like that shown in Figure 11-1 is extremely simple yet incredibly powerful in helping identify where improvements can be made. Never neglect this powerful tool.

Kano's framework: Hearing the voice of the customer

Yes, your customer has a voice. But that doesn't mean it's speaking in a language you understand! You need some tools to decipher what the customer is saying.

Noriaki Kano is a Japanese engineer and quality professional who developed a now-famous model for characterizing the various requirements from your customer. Kano believed that not all customer requirements are created equal. Some create higher levels of customer satisfaction than others, as shown in Figure 11-2.

In Kano's model, the horizontal axis represents the level to which you meet a customer requirement. The more you fulfill the requirement, the farther you are to the right of the axis; the less you fulfill it, the more you are to the left.

The vertical axis represents the degree of satisfaction the customer experiences from how well or completely you meet the requirement. In the middle of this vertical customer satisfaction axis is a neutral point where the customer is neither satisfied nor dissatisfied by your performance.

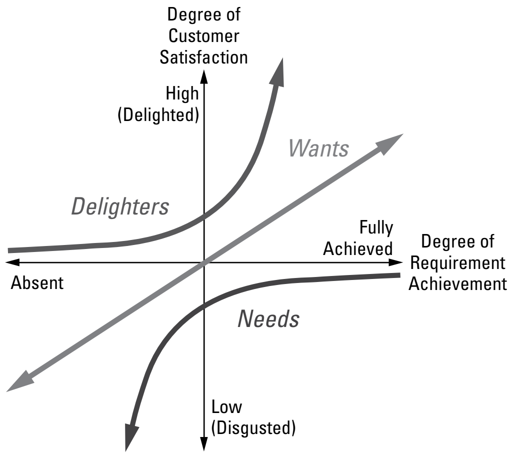


Figure 11-2: Kano's model of customer satisfaction.

Kano reasoned that customer requirements fall into three categories, which are also shown in Figure 11-2:

- **Needs:** *Needs* are expected requirements that the customer assumes will be in your product or process; they're such a given that even when you fully achieve them, the customer's satisfaction is only neutral (that is, no one gives you an extra pat on the back for performing to the base level of expectation). When you don't fully achieve this type of requirement, the customer is dissatisfied.
- **Wants:** These one-dimensional requirements are the stated requirements from the customer. The customer is either satisfied or dissatisfied in direct proportion to how fully you achieve or fail to achieve these requirements.
- **Delighters:** Exciting requirements, or *delighters,* are those expectations that the customer hasn't anticipated and may not even be aware of. Failing to deliver them doesn't cost you because the customer wasn't expecting them. But as you identify and deliver on these requirements, even to a small degree, you quickly satisfy the customer, perhaps to the point of surprising and impressing him or her. Identifying and achieving delighter characteristics is critical to business success because they're innovative and differentiate you from your competition.

Kano's model helps you evaluate the set of requirements from your customer and understand what mix of performance on these requirements will delight the customer overall. This knowledge puts you in control of differentiating your company from competitors and can lead you to great market success.

Analyzing Process Flow for Value: Introducing Take One, Make One

A process where material and information flow continuously is one that has minimal waste, so one way to identify waste and improve value is to look for disruptions to flow. Here are some indicators of poor flow:

- Materials, products, or information being processed or moved in batches
- Bottlenecks that choke the flow of a process
- Stops and starts in the flow of the process
- Uneven pacing of items through the process
- Physical movement of items back and forth across a process
- Differences or exceptions in the sequence or pacing of items through the process
- Staging or prepping of batches of items for a subsequent step

As an example of perfect flow, and thus perfect value, imagine standing in the bakery aisle at the supermarket. As you pick a loaf of bread from the shelf, a freshly baked loaf immediately replaces the one you took. The act of you, the customer, purchasing a loaf of bread automatically signaled the producer to make a new loaf. Under this theoretical ideal, the customer always gets the freshest loaf possible, the producer carries no wasteful inventory, and no waiting or transportation delays occur. This setup is the imaginary image of a perfectly configured process.

This perfect *take one, make one* ideal, as it's sometimes called, stems from a philosophy of *single piece production flow.* The opposite of single piece flow is *batch processing,* where multiple items are advanced through process steps together. Unlike single piece flow, batch processing always creates waste. For example, the first items processed through each step have to wait as the rest of the batch catches up. Batches waiting for the next step create inventory. Changes or mistakes mean an entire batch may have to be scrapped. And so on.

REMEMBER

Anything that disrupts single piece production flow always creates waste. You may not see the waste at first, but with careful eyes, you can always find it.

Your goal should be to configure your process so that it is as close to the ideal of take one, make one as possible. That's the start of your improvement journey. Then every day thereafter, seek to improve your process to be that much closer to the ideal.

Considering Cause-and-Effect (C&E) Analysis

The Pareto principle, which we cover in Chapter 3, indicates that not all factors have an equal effect on process or product outputs — and that, in most cases, only one or two factors account for nearly all the influence on process and/or product outcomes.

A *cause-and-effect matrix* — sometimes called a *C&E matrix* for short — helps you discover which factors affect the outcomes. It provides a way of mapping out how value is transmitted from the input factors of your system (the *X*s) to the process or product outputs (the *Y*s). With these relationships visible and quantified, you can readily discover the most-influential factors contributing to value — the ones that are truly critical.

Laying out the matrix

The method employed in a C&E matrix may look familiar because it's the basis for many familiar ranking and decision-making tools. The C&E method starts by listing all the possible input factors (the *X*s) as individual rows of the matrix.

This listing of inputs should come from a previously completed process flow map or value stream map (both covered in Chapter 7) or a fishbone diagram (Chapter 8). Using these tools before doing a C&E matrix allows you to make a comprehensive list of potential input factors without the limitations of bias or opinion.

Next, list the multiple outputs (the *Y*s) of the process or product across the columns of the matrix. Sometimes you have only a single output, but you usually have to simultaneously achieve several outputs, such as a performance level, a cost target, and a maximum cycle time.

With the inputs placed on the rows and the outputs listed as column headings, the C&E matrix looks like Figure 11-3.

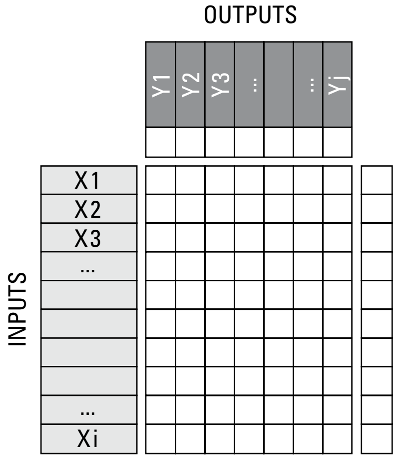


Figure 11-3: The laid out C&E matrix with inputs (the *X*s) on rows and outputs (the *Y*s) as columns.

Adding some weight

With the basic matrix constructed, give each listed output a weight score based on how important that output is to the customer. Weight scores range from 1 to 10, with 10 indicating extreme importance and 1 indicating insignificance. List these weight scores in each column, immediately below the column name.

Next up is the relationship score — the heart of the C&E matrix. Analyze and quantify the relationships between each listed input and each output by placing a relationship score (on a scale of 0 to 9) at the matrix intersection of each row and column. Strong cause-effect relationships are scored as 9s; moderate cause-effect relationships get 3s; weak relationships are 1s; and having no relationship means a score of 0. For each matrix row-column intersection, ask yourself whether the associated input affects the level of variation in the associated output. Then place the appropriate score in the matrix cell. This process is shown in Figure 11-4.

In Figure 11-4, the intersection of X3 and Y3 is highlighted in black to illustrate how each row-column intersection is considered individually to score how strong of a relationship exists between the corresponding *X* and *Y*. In this example, it's a *3* — a moderate correlation.

Figuring the final score

With the scoring of the matrix completed, summarize the results by calculating the weighted score for each row. Go to each row and multiply the first matrix cell score by the first column weight; add that result to the second matrix cell score and multiply the result by the second column weight, and so on, adding up the weighted scores for the entire row. Place this weighted row sum in the far right column of the C&E matrix, as shown in Figure 11-5. (In this example, the sum of all the entries in the X3 row, multiplied by their column weights, would equal 54.)

The final step is to apply Pareto analysis to the scores for each row. Those rows with high scores are the ones that indicate important, high-leverage input factors. You can effectively ignore the low scores from further consideration.

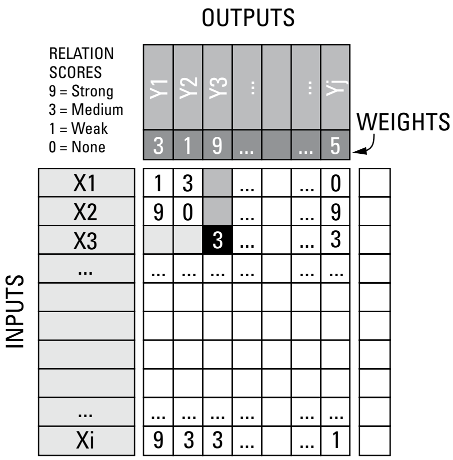


Figure 11-4: The C&E matrix with weighting factors for the outputs and relationship scores.

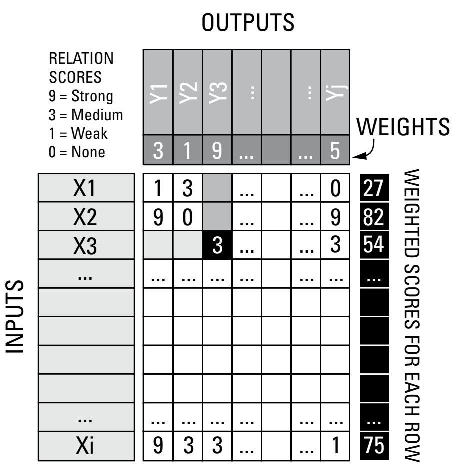


Figure 11-5: Weighted row sum scores are shown in the completed C&E matrix.

Go team! Appreciating group input when using C&E

The C&E matrix tool works best when performed with a small cross-functional improvement team. You may think the more ideas and inputs, the better, but an accurate and comprehensive listing of process/product outputs comes when team members from various functions are able to voice multiple perspectives on customer requirements; that requires a small team. Plus, these multiple perspectives come in handy when you're ranking the weights applied to each output. And a consensus among the team members is vital in determining the scores for each individual row-column intersection. This way, the scores are accurate, and the collaborative method means everyone is invested in the analysis and the discovery of root causes.

Leveraging Your Old Friend FMEA for Value

In Chapter 8, we introduce you to failure mode effects analysis (FMEA). There, you see how an FMEA helps you identify possible critical factors that influence an output. But an FMEA also helps you discover the factors leading to true value for your customer.

Use the FMEA to list the input factors of your process or service and link them to potential risks. You can also rank these items by overall priority — answering the question of which ones pose the greatest risk to you and your customers.

When you arrive at the Analyze phase of your DMAIC project, you need to open your FMEA and review the cause-and-effect relationships between process steps or product features and risk. Those items in your FMEA receiving the highest risk priority are the factors that will have the greatest influence on delivering true value to your customer.

TIP

Ask yourself whether your improvements address the factors the FMEA indicates have the highest priority. If they don't, you're likely bypassing the voice of the customer and are in danger of delivering something to your customer that doesn't necessarily satisfy its needs!

The analysis of your FMEA provides a comprehensive and extremely valuable view of the most critical factors and elements in your system. We recommend you keep a current version of your FMEA close to your improvement project; it's an extremely useful reference and guide as you work to understand the customer value within your process or product.

Chapter 12

What's Normal? Recognizing Normally-Shaped Variation

In This Chapter

- Understanding the pervasiveness of bell-shaped, normally-distributed data
- Calculating probabilities by using the standard normal model
- Transforming real-world data to the standard normal model
- Verifying that your data are normal (or close enough)

Most data distributions you encounter have what's called *normally-shaped variation.* And many of the statistical tools of Six Sigma we describe throughout this book assume a normal distribution. So before you dive into using the Six Sigma toolkit, you first need to know what normal variation is, what it looks like, and how to gauge how close your data are to the normal ideal.

Another important topic — describing or summarizing the probability of past events and forecasting or predicting the probability of future ones — is related to this idea of normally-shaped variation. Successful Six Sigma practitioners know how to check their data for normally-shaped variation. This chapter gets you to the heart of the proper technical foundation of the statistical tools and methods of Six Sigma.

Defining Normal: Bell-Shaped Variation and Probability

All process and product data have variation; each repeated instance of any measured data point is different from the instance before. And as the collection of repeated measurements piles up, a shape begins to form.

As we discuss in Chapter 9, real data usually cluster around a central value, and the occurrence of data points farther and farther from the central value tapers off. This setup, shown in Figure 12-1, is the classic bell-shaped kind of variation you constantly run across — in life and in your improvement work.

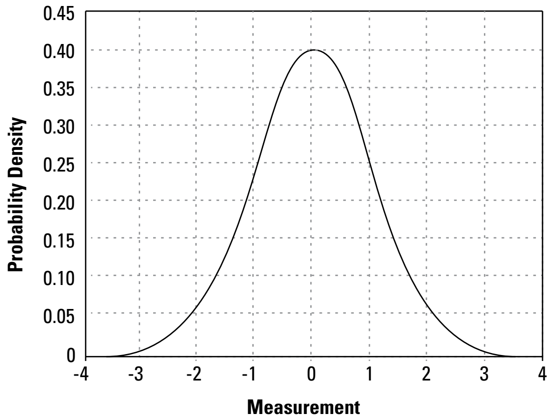


Figure 12-1: A normal bell-shaped variation distribution.

REMEMBER

Real data may come close, but no data are *perfectly* normal; the smooth bell-shaped curve so often depicted in books and presentations is an idealized model. Still, models possess great value. A model not only provides insight into the reality of the current situation but also offers a forecast of the future.

The normal model shown in Figure 12-1 represents the density of all probabilities for a process or product characteristic — all past, current, and future occurrences of the characteristic in its present configuration.

In Figure 12-1, the horizontal axis is scaled to units of the distribution's standard deviation. (See Chapter 9 for an explanation of the standard deviation.) And although the figure shows only the bell curve from –4 standard deviations to +4 standard deviations, it in fact extends out to negative infinity on the left and all the way to positive infinity on the right. The vertical axis measures the probability density for each value of the measurement from negative infinity to positive infinity; the higher the bell curve, the greater the probability of the corresponding value on the horizontal axis occurring.

Notice that the normal curve is always positive; that is, its value is never zero or negative. It's also perfectly symmetrical; if you fold the curve at its peak, the left and right halves match perfectly. The average value — called μ for the perfect model — occurs at the peak or center of the bell. The standard deviation — called σ for the perfect model — is equivalent to the horizontal distance from the center of the curve (the average, or μ) to either point on the curve where its shape changes from concave to convex. In Figure 12-1, with the horizontal scale in units of standard deviations, you can see that this distance occurs at the measurement points of –1 and 1.

A final point to note about the normal model is that, if you measure the area enclosed by the bell curve and the horizontal axis, from negative infinity to positive infinity, it always equals 1. That is, the total area under the normal curve represents 100 percent of all possibilities — with 50 percent falling above the average and 50 percent below.

Working in from negative and positive infinity, if you calculate the area under the normal curve between –3 and +3 standard deviations, the result is 0.997, or 99.7 percent of the possible outcomes for the process characteristic. Farther in, between –2 and +2 standard deviations, about 95 percent all possibilities are captured. And 68 percent of all possibilities lie between –1 and +1 standard deviations. Figure 12-2 illustrates this breakdown.

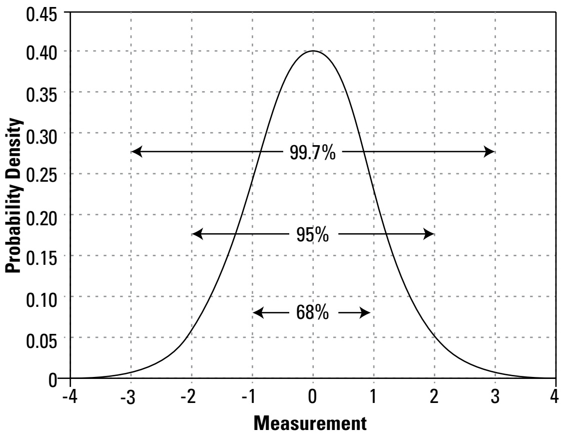


Figure 12-2: Areas of probability under the normal curve.

Because of the normal model's symmetry, you can use these same area probabilities to determine the possibilities that lie beyond the parameters. For example, because 99.7 percent of all outcome possibilities lie between –3 and +3 standard deviations, you know that 0.3 percent of possibilities must lie beyond –3 and +3 standard deviations, with 0.15 percent lower than –3 standard deviations and 0.15 percent greater than +3 standard deviations. And similarly, because about 95 percent of probabilities lie between –2 and +2 standard deviations, about 5 percent of probabilities must lie beyond –2 and +2 standard deviations. In all these examples, you can see that all the possibilities always combine to 100 percent.

Meeting the model: The standard normal distribution

Think about a special case of the normal model, where the average equals zero ($\mu = 0$) and the standard deviation is equal to one ($\sigma = 1$). (Check out the preceding section for info on the normal model.) A normal distribution with these exact parameters is called the *standard normal distribution.*

Statisticians have spent a lot of time studying the standard normal distribution. One of the important things they have done is tabulate the area under the standard normal curve for various measurement values. Figure 12-3 gives an example of such a standard normal probability table.

	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
6.0	9.87E-10	9.28E-10	8.72E-10	8.20E-10	7.71E-10	7.24E-10	6.81E-10	6.40E-10	6.01E-10	5.65E-10
5.9	1.82E-09	1.71E-09	1.61E-09	1.51E-09	1.43E-09	1.34E-09	1.26E-09	1.19E-09	1.12E-09	1.05E-09
5.8	3.32E-09	3.12E-09	2.94E-09	2.77E-09	2.61E-09	2.46E-09	2.31E-09	2.18E-09	2.05E-09	1.93E-09
5.7	5.99E-09	5.65E-09	5.33E-09	5.02E-09	4.73E-09	4.46E-09	4.21E-09	3.96E-09	3.74E-09	3.52E-09
5.6	1.07E-08	1.01E-08	9.55E-09	9.01E-09	8.50E-09	8.02E-09	7.57E-09	7.14E-09	6.73E-09	6.35E-09
5.5	1.90E-08	1.79E-08	1.69E-08	1.60E-08	1.51E-08	1.43E-08	1.35E-08	1.27E-08	1.20E-08	1.14E-08
5.4	3.33E-08	3.15E-08	2.98E-08	2.82E-08	2.66E-08	2.52E-08	2.38E-08	2.25E-08	2.13E-08	2.01E-08
5.3	5.79E-08	5.48E-08	5.19E-08	4.91E-08	4.65E-08	4.40E-08	4.16E-08	3.94E-08	3.72E-08	3.52E-08
5.2	9.96E-08	9.44E-08	8.95E-08	8.48E-08	8.03E-08	7.60E-08	7.20E-08	6.82E-08	6.46E-08	6.12E-08
5.1	1.70E-07	1.61E-07	1.53E-07	1.45E-07	1.37E-07	1.30E-07	1.23E-07	1.17E-07	1.11E-07	1.05E-07
5.0	2.87E-07	2.72E-07	2.58E-07	2.45E-07	2.33E-07	2.21E-07	2.10E-07	1.99E-07	1.89E-07	1.79E-07
4.9	4.79E-07	4.55E-07	4.33E-07	4.11E-07	3.91E-07	3.71E-07	3.52E-07	3.35E-07	3.18E-07	3.02E-07
4.8	7.93E-07	7.55E-07	7.18E-07	6.83E-07	6.49E-07	6.17E-07	5.87E-07	5.58E-07	5.30E-07	5.04E-07
4.7	1.30E-06	1.24E-06	1.18E-06	1.12E-06	1.07E-06	1.02E-06	9.68E-07	9.21E-07	8.76E-07	8.34E-07
4.6	2.11E-06	2.01E-06	1.92E-06	1.83E-06	1.74E-06	1.66E-06	1.58E-06	1.51E-06	1.43E-06	1.37E-06
4.5	3.40E-06	3.24E-06	3.09E-06	2.95E-06	2.81E-06	2.68E-06	2.56E-06	2.44E-06	2.32E-06	2.22E-06
4.4	5.41E-06	5.17E-06	4.94E-06	4.71E-06	4.50E-06	4.29E-06	4.10E-06	3.91E-06	3.73E-06	3.56E-06
4.3	8.54E-06	8.16E-06	7.80E-06	7.46E-06	7.12E-06	6.81E-06	6.50E-06	6.21E-06	5.93E-06	5.67E-06
4.2	1.33E-05	1.28E-05	1.22E-05	1.17E-05	1.12E-05	1.07E-05	1.02E-05	9.77E-06	9.34E-06	8.93E-06
4.1	2.07E-05	1.98E-05	1.89E-05	1.81E-05	1.74E-05	1.66E-05	1.59E-05	1.52E-05	1.46E-05	1.39E-05
4.0	3.17E-05	3.04E-05	2.91E-05	2.79E-05	2.67E-05	2.56E-05	2.45E-05	2.35E-05	2.25E-05	2.16E-05
3.9	4.81E-05	4.61E-05	4.43E-05	4.25E-05	4.07E-05	3.91E-05	3.75E-05	3.59E-05	3.45E-05	3.30E-05
3.8	7.23E-05	6.95E-05	6.67E-05	6.41E-05	6.15E-05	5.91E-05	5.67E-05	5.44E-05	5.22E-05	5.01E-05
3.7	0.000108	0.000104	0.000100	0.000096	0.000092	0.000088	0.000085	0.000082	0.000078	0.000075
3.6	0.000159	0.000153	0.000147	0.000142	0.000136	0.000131	0.000126	0.000121	0.000117	0.000112
3.5	0.000233	0.000224	0.000216	0.000208	0.000200	0.000193	0.000185	0.000178	0.000172	0.000165
3.4	0.000337	0.000325	0.000313	0.000302	0.000291	0.000280	0.000270	0.000260	0.000251	0.000242
3.3	0.000483	0.000466	0.000450	0.000434	0.000419	0.000404	0.000390	0.000376	0.000362	0.000349
3.2	0.000687	0.000664	0.000641	0.000619	0.000598	0.000577	0.000557	0.000538	0.000519	0.000501
3.1	0.000968	0.000935	0.000904	0.000874	0.000845	0.000816	0.000789	0.000762	0.000736	0.000711
3.0	0.001350	0.001306	0.001264	0.001223	0.001183	0.001144	0.001107	0.001070	0.001035	0.001001
2.9	0.001866	0.001807	0.001750	0.001695	0.001641	0.001589	0.001538	0.001489	0.001441	0.001395
2.8	0.002555	0.002477	0.002401	0.002327	0.002256	0.002186	0.002118	0.002052	0.001988	0.001926
2.7	0.003467	0.003364	0.003264	0.003167	0.003072	0.002980	0.002890	0.002803	0.002718	0.002635
2.6	0.004661	0.004527	0.004396	0.004269	0.004145	0.004025	0.003907	0.003793	0.003681	0.003573
2.5	0.006210	0.006037	0.005868	0.005703	0.005543	0.005386	0.005234	0.005085	0.004940	0.004799
2.4	0.008198	0.007976	0.007760	0.007549	0.007344	0.007143	0.006947	0.006756	0.006569	0.006387
2.3	0.010724	0.010444	0.010170	0.009903	0.009642	0.009387	0.009137	0.008894	0.008656	0.008424
2.2	0.013903	0.013553	0.013209	0.012874	0.012545	0.012224	0.011911	0.011604	0.011304	0.011011
2.1	0.017864	0.017429	0.017003	0.016586	0.016177	0.015778	0.015386	0.015003	0.014629	0.014262
2.0	0.022750	0.022216	0.021692	0.021178	0.020675	0.020182	0.019699	0.019226	0.018763	0.018309
1.9	0.028717	0.028067	0.027429	0.026803	0.026190	0.025588	0.024998	0.024419	0.023852	0.023295
1.8	0.035930	0.035148	0.034380	0.033625	0.032884	0.032157	0.031443	0.030742	0.030054	0.029379
1.7	0.044565	0.043633	0.042716	0.041815	0.040930	0.040059	0.039204	0.038364	0.037538	0.036727
1.6	0.054799	0.053699	0.052616	0.051551	0.050503	0.049471	0.048457	0.047460	0.046479	0.045514
1.5	0.066807	0.065522	0.064255	0.063008	0.061780	0.060571	0.059380	0.058208	0.057053	0.055917
1.4	0.080757	0.079270	0.077804	0.076359	0.074934	0.073529	0.072145	0.070781	0.069437	0.068112
1.3	0.096800	0.095098	0.093418	0.091759	0.090123	0.088508	0.086915	0.085343	0.083793	0.082264
1.2	0.115070	0.113139	0.111232	0.109349	0.107488	0.105650	0.103835	0.102042	0.100273	0.098525
1.1	0.135666	0.133500	0.131357	0.129238	0.127143	0.125072	0.123024	0.121000	0.119000	0.117023
1.0	0.158655	0.156248	0.153864	0.151505	0.149170	0.146859	0.144572	0.142310	0.140071	0.137857
0.9	0.184060	0.181411	0.178786	0.176186	0.173609	0.171056	0.168528	0.166023	0.163543	0.161087
0.8	0.211855	0.208970	0.206108	0.203269	0.200454	0.197663	0.194895	0.192150	0.189430	0.186733
0.7	0.241964	0.238852	0.235762	0.232695	0.229650	0.226627	0.223627	0.220650	0.217695	0.214764
0.6	0.274253	0.270931	0.267629	0.264347	0.261086	0.257846	0.254627	0.251429	0.248252	0.245097
0.5	0.308538	0.305026	0.301532	0.298056	0.294599	0.291160	0.287740	0.284339	0.280957	0.277595
0.4	0.344578	0.340903	0.337243	0.333598	0.329969	0.326355	0.322758	0.319178	0.315614	0.312067
0.3	0.382089	0.378280	0.374484	0.370700	0.366928	0.363169	0.359424	0.355691	0.351973	0.348268
0.2	0.420740	0.416834	0.412936	0.409046	0.405165	0.401294	0.397432	0.393580	0.389739	0.385908
0.1	0.460172	0.456205	0.452242	0.448283	0.444330	0.440382	0.436441	0.432505	0.428576	0.424655
0.0	0.500000	0.496011	0.492022	0.488034	0.484047	0.480061	0.476078	0.472097	0.468119	0.464144

Figure 12-3: A standard normal probability table.

The row labels on the far left of this standard normal table correspond to various plus or minus distances (to one decimal place) from the zero center of the standard normal distribution. The column labels across the top row add a second decimal place to the distances. The cell contents correspond to the probability (area under the normal curve) beyond the specified distance.

Calculating the probability above or below a single value

In the statistical tools of Six Sigma, you frequently calculate probabilities using the standard normal table. For example, you can easily look up the area under the standard normal curve greater than 1.24 in the table, as illustrated in Figure 12-4.

The probability from the table is 0.107488. So, for a normal distribution with mean of 0 and standard deviation of 1, the probability of observing a data value greater than 1.24 is 0.107488 (10.7 percent). Because of the symmetry of the model, this figure is also the exact probability of observing a value less than –1.24.

But that's not all! Using the idea of complementary probabilities, you can calculate a 1 – 0.107488 = 0.892512 (89.3-percent) probability of observing a measurement less than 1.24 (and conversely, an 89.3-percent probability of observing a measurement greater than –1.24). Check out Figure 12-5 to see these probabilities in action.

Calculating the probability between or outside two values

Figuring out probabilities with single values is relatively simple (see the preceding section). Finding out how much area (probability) is under the standard normal curve between two finite values is only a little bit more difficult. For example, what is the area under the standard normal curve between the horizontal axis values of 1.87 and 2.05? For that matter, how the heck are you supposed to determine that area if you can only look up one probability value in the standard normal probability table at a time? Well, we suggest a clever way!

Look up the area for each value separately and then subtract the second number from the first number to find the area between those values (that's the clever part). For example, you can find the area under the standard normal curve greater than 1.87 (which happens to be 0.030742) and the area under the standard normal curve greater than 2.05 (which happens to be 0.020182). The answer is simply 0.030742 – 0.020182 = 0.10560 (10.6 percent).

On the flip side, you have a 1 – 0.10560 = 0.89440 (89.4 percent) probability of observing a value outside this interval. These probabilities correspond to a process characteristic that has an average of 0 and a standard deviation of 1. Figure 12-6 shows this example.

	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
6.0	9.87E-10	9.28E-10	8.72E-10	8.20E-10	7.71E-10	7.24E-10	6.81E-10	6.40E-10	6.01E-10	5.65E-10
5.9	1.82E-09	1.71E-09	1.61E-09	1.51E-09	1.43E-09	1.34E-09	1.26E-09	1.19E-09	1.12E-09	1.05E-09
5.8	3.32E-09	3.12E-09	2.94E-09	2.77E-09	2.61E-09	2.46E-09	2.31E-09	2.18E-09	2.05E-09	1.93E-09
5.7	5.99E-09	5.65E-09	5.33E-09	5.02E-09	4.73E-09	4.46E-09	4.21E-09	3.96E-09	3.74E-09	3.52E-09
5.6	1.07E-08	1.01E-08	9.55E-09	9.01E-09	8.50E-09	8.02E-09	7.57E-09	7.14E-09	6.73E-09	6.35E-09
5.5	1.90E-08	1.79E-08	1.69E-08	1.60E-08	1.51E-08	1.43E-08	1.35E-08	1.27E-08	1.20E-08	1.14E-08
5.4	3.33E-08	3.15E-08	2.98E-08	2.82E-08	2.66E-08	2.52E-08	2.38E-08	2.25E-08	2.13E-08	2.01E-08
5.3	5.79E-08	5.48E-08	5.19E-08	4.91E-08	4.65E-08	4.40E-08	4.16E-08	3.94E-08	3.72E-08	3.52E-08
5.2	9.96E-08	9.44E-08	8.95E-08	8.48E-08	8.03E-08	7.60E-08	7.20E-08	6.82E-08	6.46E-08	6.12E-08
5.1	1.70E-07	1.61E-07	1.53E-07	1.45E-07	1.37E-07	1.30E-07	1.23E-07	1.17E-07	1.11E-07	1.05E-07
5.0	2.87E-07	2.72E-07	2.58E-07	2.45E-07	2.33E-07	2.21E-07	2.10E-07	1.99E-07	1.89E-07	1.79E-07
4.9	4.79E-07	4.55E-07	4.33E-07	4.11E-07	3.91E-07	3.71E-07	3.52E-07	3.35E-07	3.18E-07	3.02E-07
4.8	7.93E-07	7.55E-07	7.18E-07	6.83E-07	6.49E-07	6.17E-07	5.87E-07	5.58E-07	5.30E-07	5.04E-07
4.7	1.30E-06	1.24E-06	1.18E-06	1.12E-06	1.07E-06	1.02E-06	9.68E-07	9.21E-07	8.76E-07	8.34E-07
4.6	2.11E-06	2.01E-06	1.92E-06	1.83E-06	1.74E-06	1.66E-06	1.58E-06	1.51E-06	1.43E-06	1.37E-06
4.5	3.40E-06	3.24E-06	3.09E-06	2.95E-06	2.81E-06	2.68E-06	2.56E-06	2.44E-06	2.32E-06	2.22E-06
4.4	5.41E-06	5.17E-06	4.94E-06	4.71E-06	4.50E-06	4.29E-06	4.10E-06	3.91E-06	3.73E-06	3.56E-06
4.3	8.54E-06	8.16E-06	7.80E-06	7.46E-06	7.12E-06	6.81E-06	6.50E-06	6.21E-06	5.93E-06	5.67E-06
4.2	1.33E-05	1.28E-05	1.22E-05	1.17E-05	1.12E-05	1.07E-05	1.02E-05	9.77E-06	9.34E-06	8.93E-06
4.1	2.07E-05	1.98E-05	1.89E-05	1.81E-05	1.74E-05	1.66E-05	1.59E-05	1.52E-05	1.46E-05	1.39E-05
4.0	3.17E-05	3.04E-05	2.91E-05	2.79E-05	2.67E-05	2.56E-05	2.45E-05	2.35E-05	2.25E-05	2.16E-05
3.9	4.81E-05	4.61E-05	4.43E-05	4.25E-05	4.07E-05	3.91E-05	3.75E-05	3.59E-05	3.45E-05	3.30E-05
3.8	7.23E-05	6.95E-05	6.67E-05	6.41E-05	6.15E-05	5.91E-05	5.67E-05	5.44E-05	5.22E-05	5.01E-05
3.7	0.000108	0.000104	0.000100	0.000096	0.000092	0.000088	0.000085	0.000082	0.000078	0.000075
3.6	0.000159	0.000153	0.000147	0.000142	0.000136	0.000131	0.000126	0.000121	0.000117	0.000112
3.5	0.000233	0.000224	0.000216	0.000208	0.000200	0.000193	0.000185	0.000178	0.000172	0.000165
3.4	0.000337	0.000325	0.000313	0.000302	0.000291	0.000280	0.000270	0.000260	0.000251	0.000242
3.3	0.000483	0.000466	0.000450	0.000434	0.000419	0.000404	0.000390	0.000376	0.000362	0.000349
3.2	0.000687	0.000664	0.000641	0.000619	0.000598	0.000577	0.000557	0.000538	0.000519	0.000501
3.1	0.000968	0.000935	0.000904	0.000874	0.000845	0.000816	0.000789	0.000762	0.000736	0.000711
3.0	0.001350	0.001306	0.001264	0.001223	0.001183	0.001144	0.001107	0.001070	0.001035	0.001001
2.9	0.001866	0.001807	0.001750	0.001695	0.001641	0.001589	0.001538	0.001489	0.001441	0.001395
2.8	0.002555	0.002477	0.002401	0.002327	0.002256	0.002186	0.002118	0.002052	0.001988	0.001926
2.7	0.003467	0.003364	0.003264	0.003167	0.003072	0.002980	0.002890	0.002803	0.002718	0.002635
2.6	0.004661	0.004527	0.004396	0.004269	0.004145	0.004025	0.003907	0.003793	0.003681	0.003573
2.5	0.006210	0.006037	0.005868	0.005703	0.005543	0.005386	0.005234	0.005085	0.004940	0.004799
2.4	0.008198	0.007976	0.007760	0.007549	0.007344	0.007143	0.006947	0.006756	0.006569	0.006387
2.3	0.010724	0.010444	0.010170	0.009903	0.009642	0.009387	0.009137	0.008894	0.008656	0.008424
2.2	0.013903	0.013553	0.013209	0.012874	0.012545	0.012224	0.011911	0.011604	0.011304	0.011011
2.1	0.017864	0.017429	0.017003	0.016586	0.016177	0.015778	0.015386	0.015003	0.014629	0.014262
2.0	0.022750	0.022216	0.021692	0.021178	0.020675	0.020182	0.019699	0.019226	0.018763	0.018309
1.9	0.028717	0.028067	0.027429	0.026803	0.026190	0.025588	0.024998	0.024419	0.023852	0.023295
1.8	0.035930	0.035148	0.034380	0.033625	0.032884	0.032157	0.031443	0.030742	0.030054	0.029379
1.7	0.044565	0.043633	0.042716	0.041815	0.040930	0.040059	0.039204	0.038364	0.037538	0.036727
1.6	0.054799	0.053699	0.052616	0.051551	0.050503	0.049471	0.048457	0.047460	0.046479	0.045514
1.5	0.066807	0.065522	0.064255	0.063008	0.061780	0.060571	0.059380	0.058208	0.057053	0.055917
1.4	0.080757	0.079270	0.077804	0.076359	0.074934	0.073529	0.072145	0.070781	0.069437	0.068112
1.3	0.096800	0.095098	0.093418	0.091759	0.090123	0.088508	0.086915	0.085343	0.083793	0.082264
1.2	0.115070	0.113139	0.111232	0.109349	0.107488	0.105650	0.103835	0.102042	0.100273	0.098525
1.1	0.135666	0.133500	0.131357	0.129238	0.127143	0.125072	0.123024	0.121000	0.119000	0.117023
1.0	0.158655	0.156248	0.153864	0.151505	0.149170	0.146859	0.144572	0.142310	0.140071	0.137857
0.9	0.184060	0.181411	0.178786	0.176186	0.173609	0.171056	0.168528	0.166023	0.163543	0.161087
0.8	0.211855	0.208970	0.206108	0.203269	0.200454	0.197663	0.194895	0.192150	0.189430	0.186733
0.7	0.241964	0.238852	0.235762	0.232695	0.229650	0.226627	0.223627	0.220650	0.217695	0.214764
0.6	0.274253	0.270931	0.267629	0.264347	0.261086	0.257846	0.254627	0.251429	0.248252	0.245097
0.5	0.308538	0.305026	0.301532	0.298056	0.294599	0.291160	0.287740	0.284339	0.280957	0.277595
0.4	0.344578	0.340903	0.337243	0.333598	0.329969	0.326355	0.322758	0.319178	0.315614	0.312067
0.3	0.382089	0.378280	0.374484	0.370700	0.366928	0.363169	0.359424	0.355691	0.351973	0.348268
0.2	0.420740	0.416834	0.412936	0.409046	0.405165	0.401294	0.397432	0.393580	0.389739	0.385908
0.1	0.460172	0.456205	0.452242	0.448283	0.444330	0.440382	0.436441	0.432505	0.428576	0.424655
0.0	0.500000	0.496011	0.492022	0.488034	0.484047	0.480061	0.476078	0.472097	0.468119	0.464144

Figure 12-4: Looking up the probability for a value of 1.24 in the standard normal table.

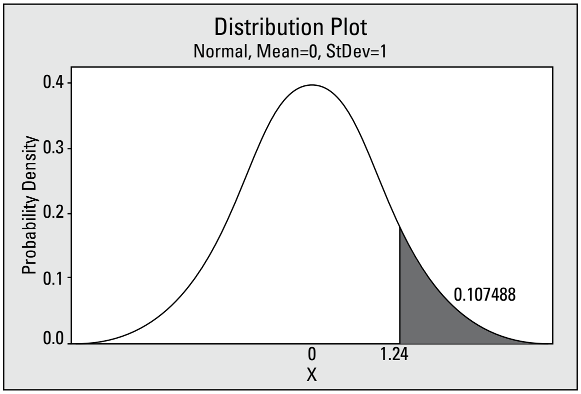


Figure 12-5: The probability of observing a point greater than 1.24 on the standard normal curve.

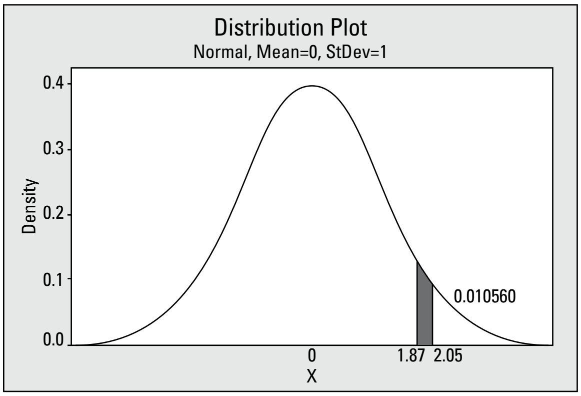


Figure 12-6: Computing the probability between two values in the standard normal distribution.

Working with nonstandard normal data: The Z transformation

How often do you come across a process or product characteristic that has an average of 0 and a standard deviation of 1? Not very often, if ever. So where's the usefulness in the standard normal distribution and the standard normal probability tables? (Head to the earlier section "Meeting the model: The standard normal distribution" for details on those items.) For example, what if a process characteristic you're studying has an average of 10.2 and a standard deviation of 0.68, and you need to know what the probability is of observing a process value greater than 12.0? (Figure 12-7 graphically represents this hypothetical example.) Why, you use the *Z transformation,* of course!

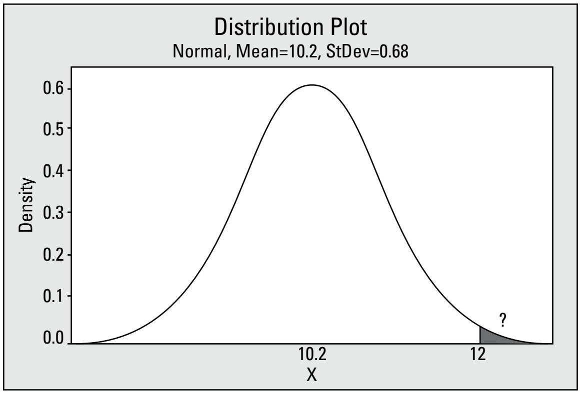


Figure 12-7: Distribution that doesn't match the standard normal distribution.

With this simple transformation of your process data, the standard normal distribution becomes highly useful. Consider the following mathematical transformation that changes your real-world data — which we call x — and scales them to the domain of the standard normal distribution:

$$Z = \frac{x - \bar{x}}{s}$$

What you're doing mathematically is finding Z, the distance from your point of interest (x) to the real-world process average ($\bar{x}$), and then calculating how many real-world standard deviations (s) you can fit within that distance. Try plugging in the values for the example situation:

$$Z = \frac{x - \bar{x}}{s} = \frac{12.0 - 10.2}{0.68} = 2.65$$

Figuring out the probability of observing a value greater than 12.0 on the curve in Figure 12-7 is exactly the same as figuring out the probability of observing a value greater than 2.65 on the standard normal distribution. Now that the problem is in the standard normal domain, you can use the standard normal probability table to find that the probability of being greater than 2.65 is 0.004025 (0.40 percent). Figure 12-8 shows this result. This procedure holds for all situations where you are using a normal model to approximate your real-world data.

Using Excel to calculate normal probabilities

Nearly every computer today has ready access to a spreadsheet application like Microsoft Excel. We use Excel here as an example for calculating normal probabilities, but all spreadsheets — whether another commercial package, an open source alternative, or a Google web application — offer similar utility. (See Chapter 22 for more on statistical analysis tools.)

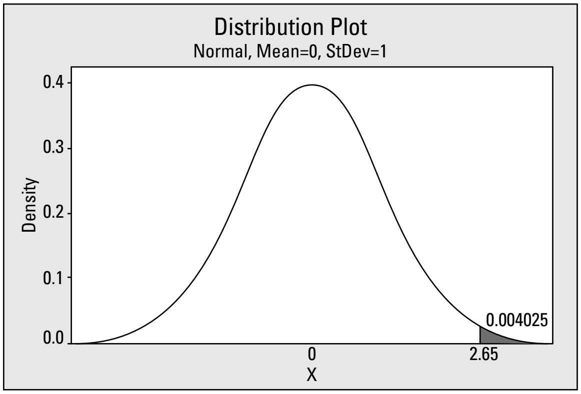


Figure 12-8: Using the *Z* transformation to calculate probability on a distribution that isn't standard normal.

Excel has two pairs of built-in formulas that are indispensible:

- **NORMSDIST(z)**. Notice the *S* in the spelling of this formula; it stands for "standard normal." This formula takes an input value and calculates the area under the standard normal distribution *to the left* of the value. (This process is called the *left-hand probability.*) For example, =NORMSDIST(–1.0) returns 0.159 (15.9 percent), while =NORMSDIST(1.0) returns 0.841 (84.1 percent). To decipher the results from Excel, remember the symmetry and complementary rules we cover in "Defining Normal: Bell-Shaped Variation and Probability" earlier in the chapter, and that Excel always bases its calculations off the left-hand probability.
- **NORMSINV(probability)**. The *S* for "standard normal" is also in the spelling of this formula. NORMSINV is the *inverse* of NORMSDIST; it takes a probability input between 0 and 1 and returns the corresponding value on the standard normal distribution.
- **NORMDIST(x, $\bar{x}$, s, 1)**. This formula is probably the most used of the four because it includes the *Z* transformation. You provide an x input along with the real-world characteristic average ($\bar{x}$) and standard deviation (s), and the formula returns the probability to the left of the x value under the normal curve. For example, 1 – NORMDIST(12.0, 10.2, 0.68, 1) returns a value of 0.00406.
- **NORMINV(probability, $\bar{x}$, s)**. This formula is the inverse of NORMDIST. It takes a probability input between 0 and 1 and returns the corresponding value on a normal distribution given the real-world average and standard deviation you specify. Remember the symmetry and complementary rules, and that Excel always bases its calculations off the left-hand probability, to decipher the results.

Checking How Well Data Follow a Normal Curve: Normal Probability Plots

In much of the statistical analysis work you do in Six Sigma, a technical prerequisite is that the data you're analyzing follow a normal distribution. Some assume that validating how well your data meet this requirement is a simple question; either your data are normal or they aren't. But it's a little more involved than that. A joke illustrates the point:

> COMEDIAN: "Whew! It's cold outside."
>
> SIDEKICK: "How cold is it?"
>
> COMEDIAN: "It's so cold that on the way here, I saw two chickens walk into KFC and ask to use the pressure cooker!"

Although the sidekick is really just setting up the gag's punch line by asking for specifics, this kind of clarification is critical in Six Sigma. When someone tells you that his or her data are normal, always respond with, "How normal are they?" No real-world data are perfectly normal. So the question you should be asking isn't "Are the data normal?" but rather "*How* normal are the data?" Before performing an analysis, we recommend that you determine just how closely your data follow a normal distribution by creating a normal probability plot. Then, depending on your situation, you can decide whether your data are normal enough to proceed with using the statistical tools that assume normality. The following sections show you how to create and use a normal probability plot.

Constructing a normal probability plot

TIP

If you have hundreds of points of data in your sample, one way to check for how normal your data are is to simply create a dot plot or histogram of the data. (Chapter 10 gives you the lowdown on these and other graphical tools.) The closer the plot follows a symmetrical bell shape, the more normal it is.

When you don't have hundreds of data points, however, the dot plot/histogram method becomes less and less reliable. A *normal probability plot* is a straightforward way to gauge how normal your data are regardless of how much data you have.

With a set of data from a process or product characteristic, you're ready to begin the steps to creating a normal probability plot:

1. **Order your *n* number of points of raw data from the minimum value to the maximum observed values.**

2. **Assign a rank order number (*i*) to each of the *n* points of data.**

   That is, from minimum to maximum, is the point of data the 1st, 7th, or 98th?

3. **Calculate the cumulative probability (p_i) associated with each rank-ordered point of data.**

   Use the following formula:

   $$p_i = \frac{i - 0.5}{n}$$

4. **Use the standard normal table found in Table 12-3 to calculate the z_i value for each of your *n* points of data.**

   For example, if the calculated cumulative probability for your seventh rank-ordered data point $p_7 = 0.140$, you find the closest value in the body of the table and record the associated *z* value. For 0.140, the closest entry in the table is 0.140071, which corresponds to a z_7 of 1.08.

   Because a standard normal curve is perfectly symmetrical, each probability has two possible corresponding *z* values. Both values have the exact same magnitude, but one is positive and the other is negative. Imagine a drawing of a perfect bell curve: For any selected point on the curve, another point has the exact same vertical height on the mirrored side. For every normal probability plot, as you figure the *z* values for least to the greatest rank-ordered data points, the *z* values start negative, pass through zero, and then become positive.

   WARNING!

   Make sure your determined *z* values are negative for every data point that has an associated *p* less than 0.500 and positive for those that have a *p* greater than 0.500. Otherwise, the scatter plot you create with these values will be incorrect.

5. **Create an *x-y* scatter plot of your measured data points versus their determined *z* values.**

   The measured data go on the *x*-axis, and the *z* values go on the *y*-axis.

Table 12-1 and Figure 12-9 illustrate this process for creating a normal probability plot for a set of 20 measurements of a critical process characteristic.

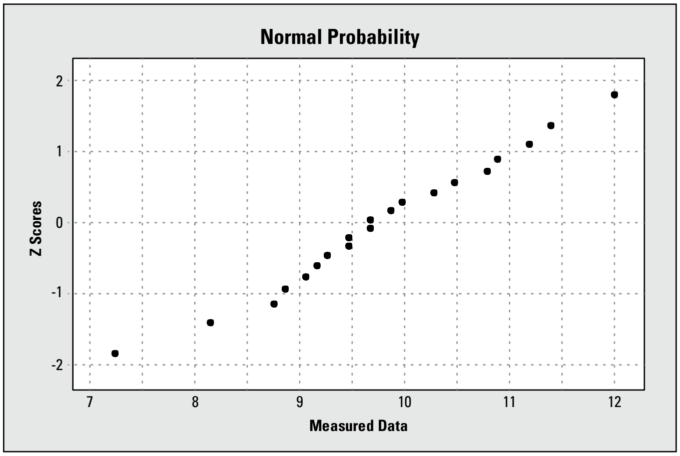


Figure 12-9: The normal probability plot of the data in Table 12-1.

Table 12-1 Rank-Ordered Data for a Normal Probability Plot

Rank-Ordered Data	*I*	p_i	z_i
7.3	1	0.025	–1.96
8.2	2	0.075	–1.44
8.8	3	0.125	–1.15
8.9	4	0.175	–0.93
9.1	5	0.225	–0.76
9.2	6	0.275	–0.60
9.3	7	0.325	–0.45
9.5	8	0.375	–0.32
9.5	9	0.425	–0.19
9.7	10	0.475	–0.06
9.7	11	0.525	0.06
9.9	12	0.575	0.19
10.0	13	0.625	0.32
10.3	14	0.675	0.45
10.5	15	0.725	0.60
10.8	16	0.775	0.76
10.9	17	0.825	0.93
11.2	18	0.875	1.15
11.4	19	0.925	1.44
12.0	20	0.975	1.96

Interpreting your normal probability plot

After you have created your normal probability plot, look at it. Do the plotted points form a linear pattern? The closer the points are to forming a single line, the more normal your data are; the more scattered the points are, the less normal your data are.

TIP

If your normal probability plot forms even the fuzziest impression of a line, you're close enough to normal for all the statistical tools to be validly applied for nearly all but the most sensitive situations.

Yes, the closer your data are to normal, the more closely the results of your statistical analysis will match reality. But very often, all you need for breakthrough improvement is an indication of the basic, right direction. As long as your data aren't drastically different from normal, you're set.

Figure 12-10 gives examples of normal probability plots that show data that are clearly not normal. Watch out for these before jumping into statistical analysis.

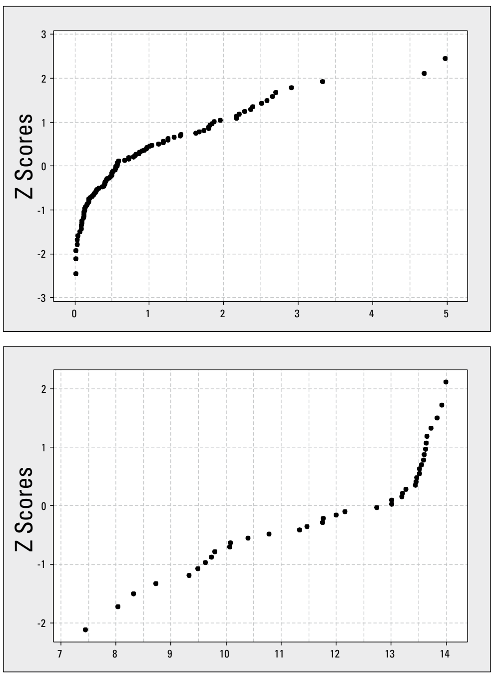


Figure 12-10: Examples of non-normal patterns in normal probability plots.

Chapter 13

Assessing Capability: Comparing the Voices of the Customer and the Process

In This Chapter

- Dealing with measures of yield and defect rate
- Calculating and interpreting the sigma (Z) score of a process or characteristic
- Using short- and long-term capability indices (C_P, C_{PK}, P_P, and P_{PK})

This chapter is about two voices — the voice of the process and the voice of the customer — and the effect each has on the other. In Six Sigma, this relationship is called *capability*. Capability is how well the voice of your process or characteristic matches up with the voice of your customer, or in other words, how well your process performs in meeting customer expectations.

Following the DMAIC strategy, calculate capability in order to quantify, analyze, and communicate the performance of characteristics and processes relative to their requirements. With these capability metrics, you will know where to focus your attention and how to verify that you've made real improvement.

Working with Yield and Defect Rates

Creating a specification is one thing. Meeting that specification through your processes and characteristics is another. A central task of Six Sigma is to understand how well your processes or characteristics meet their associated customer specifications.

Measuring yield

In the simplest terms, a process or characteristic can either meet or not meet its specification. Just as when you harvest the fruit from an apple tree, the yield of a characteristic or process relates to how much good stuff — performance within specifications — you get out. Table 13-1 compiles all the formulas we use to discuss yield in the following sections. Check out the individual sections for more details.

Table 13-1 Summary of Yield Metrics

Metric Name	***Calculation Formula***	***Description***
Traditional yield (*Y*)	$Y = \frac{out}{in} = \frac{in - scrap}{in} = 1 - \frac{scrap}{in}$	Is a misleading perspective that obscures the impact of inspection and rework.
First time yield (*FTY*)	$FTY = \frac{in - scrap - rework}{in} = 1 - \frac{scrap + rework}{in}$	Shows the likelihood of an item passing through a process successfully the very first time. Includes the effects of inspection, rework and scrap.
Rolled throughput yield (*RTY*)	$RTY = \prod_{i=1}^{n} FTY_i$	Is the combined overall yield of an entire process stream. Tells you the likelihood of an item passing through all process steps successfully the first time.

Traditional yield: Output versus input

Traditionally, *yield* is the proportion of correct items (conforming to specifications) you get out of a process compared to the number of raw items you put into it. Figure 13-1 illustrates the idea of *traditional yield.*

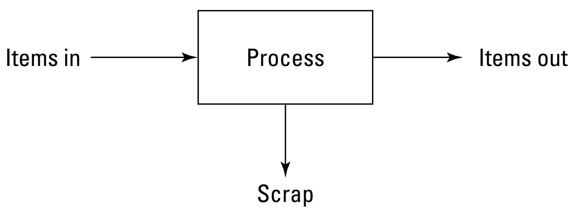


Figure 13-1: The traditional view of yield and of output compared to input.

The traditional calculation of yield is often employed on the last, final inspection step of a process to measure the effectiveness of the overall process. So for the process of inflating the tires on cars in an assembly line, a study may reveal that of the 352 cars that went through the tire-inflation process during a day's production, 347 were later found to have a pressure within the required specification limits. In this case, the traditional yield is

$$Y = \frac{out}{in} = \frac{347}{352} = 0.986$$

or 98.6 percent.

TIP

You can convert from a proportion such as 0.986 to perhaps a more familiar percentage scale by simply multiplying the proportion by 100. To go from percentage back to proportion, divide the percentage by 100. Just remember to always perform mathematical operations on proportions, not on percentages.

The Six Sigma perspective: First time yield (FTY)

The results of calculating yield the traditional way are misleading because they don't account for the intricacies of the process. The calculation known as *first time yield* (*FTY*) is often much different than traditional yield. That's because, unlike traditional yield, it captures the harsh reality of the effectiveness of the process. Take a closer look at the tire-inflating example process in Figure 13-2.

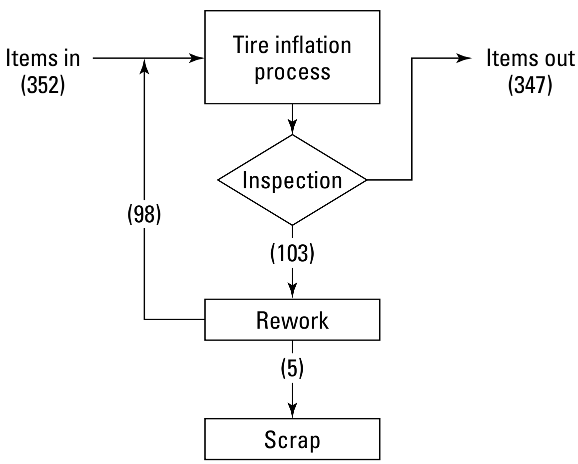


Figure 13-2: Detailed view of a tire-inflation process.

After inflation, the tire is immediately inspected to make sure it meets the required pressure specification limits. In the example, 103 tires are detected that don't comply with the pressure specification. Of course, the operators of the process reviewed each of these 103 and corrected (or *reworked*) 98 of them, leaving only five that they couldn't bring back within the correct pressure range and had to scrap. With this detailed information, you now know that the proportion of tires going through the inflation process correctly the first time is

$$\frac{249}{352} = 0.707$$

or 70.7 percent

Uncovering the hidden factory

The *hidden factory* (which we cover in Chapters 2 and 6) is a natural outgrowth of a system's inability to correctly comply with required specifications the first time through the process. Here and there throughout organizations, rework and fix practices arise and become engrained as "that's just the way we do it" parts of the standard practices. But if you measure yield by using the first-time yield method described in the preceding section, you naturally objectively review and acknowledge process effectiveness. Figure 13-3 shows the tire-inflation process again, this time with the previously hidden part of the process clearly identified.

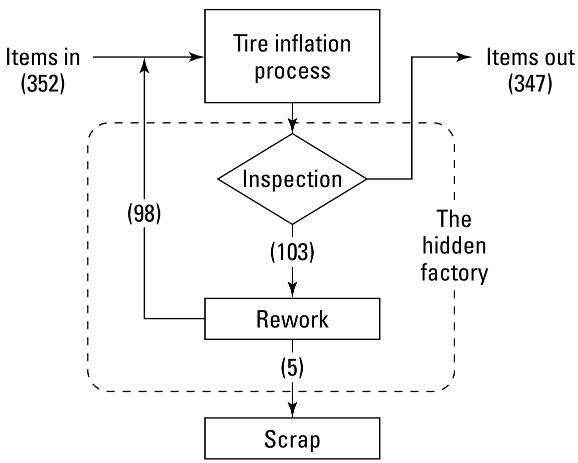


Figure 13-3: The hidden factory caused by inspection and rework.

In the case of the example tire-inflation process, the hidden factory of in-process inspection and rework accounts for 0.986 – 0.707 = 0.279 or 27.9 percent of production. All together, value-sapping hidden factories within organizations combine to consume valuable resources and time.

Rolled throughput yield (RTY)

In reality, individual process steps — such as the tire-inflation example in the previous section — are strung together to create an overall process structure for accomplishing complex tasks. One way Six Sigma quantifies the complexity of a system is to count the number of processes involved. For example, Figure 13-4 illustrates a purchase order process that is made up of five individual process steps.

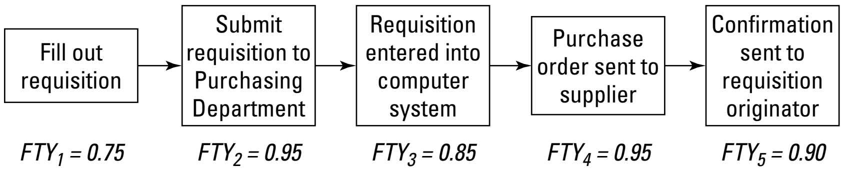


Figure 13-4: Several smaller process steps link together to create a complex process.

How do you calculate the overall yield for a string of processes? You multiply the first time yields for each step together, creating what is called the *rolled throughput yield* (*RTY*). For the purchase order example, the rolled throughput yield for this five-step process is

$$RTY = FTY_1 \times FTY_2 \times FTY_3 \times FTY_4 \times FTY_5$$
$$RTY = 0.75 \times 0.95 \times 0.85 \times 0.95 \times 0.90$$
$$RTY = 0.518$$

That means that the chance of a purchase order going through the process the first time with no rework or scrap is only 51.8 percent! (The last "confirmation" step in the process acts as a final test. This last step has a 90-percent yield, so you know a lot of hidden factory stuff must be going on to drop the *RTY* to 51.8 percent.)

TIP

Like a chain that is only as strong as its weakest link, rolled throughput yield can never be greater than the lowest first time yield within the system. To immediately improve the overall system performance, focus first on the individual process step with the lowest first time yield. Then move on to the step with the next-lowest first time yield.

TECHNICAL STUFF

You can simplify the formula for rolled throughput yield as

$$RTY = \prod_{i=1}^{n} FTY_i$$

where the capital Greek letter pi (Π) tells you to multiply all the first time yields of the system together.

Even if the first time yields of the individual process steps are high, if the overall process becomes more and more complex (that is, it contains more and more process steps), the system rolled throughput yield will continue to erode. Figure 13-5 charts how complexity degrades rolled throughput yield for different levels of individual first time yield.

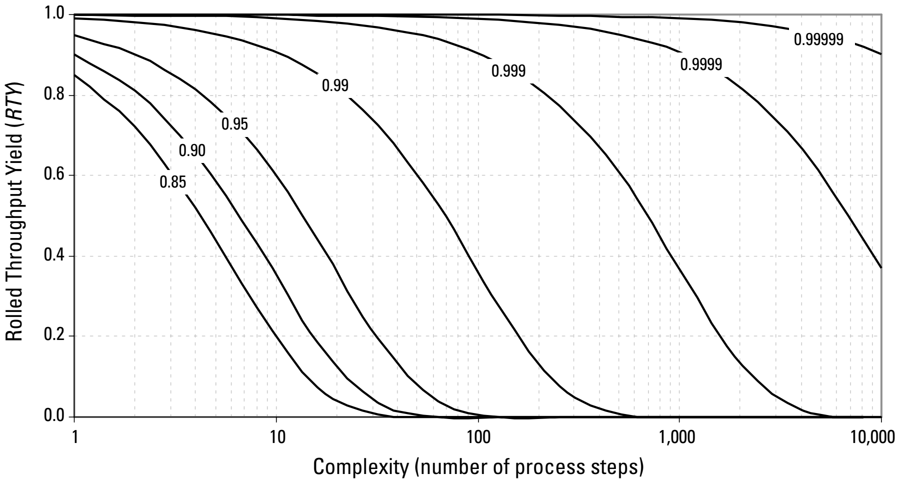


Figure 13-5: *RTY* as a function of complexity for several constant *FTY* values.

For very complex systems — such as automobiles, aircraft, data switching systems, enterprise-level business processes, and so on — a very high individual first time yield must be achieved in order to have any hope of an acceptable rolled throughput yield.

Measuring defect rate

The complementary measurement of yield is defects. When a process or characteristic doesn't perform within its specifications, it produces a non-compliant condition, called a *defect.* If your yield is 90 percent, you naturally must have 10 percent defects. Measuring defects and calculating how often they occur is like looking at the flip side of the yield coin. Check out Table 13-2 for an overview of defect metrics; we discuss these topics in more detail in the following sections.

Table 13-2 Summary of Defect Rate Metrics

Metric Name	Calculation Formula	Description
Defects per unit (*DPU*)	$DPU = \frac{\textit{number of defects observed}}{\textit{number of units inspected}}$	*DPU* provides a measurement of the average number of defects on a single unit.
Defects per opportunity (*DPO*)	$DPO = \frac{\textit{number of defects observed on a unit}}{\textit{number of opportunities on a unit}}$	*DPO* measures the number of defects that occur per opportunity for success or failure. DPO allows you to fairly compare the defect rates of things with very different levels of complexity.
Defects per million opportunities (*DPMO*)	$DPMO = DPO \times 1{,}000{,}000$	*DPMO* is the average number of defects found over a million opportunities. It's best used when the process or characteristic is repeated many times.
Defective parts per million (*DPPM*)	$DPPM = DPO \times 1{,}000{,}000$	*DPPM* is synonymous with *DPMO.*

Defects equal failure

When a process or characteristic doesn't perform within its specifications, it is considered defective; in other words, it produces a noncompliant condition called a *defect.*

Automatically defining a defect as a noncompliance with specifications may seem overly simplified. Just because a characteristic exceeds a specification doesn't necessarily mean that the system it's part of will break or stop functioning. For example, misspelling a customer's name on a billing statement (a defect) may or may not turn into a *complaint* (a failure) that costs money to correct. But over and over again, experts have verified that product or process failures are directly related to compliance with specifications; the less you're compliant with specifications, the more likely you are to have a failure or breakdown.

So given the difficulty in directly linking compliance with specifications to product or process performance, the safe thing to do is to make sure you strive to comply with specifications. Eliminating or reducing noncompliance with specifications always reduces failures or breakdowns in your customers' experiences.

Defects per unit (DPU)

Six Sigma applies to all areas of business and productivity — manufacturing, design, sales, office administration, accounts receivable, healthcare, finance, and so on. Each of these areas works on and produces different things — products, services, processes, environments, solutions, among others. To bridge these diverse disciplines, in Six Sigma you call the thing you're working on a *unit.* A unit may be a discretely manufactured product, an invoice that crosses your desk, a month's worth of continually produced product, a hospital patient, or a new design. Whatever it is you do, in Six Sigma it's called a *unit.*

A basic assessment of characteristic or process capability is to measure the total number of defects that occur over a known number of units. You then transform this measurement into a calculation of how often defects occur on a single unit, like this:

$$DPU = \frac{number\ of\ defects\ observed}{number\ of\ units\ inspected}$$

where *DPU* stands for defects per unit.

For example, if you process 23 loan applications during a month and find 11 defects — misspelled names, missing prior residence information, incorrect loan amounts — the *DPU* for your loan application process is

$$DPU = \frac{11}{23} = 0.478$$

That means that for every two loans that leave your desk, you expect to see about one defect.

Leveling the field: Defects per opportunity (DPO) and per million opportunities (DPMO)

A *DPU* of 0.478 for an automobile is viewed very differently than the same per-unit defect rate on a bicycle. That's because the automobile, with all its thousands of parts, dimensions, and integrated systems, has many more opportunities for defects than the bicycle has. A *DPU* of 0.478 on an automobile is evidence of a much lower defect rate than the same *DPU* on a simpler product, such as a bicycle. It's just not a fair comparison. (Hit the preceding section for info on *DPU.*)

So how do you compare or contrast the defect rates of things that have very different levels of complexity? The key is in transforming the defect rate into terms that are common to any unit, whatever it is or however complex it may be. The following sections dive into two such transformations: defects per opportunity (DPO) and defects per million opportunities (DPMO).

Opportunity knocks: Dealing with DPO

The way to level the playing field so you can directly compare the defect rates of systems with very different complexities is to create a per-opportunity defect rate, known as *defects per opportunity (DPO).* The common ground between any different units is opportunity. For any product, process, service, transaction, or environment, an *opportunity* is a specific characteristic that can either turn out as a defect or as a success. Success or failure for the opportunity is defined as compliance to the opportunity's specification. Examples of opportunities include the following:

- In a product, the critical dimension of diameter on an automobile axle
- In a transactional process, the applicant's mailing address on a loan approval form
- In a hospital, getting the correct medical history records into the patient's file
- In the design of a retail store environment, the placement of clearance sale racks
- In a manufacturing process, the tightening of a bolt to the correct torque

The number of opportunities inherent to a unit, whatever that unit may be, is a direct measure of its complexity. In fact, when you want to know how complex a unit is, you count or estimate how many opportunities for success or failure exist. Sometimes, opportunities are individual characteristics that are critical to the system's performance. Other opportunities are characteristics that have a specification.

Use the following formula to calculate *DPO:*

$$DPO = \frac{\textit{number of defects observed on a unit}}{\textit{number of opportunities on a unit}}$$

With a calculated *DPO* measurement, you can now fairly compare how capable an automobile is to how capable a bicycle is. For example, you may observe 158 out-of-specification characteristics on an automobile. After some study, you also determine that the number of opportunities for success or failure within that automobile is 14,550. Its *DPO* is then

$$DPO = \frac{158}{14{,}550} = 0.011$$

For a bicycle, on the other hand, you may find only two non-compliant characteristics among its 173 critical characteristics. So its *DPO* is

$$DPO = \frac{2}{173} = 0.012$$

Even though an automobile and a bicycle are two very different items with very different levels of complexity, the *DPO* calculations tell you that they both have about the same real defect rate. But you observe more defects on the automobile, because that item has many more opportunities for defects.

Be careful not to overestimate the number of opportunities on a unit. You can artificially make the *DPO* of your product, process, or service look better than it really is by inflating its number of opportunities. For example, you can count the correct name on a patient record — that is, whether the name on the form is right or wrong — as a single opportunity for success or failure. Or you can count one opportunity for the correct spelling, another for the correct font, another for the correct darkness of the printed text, another for the name's placement within the form box, and so on. Playing opportunity counting games only shrinks your ability to make an honest assessment and begin to make real improvement.

Addressing larger and accumulated units with DPMO

When the number of opportunities on a unit gets large and the number of observed defects gets small, calculated *DPO* measurements become so small they're hard to work with. For example, two commercial airline crashes (defects) observed out of 6 million flights in a year translates into

$$DPO = \frac{2}{6{,}000{,}000} = 0.000000333$$

Although 0.000000333 is fortunate, it's definitely an inconvenient number to work with! Additionally, you may also want to estimate out into the future to know how many defects will pile up after running the process or observing the characteristic for a long time. After all, *DPU* and *DPO* look only at a single unit or a single opportunity.

A simple way to solve both of these problems is to count the number of defects over a larger number of opportunities. For example, how many defects occur over a set of one million opportunities? This defect rate measurement is called *defects per million opportunities* (or *DPMO*) and is used very frequently in Six Sigma. In fact, Six Sigma is famous for its defect rate goal of 3.4 defects per million opportunities.

When a process is repeated over and over again many times — like an automobile assembly process, an Internet order process, or a hospital check-in process — *DPMO* becomes a convenient way to measure capability. When calculating *DPMO*, you don't want to actually measure the defects over a million opportunities. That would take way too long. Instead, the way you calculate *DPMO* is by using *DPO* as an estimate, like this:

$$DPMO = DPO \times 1{,}000{,}000$$

This setup also means you can track backward, going from *DPMO* to *DPO:*

$$DPO = \frac{DPMO}{1{,}000{,}000}$$

A common alternative form of *DPMO* is *DPPM* — defective parts per million. *DPPM* is often used when assessing the defect rate of a continuous material or process where the "part" is the opportunity. Like in ongoing shipments of bolts to a supplier, the cumulative number of defective bolts found compared to the total number shipped over time can be translated into *DPPM.*

Brought to you by the number e: Linking yield and defect rate

Yield and defect rate (see the preceding sections) aren't completely independent of each other. When you have an overall process with a relatively low defect rate — say, a process that produces units with a *DPU* less than 0.10 (or 10 percent) — you can mathematically link the process defect rate to the overall process yield with the following equation:

$$RTY = \mathrm{e}^{-DPU}$$

where e in the equation is a mathematical constant equal to 2.718. ***Tip:*** You can find a function or key for raising e to a power on any scientific calculator or computer spreadsheet program. (Look for the e^x key on your calculator.)

The actual value of the constant e is 2.71828182845905. . . . The decimal digits of e go on forever, never repeating. But you don't need to know the details of this curious constant called e to excel at Six Sigma.

The power of this mathematical link between yield and defects is that if you can only measure or have only measurements of the defect rate of a process, you can still calculate its rolled throughput yield. A little bit of algebraic contortion provides an equation to calculate *DPU* based only on the rolled throughput yield of a process:

$$DPU = -\ln(RTY)$$

where ln is the natural logarithm. (***Hint:*** Every scientific calculator has an ln button.)

What's Your Sigma, Baby? Deciphering Sigma (Z) Score

From a quality perspective, Six Sigma is defined as 3.4 defects per million opportunities. This figure is called a *Six Sigma level of quality.* Sigma scores are thrown about so much that you definitely need to be comfortable understanding what they are and how they're calculated. Basically, a *sigma score* tells you how many standard deviations can fit between the mean and specification limit of any process or specification.

The sigma score can be applied to the performance of anything that has a specification and a defect rate: the performance of the mail system in delivering letters to the correct address, the ability of an automobile manufacturer to produce a door that fits to the body within a required dimensional tolerance, or a repeated budgeting process that must be completed within its specified schedule window.

All sigma scores can be directly compared to see how capable the process or characteristic is. And when you communicate capability with a sigma score, everyone else in Six Sigma knows exactly what you're talking about. The following sections cover the concepts that will have you discussing sigma scores like a pro.

Breaking down how many standard deviations can fit

Figure 13-6 illustrates a process or characteristic performance distribution compared to its one-sided specification.

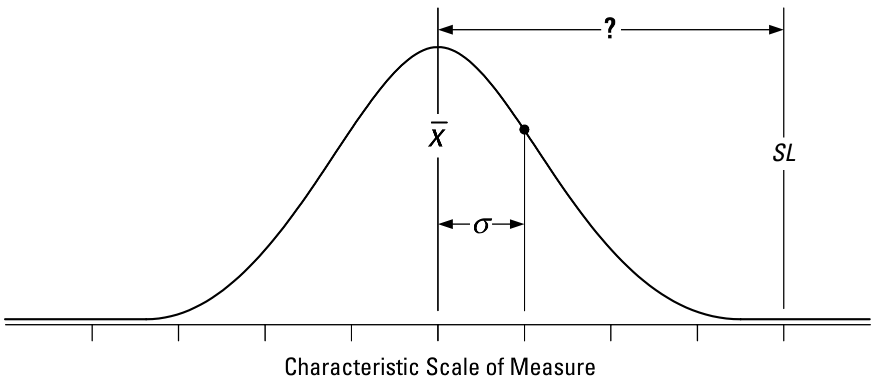


Figure 13-6: A characteristic's performance distribution as defined by its mean and its standard deviation σ.

The central tendency of the performance distribution is defined by its mean. The amount of variation in the performance, or the width of the distribution, is defined by its standard deviation σ. The question is how many standard deviations can you fit between the process or characteristic's mean and its specification limit *SL?*

Graphically, in Figure 13-6, you can see that four standard deviations can fit between the mean and the specification limit. The exact number can always be calculated (even without a graph!) by the formula

$$Z = \frac{|SL - \bar{x}|}{\sigma}$$

Statisticians usually call this same value the *Z score* or *normal score.* In Six Sigma, however, you need to be careful not to confuse the sigma score (sometimes called a *sigma value* or even just *sigma*) with the standard deviation represented by the Greek letter sigma (σ). *Z score, Z value, Z, sigma score, sigma value,* and *sigma* are all different names for how many standard deviations can fit between the mean and the specification limit. Things get confused when practitioners call the standard deviation "sigma." In this book, we always call the standard deviation the standard deviation. To avoid the confusion yourself, whenever you're reading or speaking about a σ, don't call it "sigma." Instead, call out "standard deviation" for what the symbol always represents.

Use a sigma (*Z*) score only on a characteristic that is approximately *normal* (has a bell-shaped distribution). When the distribution is far from normal, the formula for calculating the sigma (*Z*) score breaks down. The quickest way to check whether the distribution is approximately normal is to create a dot plot or histogram. (See Chapters 10 and 12 for info on creating these graphics and on verifying whether your data are normal, respectively.)

A low sigma (*Z*) score means that a significant part of the tail of the distribution extends past the specification limit. So the higher the sigma (*Z*) score, the fewer the defects. A process or characteristic gets a good sigma (*Z*) score when the variation distribution is safely away from the edge of the specification cliff. A sigma (*Z*) score can change in one of three ways:

- The location of the central tendency of the distribution — the mean — moves either closer or farther from the specification limit.
- The width of the distribution, as defined by the standard deviation σ, changes.
- The location of the specification limit *SL* moves either closer or farther from the characteristic or process variation.

Actually, changes to $\bar{x}$ and σ often happen at the same time, with both simultaneously contributing to a change in the computed sigma (*Z*) score.

Comparing short-term versus long-term sigma score calculations

From the mean and the standard deviation, you can calculate a sigma (*Z*) score. A wrinkle here is that you must know what type of standard deviation you're using to calculate the sigma (Z) score: Is it a short-term standard deviation σ_{ST}, or is it a long-term standard deviation σ_{LT}? (To understand the critical differences in short- and long-term standard deviations and their implications, see Chapter 9.)

If you're using a short-term standard deviation, the sigma (Z) score you calculate is a short-term sigma score Z_{ST}:

$$Z_{ST} = \frac{|SL - \bar{x}|}{\sigma_{ST}}$$

If, however, you have a long-term standard deviation, you can calculate the long-term sigma score Z_{LT}:

$$Z_{LT} = \frac{|SL - \bar{x}|}{\sigma_{LT}}$$

Linking short-term capability to long-term performance with the 1.5-sigma shift

Short-term variation performance, as quantified by the short-term sigma score Z_{ST} (see the preceding section), represents the best variation performance that you can expect out of your currently configured process. It's an *idealistic* measure of capability. It's also the easiest type of data to collect; just go and quickly grab a relatively small sample of measurements from the process or characteristic, and you have it.

But in the long term, a process or characteristic doesn't operate ideally like it does in the short term. Its performance will degrade by shift, drift, and trend influences. At the heart of Six Sigma is a method that combines the best of both worlds. It allows you to leverage the economy of short-term variation data while projecting realistic, long-term performance versus the process's or characteristic's specifications. Figure 13-7 shows the short-term variation of a process or characteristic and its expanded, long-term variation.

The characteristic or process shown in Figure 13-7 stays within specifications during the short term and appears to have no problems. But over the long term, disturbances to the process cause it to expand, and this expansion creates defects beyond the specification limit. One mathematical way to simulate the effect of these degrading, long-term influences is to artificially move the short-term distribution closer to the specification limit until the amount of defects for the short-term distribution is the same as that for the long-term distribution. This approach is shown in Figure 13-8.

Early practitioners of Six Sigma proposed that mathematically shifting a characteristic's or process's short-term distribution closer to its specification limit by a distance of 1.5 times its short-term standard deviation would approximate the number of defects occurring in the long term. This breakthrough idea can be applied directly to the calculation of short-term and long-term sigma (Z) scores.

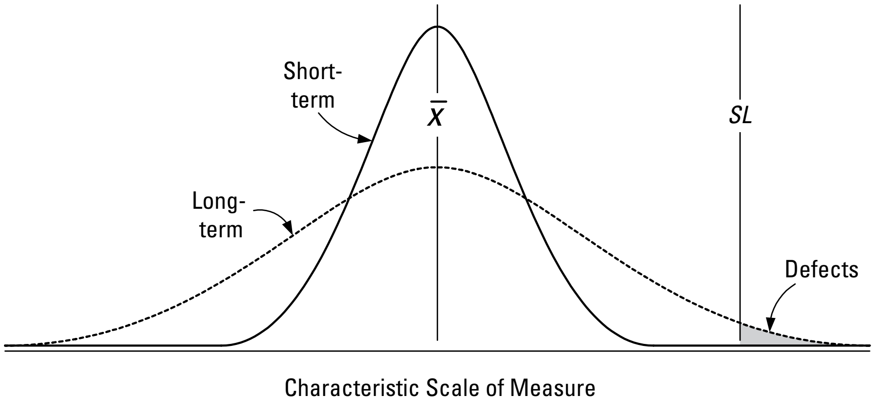


Figure 13-7: A characteristic with short-term variation that complies with specifications, but with an expanded long-term variation that creates defects.

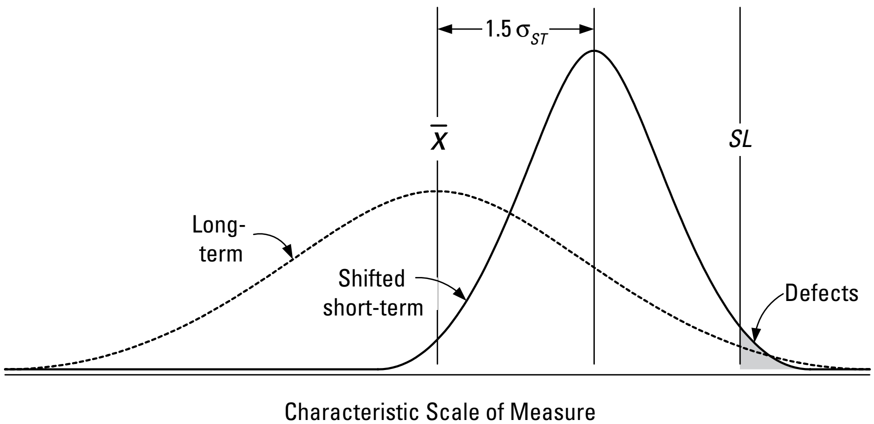


Figure 13-8: Mathematically shifted short-term distribution used to estimate the long-term variation performance.

Because Z_{ST} represents the number of short-term standard deviations between the variation center and the specification, the sigma (Z) score of the shifted distribution is

$$Z_{\text{shifted}} = Z_{ST} - 1.5$$

But with the shifted distribution being equivalent, defect-wise, to the long-term distribution, the preceding equation can be rewritten as

$$Z_{LT} = Z_{ST} - 1.5$$

So what Six Sigma practitioners do is measure the short-term variability of a process or characteristic and calculate its short-term sigma score. Then they immediately translate this score to the expected long-term defect rate performance, using the 1.5 short-term standard deviation shift. This long-term sigma score, Z_{LT}, is communicated in terms of defects per million opportunities, *DPMO*. (The earlier section "Addressing larger and accumulated units with *DPMO*" gives you the lowdown on this measurement.)

Table 13-3 is a look-up table that Six Sigma practitioners carry around in their pockets and use over and over until they have it memorized (or until they wear it out, whichever happens first). They figure the Z_{ST} for any process or characteristic and then translate that into a long-term defect rate *DPMO*. Or, in reverse, they first find the *DPMO* and then translate that back to a short-term sigma score Z_{ST}.

Table 13-3 Sigma Score Table: $Z_{ST} \leftrightarrow DPMO_{LT}$

Z_{ST}	$DPMO_{LT}$
0.0	933,193
0.5	841,345
1.0	691,462
1.5	500,000
2.0	308,538
2.5	158,655
3.0	66,807
3.5	22,750
4.0	6,210
4.5	1,350
5.0	233
5.5	32
6.0	3.4

Note: Paired table values are long term for DPMO and short term for Z (for example, a long-term DPMO of 6,210 is the result of a process with a short-term sigma score of 4.0). Add 1.5 to corresponding Z values to obtain short-term DPMO equivalents (for example, a short-term DPMO of 32 is the result of a process with a short-term sigma score of 4.0).

As you work in Six Sigma, you may hear someone ask, "What's the sigma of the process?" And the response you'll hear back is, "2 sigma" or "3.3 sigma" or such-and-such sigma. The question these people are really asking is, "What is the short-term sigma score Z_{ST} corresponding to the long-term defect rate of the process?"

After only a few times looking up sigma score values in Table 13-3, you begin to get a feel for this famous scale of capability. You may even be able to approximate sigma scores for defect rate values that fall between the rows of the table, such as a DPMO of 20,000. Its sigma score is about 3.6, a value just a little larger than the 3.5 corresponding to the DPMO of 22,750 in the table.

Considering Capability Indices

Capability indices are a set of measures that directly compare the voice of the process to the voice of the customer to quantify the capability of a process or characteristic to meet its specifications. In the following sections, we describe each capability index; you can check out the basics in Table 13-4.

Table 13-4 Summary of Short- and Long-Term Capability Indices

Index Name	*Formula*	*Description*
Short-term capability index	$C_P = \dfrac{USL - LSL}{6\sigma_{ST}}$	Compares the width of the specification to the short-term width of the process
Adjusted short-term capability index	$C_{PK} = \min\left(\dfrac{USL - \bar{x}}{3\sigma_{ST}}, \dfrac{\bar{x} - LSL}{3\sigma_{ST}}\right)$	Compares the width of the specification to the short-term width of the process and accounts for off-centering of the process from the specification
Long-term capability index	$P_P = \dfrac{USL - LSL}{6\sigma_{LT}}$	Compares the width of the specification to the long-term width of the process
Adjusted long-term capability index	$P_{PK} = \min\left(\dfrac{USL - \bar{x}}{3\sigma_{LT}}, \dfrac{\bar{x} - LSL}{3\sigma_{LT}}\right)$	Compares the width of the specification to the long-term width of the process and accounts for off-centering of the process from the specification

Short-term capability index (C_p)

The simplest capability index is called C_P. It compares the width of a two-sided specification to the effective short-term width of the process. (Flip to Chapter 2 to read about specifications.) Determining the width between the two rigid specification limits is easy; it is simply the distance between the upper specification limit (*USL*) and the lower specification limit (*LSL*). But with variation that trails out at the tails, how do you determine the width of the process?

To get over this hurdle, Six Sigma practitioners have defined the effective *limits* of any process as being three standard deviations away from the average level. At this setting, these limits surround 99.7 percent, or virtually all, of the variation in the process. Figure 13-9 shows these limits graphically.

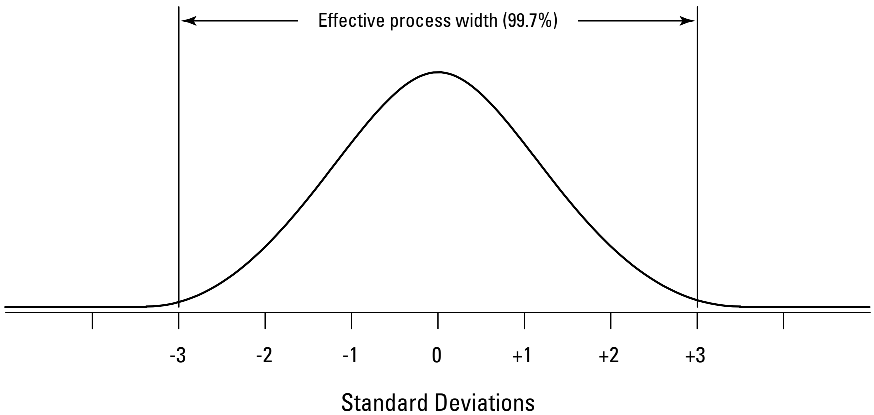


Figure 13-9: The effective width of a process or characteristic is ±3 standard deviations, containing 99.7 percent of the process variation.

So to compare the width of the specification to the short-term width of the process, you use the following formula:

$$C_P = \frac{USL - LSL}{6\sigma_{ST}}$$

where $USL - LSL$ represents the voice of the customer's requirements and $6\sigma_{ST}$ represents the inherent voice of the process. A calculated C_P value equal to 1 means that the voice of the customer is equal to the voice of the process. A C_P value less than 1 means that the process is wider than the specification, with defects spilling out over the edges. A C_P value greater than 1 means that the effective width of the process variation is less than the required specification, with fewer defects occurring.

C_P is a measure of short-term process or characteristic capability. Use only the short-term standard deviation to calculate its value. Using a long-term standard deviation in its calculation gives you incorrect results.

Adjusted short-term capability index (C_{PK})

The *adjusted short-term capability index (C_{PK})* takes care of a problem with the short-term capability index C_P in the preceding section. The issue: C_p compares only the widths of the specification and the process. Figure 13-10 illustrates this problem.

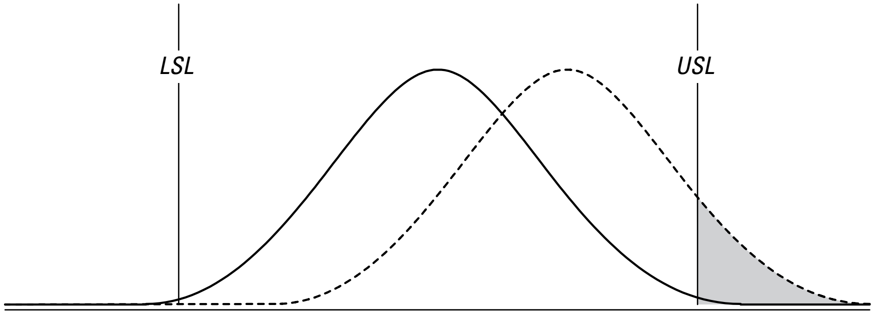


Figure 13-10: Two distributions, one centered and one offset from the specification limits.

In Figure 13-10, both the distribution drawn with the solid line and the distribution drawn with the dotted line have the same calculated C_P. That's because they both have the same specification width and the same process width. But they aren't equally capable. Because it's offset from the center of the specification, the dotted line distribution has many more defects than the solid distribution. You can compensate for this discrepancy by adjusting the C_P calculation for how far it's off center. To do this, you simply compare the distance from the distribution center to each of the specification limits with the half-width of the short-term variation that should exist between the center of the distribution and the specification limit, like this:

$$C_{PU} = \frac{USL - \bar{x}}{3\sigma_{ST}}$$

and

$$C_{PL} = \frac{\bar{x} - LSL}{3\sigma_{ST}}$$

The smallest value you calculate of C_{PU} and C_{PL} is the C_{PK}. So you can write the formula for C_{PK} as

$$C_{PK} = \min\left(C_{PU}, C_{PL}\right) = \min\left(\frac{USL - \bar{x}}{3\sigma_{ST}}, \frac{\bar{x} - LSL}{3\sigma_{ST}}\right)$$

where the *min* in the equation tells you to choose the smallest of the values in parentheses.

If the characteristic or process variation is centered between its specification limits, the calculated value for C_{PK} is equal to the calculated value for C_P. But as soon as the process variation moves off the specification center, it's penalized in proportion to how far it's offset. C_{PK} is very useful and very widely used. That's because it compares the width of the specification with the width of the process while also accounting for any error in the location of the central tendency. This approach is much more realistic than the one the C_P method offers.

TIP

Generally, a C_{PK} greater than 1.33 indicates that a process or characteristic is capable in the short term. Values less than 1.33 tell you that the variation is either too wide compared to the specification or that the location of the variation is offset from the center of the specification. Or it may be a combination of both width and location. The only way to know for sure is to create a graph and begin to review the details. Chapter 10 shows you how to use charts and graphs to analyze data.

Long-term capability indices (P_P and P_{PK})

The same capability indices that you calculate for short-term variation (C_P and C_{PK}, covered in the preceding sections) can also be calculated for long-term, or total, variation. To differentiate them from their short-term counterparts, these long-term capability indices are called P_P and P_{PK}. (The *P* stands for "performance.") The only difference in their formulas is that you use σ_{LT} in place of σ_{ST}. These long-term capability indices are important because no process or characteristic operates in just the short term. Every process extends out over time to create long-term performance.

Prescribing a capability improvement plan

How can you use the short- and long-term capability indices of a process or characteristic to chart out a plan for improvement? Table 13-5 outlines the various scenarios that may occur when you're measuring the capability of a process or characteristic and describes an improvement plan for each scenario.

Table 13-5 Prescriptive Capability Improvement Plan

Symptom	*Diagnosis*	*Prescription*
$C_P = C_{PK}$ and $P_P = P_{PK}$	Overall, your process or characteristic is centered within its specifications.	As needed, focus on reducing the long-term variation in your process or characteristic while maintaining on-center performance.
$C_P = P_P$ and $C_{PK} = P_{PK}$	Your process or characteristic suffers from a consistent offset in its center location.	Focus on correcting the set point of your process or characteristic until it's centered.
$C_P = P_{PK}$	Your process is operating at its entitlement level of variation.	Continue to monitor the capability of your process. Redesign your process to improve its entitlement level of performance.

Chapter 14

Gauging Gauges: Measurement System Analysis (MSA)

In This Chapter

- Understanding variation that comes from the act of measuring
- Speaking the language of measurement system analysis
- Using audits, attribute studies, and gauge studies

With all the attention on data capture and analysis in Six Sigma, you may be prone to overlook the quality of the measurement systems you use to capture the data in the first place. But data form the foundation of your knowledge and decisions; imagine what would happen if all your analysis and conclusions were based on faulty data. Garbage in, garbage out.

In this chapter, we show you how to use a measurement system analysis — or MSA, as it's usually called — to quantify how much observed variation is coming from the measurement system itself. You must be able to immediately eliminate any chance that the measurements you're using are creating an illusion.

Avoiding Illusion: Measurement System Capability Analysis

Measurement is critical. It's the foundation of knowledge and of subsequent improvement. You measure to find the problem, and you measure to verify that you have the right answer, have corrected the problem, or have improved the situation.

Measurement is unavoidable. Nothing is observed outside of the filter of some kind of measurement system — your eyes, your brain, or your perception; a physical ruler or a stopwatch; or a laser interferometer, for example. Everything comes to you through some kind of measurement system lens. You need to know whether your measurement system is giving you a clear picture of reality.

Looking at variation in a measurement system

The act of measuring is a process all by itself. And as with any other process, it has variation within it. Think back to the last time you watched an Olympic ice-skating competition. In that situation, expert judges act as the measurement system, but judges often assign different scores to the same routine. This discrepancy is evidence of variation in the measurement system. If you present a recording of the same performance to the same judges a year later, you'll probably even get a different score from each judge! In fact, the variability in this Olympic example is parallel to the variability in every measurement system. Everything you see is through an imperfect lens of measurement. Any time you place something into a category or quantify one of its attributes, you're doing so through an imperfect measurement system. Figure 14-1 illustrates this concept.

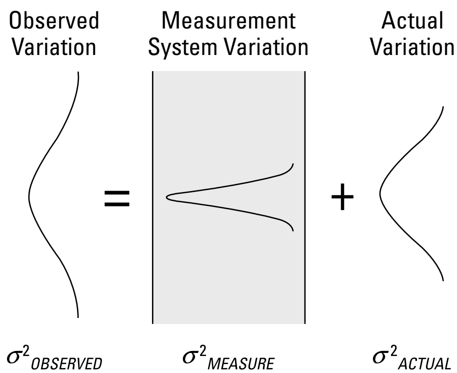


Figure 14-1: Everything you observe has the added variation of your measurement system.

Six Sigma teaches that data and measurements are the starting point of knowledge and improvement. Before you get too far down the improvement road, however, you need to determine whether your measurement system is clouding your observations to the point of illusion — whether what you see isn't what really exists.

Sources of measurement system variation

Several aspects of a measurement system affect how much clouding variation it contributes to your observations: measurement resolution, measurement accuracy, and measurement precision. In this section, you find out more about all three.

Measurement resolution

Resolution is a comparison of the smallest increment your measurement system can provide to the characteristic you're trying to measure. For example, imagine measuring a grain of sand with a tape measure. You'd be kidding yourself if you treated the results of this measurement system seriously. The $\frac{1}{16}$-inch increments on the tape measure aren't fine enough to discern the much, much smaller grain of sand. What you need instead is a system, such as maybe a microscope, that can measure in increments of $\frac{1}{1,000}$ of an inch. Then you can trust your measurements of the sand grain sizes.

TIP

A good rule of thumb is to use a measurement system with at least ten increments within the specification width you're measuring or within the process variation you're trying to observe. So for measuring the variation of a process that should be completed in between 9 and 10 minutes (a 1-minute time width), you want to use a measurement system with increments of no more than 0.1 minutes, or 6 seconds.

The idea of resolution also applies when you're measuring attribute data. A customer survey that allows only responses of "satisfied" and "dissatisfied" offers less resolution than one where the customer can mark "delighted," "satisfied," "indifferent," "dissatisfied," and "disgusted."

Measurement accuracy

Accuracy describes how centered your measurement system's variation is with the actual variation of the process or characteristic. Figure 14-2 shows this concept visually. In (a), the dots representing the measurement system variability are centered on the target that represents the actual variation of the process or characteristic being measured. The measurement system depicted in (a) is accurate. In (b), the measurement system variation is offset, or biased, from the center of the actual process or characteristic variation. The (b) measurement system isn't accurate.

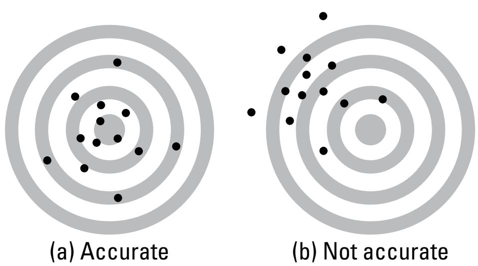
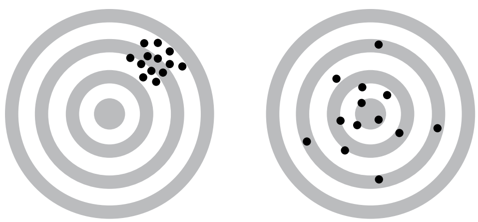


Figure 14-2: How centered is your measurement system's variation?

Several conditions can cause accuracy problems in your measurement system. Sometimes a measurement system can have problems with *linearity*. Good linearity is when the centering and the magnitude of the measurement system variation are consistent across the system's range of operation. A measurement system has poor linearity when its centering or magnitude of variation changes across its range of variation. A *stable* measurement system is one that stays centered and free of offset changes. In an unstable measurement system, the location of its variation center bounces around.

Measurement precision

Accuracy and precision are two distinct properties of a measurement system. As we note in the preceding section, accuracy describes how centered your measurement system is compared to the actual variation. *Precision* describes how widely spread the variation of your measurement system is compared to the actual variation of the process or characteristic you're measuring. Figure 14-3 illustrates the idea of measurement precision. In (a), the dots representing the measurement system variability are clustered tightly together compared to the target representing the actual variation of the process or characteristic being measured. The measurement system depicted in (a) is precise even though it isn't accurate in its location. In (b), the measurement system variation varies widely compared to the actual process or characteristic variation. Although the (b) measurement system is accurate in its location, it isn't precise.



(a) Precise (b) Not precise

Figure 14-3: Measurement system variation.

Measurement system precision is made up of two components that you hear talked about a lot in Six Sigma: repeatability and reproducibility:

- *Repeatability* is the part of measurement variation that occurs when you repeat measurements with the same item, the same measurement setup, and the same equipment under the exact same conditions (or as closely identical as you can make them). In a way, you can think of repeatability as the short-term part of measurement system variation.
- *Reproducibility* is the part of measurement variation that occurs when you repeat measurements with the same items but with different measurement setups, with different inspectors, or under different environmental conditions. Reproducibility captures all the long-term variation influences in your measurement system.

Together, the metrics of repeatability and reproducibility capture all your measurement system's precision. Six Sigma has an acronym (of course!) for repeatability and reproducibility: R&R. You see this acronym used to describe how precise a measurement gauge is, as in its gauge R&R. (When you hear "R&R," don't think of "rest and relaxation" or of a railroad line. Instead, think of how good your measurement system is.)

Measuring Measurements: Measurement System Analysis (MSA)

You can measure how good your measurement system is in several ways, depending on the type of measurement data you're collecting and the type of measurement system you're using. Typical measurement system analysis (MSA) methods include audits, attribute studies, and gauge or continuous variable studies; you discover the nitty-gritty on each in this section.

Audit measurement system studies

An *audit* is a measurement system study where you compare your measurements to a known, correct standard. For example, you may compare what your computer system says you have in inventory (your measurement system) to what is actually in your physical inventory warehouse. Any differences between the two reflect variation in your measurement system.

For example, read the following paragraph as quickly as you can. As you're reading, circle each occurrence of the sixth letter of the alphabet — either lowercase or uppercase. Don't go back or reread parts of the paragraph.

> The necessity of training Farm Hands for first-class farms in the fatherly handling of farm livestock is foremost in the minds of Farm Owners. Since the forefathers of the farm owners trained the Farm Hands for first-class farms in the fatherly handling of farm livestock, the Farm Owners feel they should carry on with the family tradition of training Farm Hands of first-class farms in the fatherly handling of farm livestock because they believe it is the basis of good fundamental farm management.

Now, count how many total *f*s you found in the paragraph. Going through this paragraph slowly and carefully, you find exactly 36 *f*s.

Reading through the paragraph quickly, circling *f*s, is a type of measurement system. (It's a lot like the inspections placed in a process to verify the quality of what is being produced.) How good was your measurement system? Of the 36 *f*s, what percentage did you find? This analysis of how well you did is an audit of your measurement system.

Performing a simple data audit tells you how effective your measurement system really is. Industrial engineers have found human screening or inspection measurement systems to be consistently about 80-percent effective. Yet most people act under an illusion that the outcome of a screening operation is 100-percent correct.

To improve the effectiveness of a screening or inspection measurement system, try the following:

- Divide a large screening task into smaller pieces and assign it among several individuals.
- Clarify inspection criteria with pictures, examples, and so on.
- Use successive inspectors to incrementally increase the effectiveness of the inspection.
- Incorporate technology or automation to remove human error.

You can also make a Pareto diagram. *Pareto diagrams* are a great diagnostic tool for detecting problems with a measurement system. Vilfredo Pareto (1848–1923) was an Italian economist who proposed that 80 percent of an economy's wealth is held by 20 percent of its population. Since Pareto proposed his famous principle, other researchers have confirmed that it also applies to many other phenomena, including the distribution of measured defects — that is, 80 percent of the observed defects on a product or in a process can be attributed to 20 percent of the possible causes. (This *Pareto principle* is also known as the 80-20 rule.)

What this correlation means is that when you create a bar chart of the observed number of each type of defect on an item and then sort the order of the bars from most-frequently observed defects to least-frequently observed, only the first few defect categories should have a significant contribution to the overall defect count. So if your measurement system divides things up into multiple defect categories and a Pareto diagram shows approximately equal contribution from each category, you should suspect that something is wrong with your measurement system. A healthy measurement system should show that only a few defect categories make up the bulk of the observed defects.

Attribute measurement system studies

When you're measuring *attribute data* — such as pass-fail measurements of an invoice process or categorizing of failed products by failure type — you need to determine whether your ability to put items into correct categories is consistent and reliable. The risk of a poor attribute measurement system is twofold: You may falsely accept bad items, and you may falsely reject good items. Either way, the risk is that you'll make a decision that isn't consistent with reality. (Flip to Chapter 9 for details on attribute data.)

A visual inspection system

A computer disk drive manufacturer in the mid-1980s was experiencing a nagging problem with poor yields. The principle concern was that the sensitive magnetic medium coating the disks was in some way defective. As a result, the company implemented a collection of very demanding standards and a battery of stringent tests with the hope of detecting and removing media problems from the system.

At one point, design engineers at the company happened to notice some visual defects and spots in the magnetic coating on the disk. They concluded that this issue was the long-sought-after cause of their persistent yield problems. The engineering department immediately requested that manufacturing implement a final visual inspection of each disk to be done at the end of the already-tedious test cycle. With the implementation of this new inspection, the disk reject rate jumped from 8 to 10 percent. At $30 a disk, the scrap bill neared $300,000 per month!

With no real improvement evident, engineering proposed to further tighten the specifications on the magnetic disk medium. With mounting assembly and scrap costs, manufacturing asked that an expert from engineering audit the test and inspection process one last time before tightening the specs again.

The engineering expert reviewed the entire test and inspection process. He then decided to run some experiments to validate the final visual inspection process on the disks. His first experiment was to send a bunch of previously rejected disks back through the final inspection process without the inspectors' knowledge. The results were so startling that he reran the experiment several times; each time the previously inspected disks were secretly sent back through the final visual inspection process, an additional 10 percent of the disks would be rejected!

Armed with this new insight, the engineer tried another test. This time he took a bunch of disks that had already passed the final inspection step and secretly reinserted them back into the inspection process. Even with these "passed" disks, the inspectors continued to find ten percent of the previously passed disks to be visually defective.

As a final confirmation, the engineer sent a collection of passed disks and a collection of failed disks into the final stages of the assembly process. At the end of the assembly process, the disks with the rejected medium actually had a slightly higher final performance yield than those disks passing the visual inspection.

Clearly, this company was living in a measurement system illusion. The visual inspection system they had added provided no benefit to the company but was costing over $300,000 per month in incorrectly rejected disk medium.

Consider a measurement system that categorizes items — whether it is a characteristic or a process — into categories of "pass" and "fail." To study the effectiveness of this type of measurement system, follow these steps:

1. **Set aside 15 to 30 samples of what is being measured.**

   You want these samples to represent the full range of variation that is typically encountered, with about half of the samples being "passes" and the other half "fails."

2. **Create a master standard by designating each of the samples as a "pass" or a "fail."**

Use a panel of experts or some standard that you know is absolutely correct to make these distinctions.

3. **Pick two or three inspectors.**

   Have them review the sample items in a random order and record their conclusions — whether each item is a "pass" or a "fail."

4. **Have each inspector repeat her measurements of the samples after you mix the samples up into a new random order and record the repeated measurements.**

   Randomizing the samples before the second measurements is critical; each inspector's second measurements must be fair, as if they were happening for the first time. You may need to wait for a day before performing the second measurements (or spin the inspectors around in place until they're very dizzy — just kidding).

5. **For each inspector, calculate (as a percentage) how often the first and second measurements agreed with each other.**

   This percentage is the repeatability for each inspector. You can also calculate an overall measurement system repeatability by averaging the repeatabilities of the individual inspectors.

   Note: The calculated repeatability for the individual inspectors needs to be as close to 100 percent as possible. Lower calculated individual repeatabilities mean that the inspectors aren't consistent in distinguishing between good and bad items. Training helps inconsistent inspectors become consistent in their measurements.

6. **For each of the sample items, calculate the percentage of the recorded measurements where each of the inspectors agreed with themselves and all inspectors agreed with each other.**

   This figure is the reproducibility for the measurement system. The calculated measurement system reproducibility tells you how precise the measurement system is over the long term — over different inspectors, different setups, and different environmental conditions.

   You can also calculate the percent of the time individual inspectors and the group of inspectors agree with themselves and agree with the "master" standard created in Step 2.

   This number tells you how consistently your measurement system detects what your experts have decided really is pass and fail.

   As an example, a calculated 63 percent agreement between all inspectors for all samples with the "master" standard in a measurement system study means that the likelihood that this measurement system will correctly measure the items is 63 percent, and the chance of error is 37 percent. Clearly, the goal is to achieve a measurement system with as high an effectiveness as possible — that is, as close to 100 percent agreement as possible.

More sophisticated analysis tools are available for situations when an attribute measurement system has more than two categories. These tools, such as kappa analysis, can be found in advanced statistical analysis software such as Minitab and JMP (which we cover in Chapter 22).

Gauge or continuous variable measurement system studies

When you're measuring *continuous* or *variable data* (data whose values you can meaningfully add or subtract), you have more tools and analyses at your disposal than you do for the attribute data in the preceding section. In all cases, measurement system studies for continuous data mathematically compare the total observed variation to the portion of the variation stemming from the measurement system itself. (Chapter 9 has more information on continuous data.)

In Figure 14-1 earlier in the chapter, the total observed variation is made up of two parts: the variation of the actual items or process being measured and the variation imparted by the measurement system itself. The following equation summarizes this makeup:

$$\sigma^2_{OBSERVED} = \sigma^2_{MEASURE} + \sigma^2_{ACTUAL}$$

In an effective measurement system, the contribution of the measurement system itself is small compared to the overall observed variation. Table 14-1 provides a summary of measurement-to-observed variance ratio scores and of how to proceed in each situation.

Table 14-1 Measurement-to-Observed Variation Ratio Values and Interpretation

Calculated Variance	*Diagnosis*	*Prescription Ratio*
$\frac{\sigma^2_{MEASURE}}{\sigma^2_{OBSERVED}} \leq 0.1$	Good measurement system. Contribution of the measurement system to the overall observed variation is small enough to enable good decisions from the measurements.	Use measurement system as it is. Look for opportunities to simplify or make the measurement system less expensive or more efficient.

(continued)

Table 14-1 *(continued)*

Calculated Variance	***Diagnosis***	***Prescription Ratio***
$0.1 \le \frac{\sigma^2_{MEASURE}}{\sigma^2_{OBSERVED}} \le 0.3$	Marginal measurement system. Contribution of the measurement system to the overall observed variation is beginning to cloud results. The risk of making a wrong decision from the measurements is significant.	Use with caution — only if no better measurement alternative exists. Begin to improve the measurement system by training operators, standardizing measurement procedures, and investigating new measurement equipment.
$\frac{\sigma^2_{MEASURE}}{\sigma^2_{OBSERVED}} \ge 0.3$	Unacceptable measurement system. Guessing is probably just as precise. Don't base important decisions on information provided by a measurement system in this condition.	Measurement system needs to be corrected before any valid information can be derived from the system. Investigate causes of gross inconsistency.

Mathematically comparing measurement system variation to the overall observed variation isn't difficult. Rather, the difficult part is obtaining a good estimate of the measurement system variation from which to make the comparison.

Valid estimates of the variance of the measurement system usually involve two to three inspectors and five to ten process outputs or characteristics to measure. Each inspector also measures each process output or characteristic two to three times. From this legwork, you can use advanced statistical analysis tools, such as Minitab or JMP, to automatically perform the gauge analysis calculations, and you can begin to diagnosis and improve your measurement system if required.

Chapter 15

Mining Data and Processes for Insight

In This Chapter

- Separating the critical few performance influencers from the trivial many
- Using observational studies as a funneling tool
- Detecting root cause with multi-vari process observation

In Chapters 7 and 8, we show you many different ways to identify and discover all the possible variables (the Xs) influencing an important outcome, process, or characteristic (the Y). This chapter helps you start whittling this large list of potential influencers to a handful of variables on which to focus your improvement efforts.

This reduction of a large collection of potential factors down to a smaller area of focus is called *data mining*, and it allows you to concentrate your limited resources on the items that really have an impact on improvement. Throughout this whole process, be certain your choices are guided by the data rather than by opinion or guesses.

Filling the Funnel

To get a concentrated stream out of the bottom of a funnel, you first must fill the top abundantly. Six Sigma is no different. You start by dispassionately carrying all possible causes into your project. But as you progress, you let your analyses of the data tell you which variables to keep along for the ride and which ones you can safely filter out.

Let the data do the talking

One of the hallmarks of maturity in Six Sigma is an unwavering reliance on data. Data are used to understand what happened in the past and to decipher and improve the current situation. And data are the basis for predicting how things will perform in the future.

In Six Sigma, data trump the usual fare of opinion, speculation, guesswork, and politics. Data-driven decision-making is the culture of Six Sigma. People say, "In God we trust; all others must have data."

In a pure application of Six Sigma, you simply let the data do the talking. You withhold judgment regarding what it is that is wrong or what the solution will be and instead quietly listen to what the data are telling you about the situation and what should be done. This new way of operating stems from an acquired confidence in the science and power of Six Sigma — that gathering and querying data from a process more efficiently reveals the real, unbiased truth of its performance as well as the most effective and lasting improvement solution.

Cast a big net

A corollary of letting the data do the talking is exposing yourself to the voice of the data in many different ways. In Chapters 7 and 8, you discover tools like processing mapping, fishbone diagrams, C&E matrices, and failure mode effects analysis (FMEA). These are very powerful tools for querying a process to discover what potential factors may be contributing to its performance. In the remainder of this chapter, you discover graphical tools that you can use to mine data for evidence of factors influencing process or characteristic performance. In Chapter 16, you find out how to employ statistical hypothesis tests; Chapter 18 discusses designed experiments. Figure 15-1 shows how all these tools are used progressively to identify — and then narrow — the field of potential input Xs in the equation $Y = f(X) + \varepsilon$.

To be successful, it is important to cast a big net, to start your improvement effort by capturing as many potential Xs as possible. Then allow the Six Sigma tools — not your prejudgment or your opinion — to naturally weed out the Xs that are not critical and retain those that in fact are. That is one of the beauties of Six Sigma: Its formulaic application guides you to the solution of your improvement task.

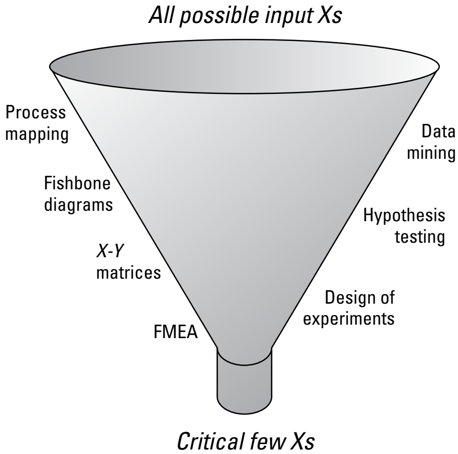


Figure 15-1: Tools for identifying all potential *X*s and funneling them down to a set of critical *X*s.

Mining Data for Insight

Data mining is just what its name implies — it's the labor of digging and sorting through data for clues to where the improvement gems may lie. Sometimes you have to go through a lot of dirt to find the gems. Searching for clues in data is not much different.

Go with what you have: Observational studies

Where do you begin your search for improvement gems? And what are the tools of the trade? Six Sigma practitioners have refined the data mining process to an efficient, powerful set of tools.

Data, data everywhere

A world of potential data exists all around you. Consider things such as

- The number of reams of paper your company uses in its copy center varies from day to day.
- Each classroom contains a different number of students.

- Different people work on a single process step, depending on their daily assignment.
- The feed rate of a milling machine is adjusted depending on the task.

One way to immediately tap into this cache of information is to simply begin to observe all the potential input and output variables in your improvement project and record them.

TIP

Record the data surrounding your project in table form — with a column for each *X* or *Y* variable and a new row for each point of observation, as shown in Table 15-1.

Table 15-1 Observational Study Data Recording Template

Obs. No.	*Dept. (X_1)*	*Hour (X_2)*	*System (X_3)*	*Processor (X_4)*	*Items/Hour (Y)*
1	B	8	Web	Sally	43
2	A	5	Web	Sally	37
3	B	4	Web	Bob	44
4	B	8	Desktop	Sally	35
5	B	4	Web	Sally	42
6	A	5	Web	Sally	39
7	B	3	Mainframe	Sally	41
8	A	8	Mainframe	Joan	36
9	A	1	Web	Sally	39
10	B	4	Mainframe	Joan	40

The curious mind: Observational studies

Thinking about, pondering over, and probing your recorded observations is a proven path to increased understanding. In Six Sigma, these activities are called observational studies. *Observational studies* revolve around analyzing the variation in the observed critical output or outputs and investigating which input variables that variation is linked to. What you're looking for are potential sources of the variation.

REMEMBER

Observational studies are different from planned experiments. In an observational study, you simply investigate the variation and data as they happen naturally, whatever the values may be. In an experiment, however, you actively control the variable values to see what the output does under certain input conditions. Experiments provide greater insight and resolution than observational studies do. (You can find out about the design and execution of experiments in Chapter 18.) But sometimes, you can't realistically or ethically perform a more powerful experiment. For example, purposely overcrowding a kindergarten classroom with 75 students to see what the effect on learning is wouldn't be right. Instead, education researchers gather naturally occurring data on classroom size and then perform observational studies.

Usually, the results of your observational study are a list of likely suspects that you then investigate further for confirmation and for conclusive evidence by using the techniques we cover in Chapters 16, 17, and 18. Sometimes, however, your observational study immediately reveals the real set of culprits. So always be on the lookout.

Digging in: Identifying potential sources of variation through graphical analysis

To study whether an observed input has an effect on an observed output, you create a set of box and whisker plots of the critical output, with each box and whisker plot corresponding to a different condition of the input variable. (See Chapter 10 for an explanation of box and whisker plots.) Several computer programs — including Minitab, JPM, and Microsoft Excel — automatically create these plots (see Part V).

Looking at an example

For example, Table 15-1 is a partial list of the data collected for a transactional process. The key output (Y) is how many items per hour are produced. The big net of possible input variables includes the department performing the transaction (X_1), the hour of the day in which the transaction was processed (X_2), the processing system used (X_3), and the actual person performing the transaction (X_4). In this example, more than 200 historical observations were collected.

What effect does the processor (X_4) have on the items per hour output (Y)? Figure 15-2 shows a set of box and whisker plots of Y for each condition of the X_4 input.

Does Bob, Joan, or Sally have much influence on the items transacted per hour? From the graphical view in Figure 15-2, you can clearly see that the number of items transacted per hour is about the same for each operator; they have about the same average level and about the same amount of variation. This result tells you that the processor variable (X_4) isn't a key contributor to the output variation.

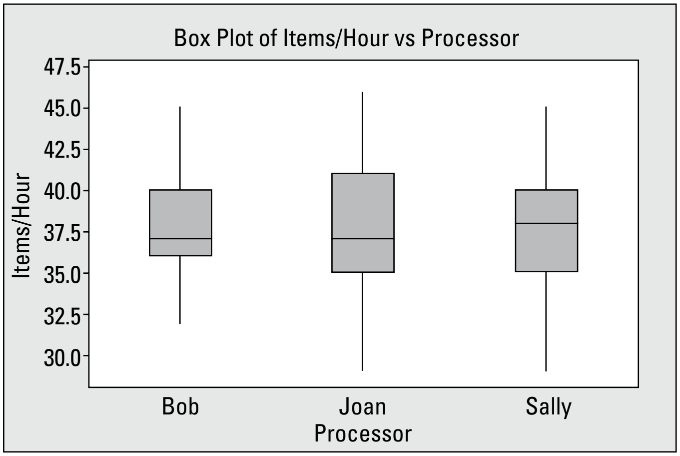


Figure 15-2: The effect of the processor on the items per hour output.

Statisticians using advanced techniques numerically compute the variation between the centers of variation for each of the different X_4 conditions and call this value the *between group variation.* They then perform a similar calculation to quantify the average width of variation for each individual condition and call that value the *within group variation.* If the between group variation is large compared to the within group variation, they conclude that the investigated variable does indeed influence the output. The box and whisker method is just a simple, intuitive way to accomplish the same thing while bypassing all math and technicalities.

What about the department performing the transaction (X_3)? Does it contribute to the output? Figure 15-3 is another box and whisker plot of the output versus the department doing the transaction.

Graphically, you can quickly see that the difference between the centers of variation from department A and department B is significant compared to the average width of variation within the departments. This variation tells you that the department performing the transaction does have some influence on the output. This variable will pass through your funnel and be investigated further for conclusive evidence.

TECHNICAL STUFF

Another way to perform observational studies is through correlation calculations (covered in Chapter 8). These calculations give you the same insight but aren't graphical, so they're harder to use and interpret.

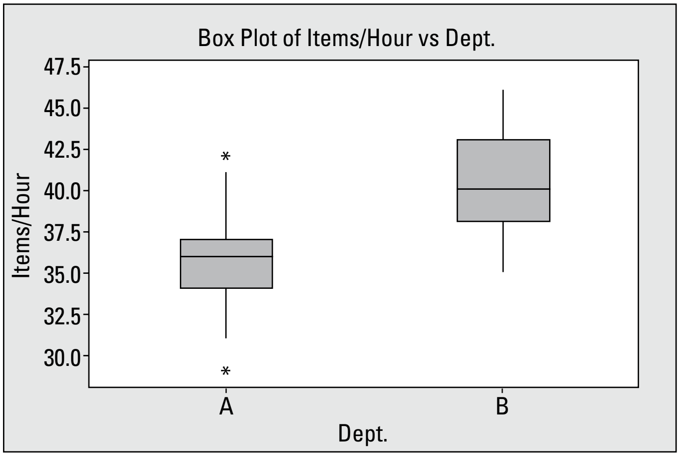


Figure 15-3: The effect of department on the items per hour output.

Considering additional studies

Many other tools are at your disposal when performing observational studies, including the following:

- **Multi-variable studies:** *Multi-vari studies,* as the name is often shortened, allow you to investigate the effect of several input variables at a time on a critical output. We cover multi-vari in the following section.
- **Main effects plots:** *Main effects plots* are a basic graphical technique we introduce in Chapter 10. They're an extremely easy and powerful way to explore the principle effect of a variable and its different levels on a critical output.
- **Interaction effects plots:** Sometimes, one variable by itself doesn't have a major impact on an output. But when you combine it with other variables, the combination has a significant influence called an *interaction effect.* For example, adding eggs by themselves to a cake batter doesn't immediately impact the cake's texture. But adding eggs to the batter and heating it in an oven produces a yummy dessert. The combined influence of adding eggs and heating has a significant influence on the cake texture.

Each of these additional observational studies is available in most off-the-shelf Six Sigma software packages (see Part V). This accessibility makes performing these analyses automatically much easier, giving you a big advantage over your predecessors.

Nearly Magical Multi-Vari Charts: Expertly Screening Factors

As we note in the preceding section, *multi-vari* stands for "multiple variable." Multi-vari charts allow you to listen to your process — to let your process tell you which of the possible factors you've identified actually are exerting an influence on its performance — in a short period of time with minimal data gathering requirements and without disrupting the normal flow of the process. You can sift literally hundreds of potential factors down to a handful (almost always fewer than 20). And sometimes, evidence from multi-vari charts is strong enough to directly pinpoint a single root cause, ending the need for more searching or experiments. In this way, a mult-vari chart is almost magic.

The key to multi-vari's power is its ability to tap into the voice of your process, bypassing the usual channels of guesswork, supposition, opinion, or politics. Think of it like a doctor's stethoscope, able to amplify and readily discern the underlying heartbeat of your process.

Categorizing the variations

Multi-vari uses a specific data sampling plan, which graphically highlights the major variation cause in the output characteristic of your process while allowing the process to operate in its normal fashion and without requiring any process disruptions. The major cause of output variation is isolated into three categories:

- Positional
- Cyclical
- Temporal

When you know which category of variation dominates the output of your process, you can concentrate on potential factors that fall under that category and eliminate factors that belong to the other categories. If, for example, you find that the major variation in your process output is coming from a temporal source, you can discount all possible factors that are positional or cyclical; the true root cause must be one of the temporal factors. The following sections describe each of these variation categories in detail.

Positional variation

The *positional variation* category is sometimes called *within unit variation.* That's because it's defined by the magnitude of variation coming from within a single unit. If you manufacture car axles that require a constant diameter across their length, you can measure the diameter at the left end, the middle, and the right end of the axle. Differences among these measurements are evidence that a positional variation factor is influencing the output of the process.

You may need to define a "unit" differently for different process situations. The basic requirement for a unit is that the output characteristic must be measureable multiple times at different points on the unit. That may be measuring the same characteristic at different locations on the unit like in the axle example; measuring the temperature of three different parts from a batch in a curing oven — one from the top of the oven, one from the middle, and one from the bottom — with the unit being an entire oven of parts; or measuring the performance of the process at three different times during a shift, with the unit being a shift's worth of production.

Cyclical variation

The *cyclical variation* category is sometimes called *between unit variation.* It's defined by the magnitude of variation that occurs between consecutive units drawn from the process. Large variation between units means that the factor driving process performance must be one that falls under the cyclical category. In the axle example, the magnitude of the variation that you observe in the diameters between consecutively produced axles is cyclical variation.

Temporal variation

The *temporal variation* category is sometimes called *time-to-time variation.* When you look at the magnitude of variation between segments of the process separated by a significant amount of time, that is temporal variation. If this type of variation is large, the factor driving process performance must be one that belongs to the temporal category; otherwise, the factor must be from another category. For the car axle example, the magnitude of the variation you observe on axles over a period of days or weeks is an example of temporal variation.

Putting it all together: Creating a multi-vari sampling plan

Here's the step-by-step procedure for pulling intermittent data from a running process:

1. **Select or establish a continuous-type data measurement of process output performance.**

   This scale may be in units of time, dollars, inches, grams, but whatever it is, it must be a continuous data type. (See Chapter 9 for an explanation of continuous data.)

2. **Explore the historical values of your selected output metric to understand what the magnitude of variation has been in the process.**

   After you begin multi-vari sampling of your process, you continue until you've observed approximately the same magnitude of variation that you've seen historically. That way, you're sure to have monitored the process long enough to have captured the activity in the input factors that is driving variation in the process output.

3. **Define what constitutes a unit in your multi-vari study.**

   Remember that your defined unit must allow two or more measurements of the process output in different "locations" within or on the unit.

4. **Collect two to five measurements from within the unit defined in Step 3 on three to five consecutive units.**

5. **Allow some time to pass — enough that potential factors have a chance to exert new influence on the process.**

6. **Repeat Steps 4 and 5 in three to five consecutive-unit intervals until you've captured at least 80 percent of the historical process variation.**

   Simply compare the range of the historical data to the range of the multi-vari data. If they're approximately equal, you've captured enough multi-vari data. If not, keep collecting.

7. **Create a multi-vari chart and analyze and interpret the chart for a primary source of variation.**

   The following section shows you how to make the multi-vari chart. Your source of variation will be positional, cyclical, or temporal.

Constructing a multi-vari chart

TIP

You don't have to wait until your multi-vari data are collected to start creating the multi-vari chart. Instead, you can build the chart, incrementally, adding more to it as you collect more data.

Multi-vari charts can be drawn by hand; in fact, the process operators themselves can create them, providing those folks with a critical opportunity to invest themselves in the discovery of the root cause and the development of the solution. A multi-vari chart looks pretty much like any other two-axis plot, with time moving from left to right on the horizontal axis and the measured process output metric plotted against the vertical axis. The multiple measurements of each unit are plotted together in a grouping. Consecutive unit groupings move from left to right over time. A break in the horizontal progression of the chart indicates a temporal break in the process sampling (used to highlight the magnitude of temporal variation sources). Figure 15-4 shows an example of a multi-vari chart.

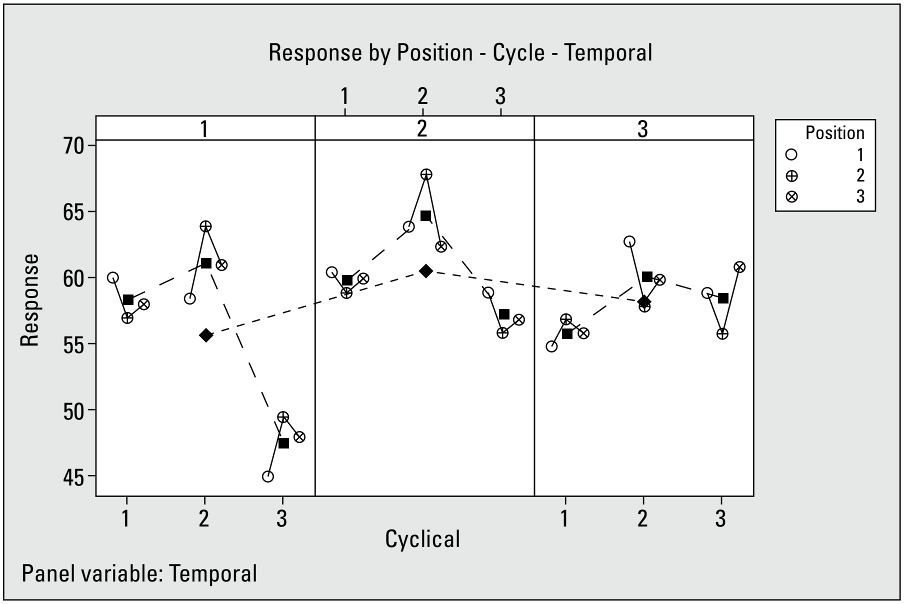


Figure 15-4: An example of a multi-vari chart.

Here are the most-important features of the multi-vari chart in Figure 15-4:

- **The multiple measurements taken on each unit are plotted as circles.** A slightly modified circle designates the first, second, and third within-unit measurements. A solid line connects the multiple measurements within each unit and graphically indicates the magnitude of variation originating within each unit — the variation contribution from positional factors.
- **An average point is plotted for each unit grouping.** In Figure 15-4, these unit averages are drawn as squares. If the multi-vari chart is drawn by hand, this average can be estimated.

  REMEMBER

  The average isn't the center point between the maximum and minimum unit measurements; instead, think of it as the "balance point" between all the unit measurements.
- **A long-dashed line is drawn connecting the averages of consecutive unit groupings measured.** The up-and-down variation of this connecting line indicates the magnitude of variation between units, or the contribution of cyclical variation factors.

- **A mark is plotted to show the overall average of the set of consecutive units measured.** Figure 15-4 uses a diamond-shaped marker. A short-dashed connecting line is drawn between the overall average points. The up-and-down variation of this connecting line indicates the magnitude of the variation between long breaks in time, or the contribution of temporal variation factors.
- **Vertical lines are drawn along the horizontal axis to indicate the end of one temporal set of measurements and the beginning of the next.** Each vertical divider embodies a relatively long duration of unmeasured process execution time.
- **The sampling pattern repeats itself for three temporal occurrences.** Note that Figure 15-4 is just an example; a typical multi-vari chart would continue for more temporal occurrences, always until enough process data are captured to match the historical levels of variation known to exist in the process.
- **Each temporal occurrence contains the measurements of three consecutive units.** Each cycle should contain at least three consecutive units, but up to five or six may be necessary.
- **Each unit consists of three measurements of the same process characteristic.** As with the temporal occurrences, having up to five or six measurements is sometimes useful.

Interpreting a multi-vari chart

To determine which category of input variable drives the performance of your process output, all you have to do is graphically decide which of the three types of variation — positional, cyclical, or temporal — displays the greatest magnitude of variation in your multi-vari chart. You can compare the variation types by homing in on each one separately. Figure 15-5 shows the multi-vari chart from Figure 15-4 in the preceding section with the magnitude of the positional variation highlighted.

The vertical range of the positional variation — indicated by the height of the gray boxes in Figure 15-5 — graphically depicts the magnitude of the process variation stemming from positional input factors. Figure 15-6 shows the same original multi-vari chart, this time with the cyclical variation highlighted.

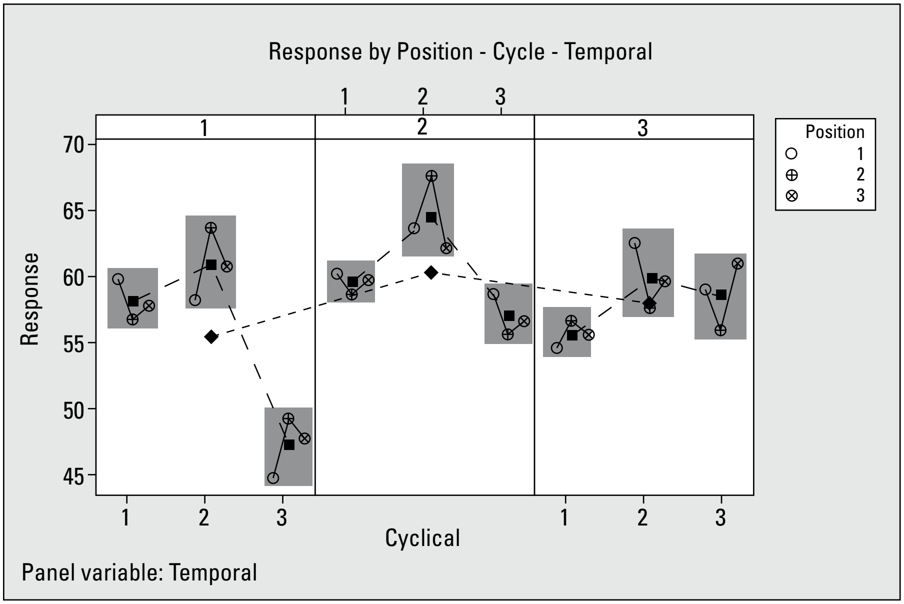


Figure 15-5: The positional or "within unit" variation highlighted on a multi-vari chart.

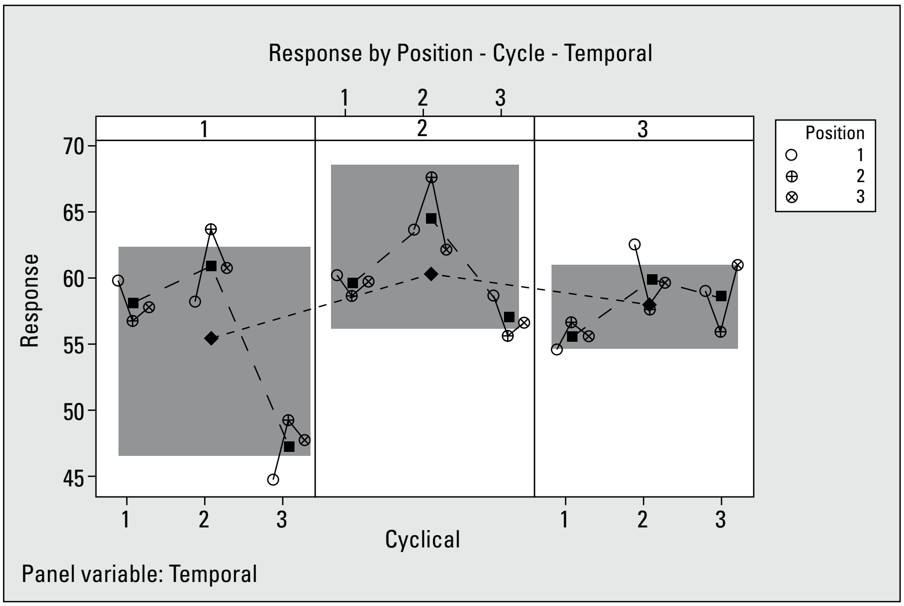


Figure 15-6: The cyclical or "between unit" variation highlighted on a multi-vari chart.

The vertical range between the unit averages — indicated by the height of the gray boxes — graphically depicts the magnitude of variation coming from cyclical factors. Finally, Figure 15-7 shows the original multi-vari chart with the temporal variation highlighted.

The vertical range between the temporal averages — shown again by the height of the gray box — graphically highlights the magnitude of the variation coming from temporal factors. Temporal factors are those that only change their input value across larger gaps of time but not within single units and not between consecutive units.

Based on Figures 15-5 through 15-7, you can see that the vertical magnitude of the cyclical variation exceeds that for the positional or temporal categories. That result is the voice of the process telling you that the real root cause of your process performance in Figure 15-4 is associated with some factor whose input value changes between production or creation of consecutive units. The multi-vari chart proves that all other factors that change input value within single units or change input value over longer times don't exert a significant influence on the performance of the process.

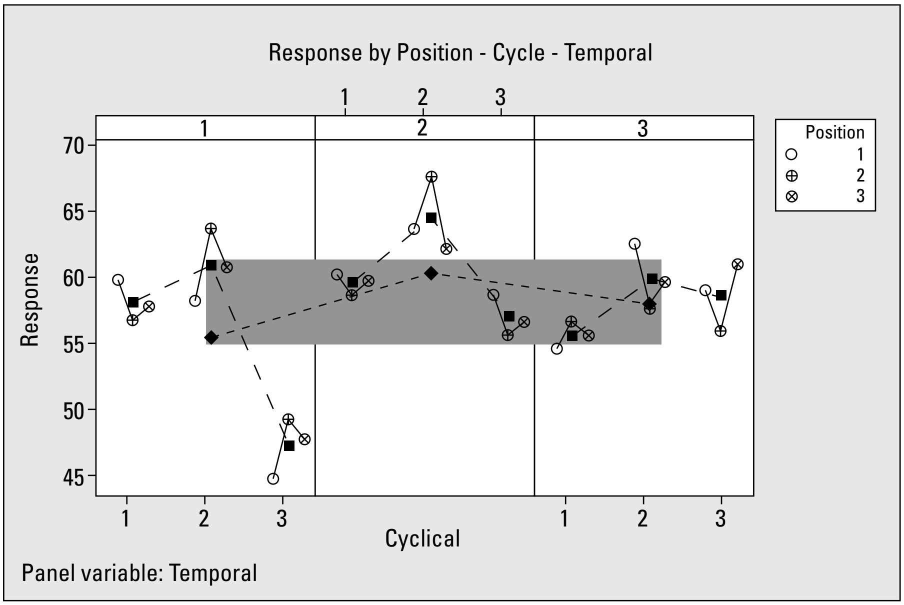


Figure 15-7: The temporal or "time-to-time" variation highlighted on a multi-vari chart.

Checking out a Multi-Vari Example

Consider an example of a real situation where you can use a multi-vari chart to pare down a large collection of potential factors and discover the "critical few" factors that truly drive the performance of the process.

A label supplier manufactures labels on rolls of adhesive backing strip. A critical characteristic of this process is the strength of adhesion of the labels to the backing strip. If it's too strong, the labels have difficulty coming loose from the backing strip and cause problems in the label-applying machinery of the company's customers. If it's too weak, the labels fall off the products they're placed on.

Over the last two months, the variation in label adhesion strength has ranged from 0.8 to 6.3 pounds. This discrepancy has become a significant customer problem. The cross-functional team has created fishbone diagrams and process flowcharts identifying numerous possible variables and causes and has come up with several theories on what factors are contributing to the label adhesion variation:

- It's a problem with the adhesive application equipment, leading to inconsistent adhesion of the labels.
- It's an operator issue driven by problems on the swing shift.
- It's due to excessive variation in the adhesive itself.

You've been asked to use data-driven methods to focus and guide the improvement project team. This scenario is a perfect situation to use multi-vari study to objectively narrow a field of many possible factors down to the true cause. Here's how you do it:

1. **Ascertain the historical level of problem variation in the process.**

   The historical level of variation in the adhesion performance of the process is 0.8 to 6.3 pounds. This example study will need to continue until about that range of variation is observed to make sure the culprit factor is captured within the study.

2. **Define the study unit.**

   How should a unit in this example study be defined — one label? Adhesion force can't be measured more than once on a single label, so setting the study unit as a single label isn't viable. What about using a five-label section cut off a roll as the unit? That setup can be measured up to five times, so you define a unit to be a five-label strip off of a roll.

3. **Collect data from the process.**

   You decide to start the multi-vari study by taking three consecutive five-label strips from each production shift and then testing all five labels on each of those strips. Table 15-2 shows the sample measurements from the uninterrupted process:

Table 15-2 Adhesion Sample Data

Time (Shift)	*11:15 a.m. (Day)*			*5:35 p.m. (Swing)*			*6:05 a.m. (Grave)*		
5-Label Strip	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Label pos. 1	5.5	4.9	4.5	5.0	4.8	3.9	3.2	1.2	4.7
Label pos. 2	4.7	4.8	2.7	4.4	3.1	4.8	0.8	3.6	3.3
Label pos. 3	4.8	5.5	4.9	3.7	3.8	4.0	4.5	0.7	5.0
Label pos. 4	5.4	4.0	4.0	4.2	3.7	4.1	5.0	5.0	4.8
Label pos. 5	5.6	5.3	6.0	4.0	4.3	4.7	4.8	3.2	5.0

   Reviewing the data, you can see that some of the force measurements drop down to the 0.7- and 0.8-pound range; some also get as high as 6 pounds. This observed range is approximately the same as the 0.8-to-6.3-pound range observed historically, so you know you've got enough data.

4. **Create the multi-vari plot.**

   Plotting the data in the positional, cyclical, and temporal groups, as we describe in the earlier section "Constructing a multi-vari chart," you can create a graphical multi-vari view of your data. (See Figure 15-8.)

5. **Interpret the multi-vari plot.**

   Review the magnitudes of each of the categories of variation — positional, cyclical, and temporal — as we discuss in the earlier section "Interpreting a multi-vari chart." The largest magnitude of variation in the process output (adhesion) occurs within single units, as shown in the highlighted version of the multi-vari chart in Figure 15-9.

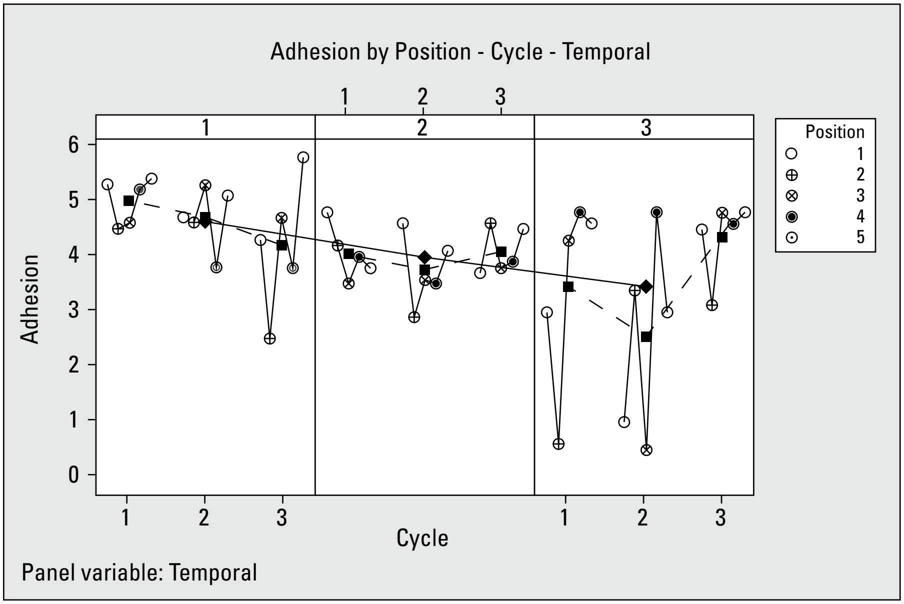


Figure 15-8: Multi-vari plot of the captured label adhesion process data.

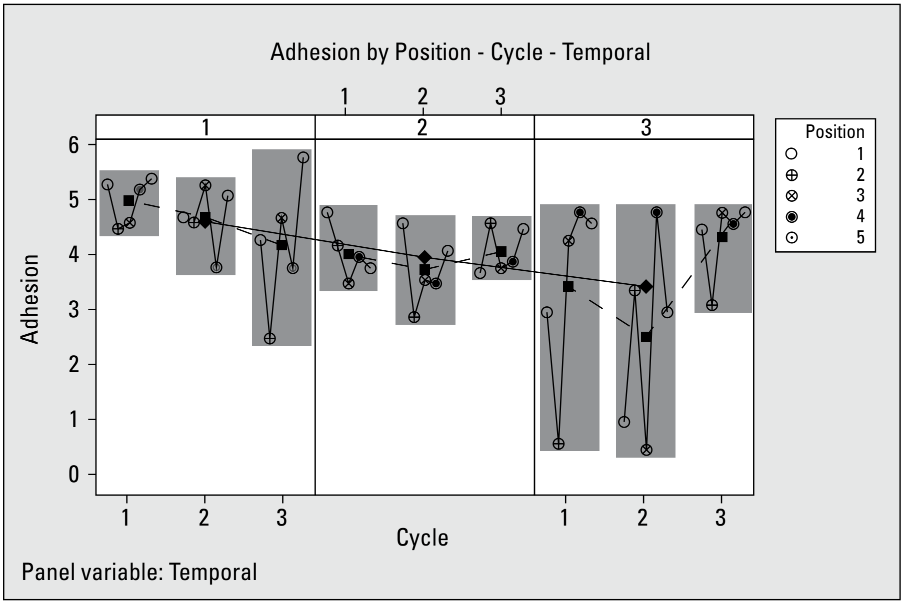


Figure 15-9: The dominant category of positional variation highlighted in the multi-vari chart.

You can draw these conclusions from the multi-vari chart:

- Positional variation is the largest source of variation.
- Adhesion shows some deterioration as the day progresses.
- The grave shift readings have the most variation.
- The swing shift readings have the least variation.
- The positional variation and temporal variation may interact.

Now you go back and review all the possible factors identified in the fishbone diagram or process flow map. You can cross any factor that was cyclical off the list of items for further investigation and flag positional factors and any related temporal factors. (Flip to "Categorizing the variations" earlier in the chapter for more on each type of variation.)

Chapter 16

Making Confident Decisions

In This Chapter

- Distinguishing populations and samples
- Surveying sampling distributions and the central limit theorem
- Establishing confidence intervals for population means, variances, and proportions

Which truck is better, Ford or Chevy? Which spread is better for you, butter or margarine? From public opinion polls to medical treatment reports to climate studies, the media literally bombards you with "scientific" information on these types of issues. Unfortunately, you don't always have sufficient evidence or the analytical skills you need to make the best choices. But you *can* make the best choices when it comes to your Six Sigma processes.

In this chapter, we share the tried-and-true methods to help you make the best decisions in your business and feel confident about them. After all, when you're operating a business, finding the truth within data is paramount to consistent success. Is Process A better than Process B? Which marketing plan is more effective? Which facility is operating with higher quality? Has our new warehouse really reduced inventory costs? With this chapter, you can be the authoritative, in-the-know source.

Introducing Populations and Samples

Statisticians think of the world of data in terms of populations and samples. Think of the city you live in. If you need to know the average age of your city's residents, you can (theoretically) track down each and every resident and record his or her age. This type of collection of data is called a *population.* It captures all occurrences of the measurement within the defined bounds of the population — for example, the cycle time of all credit card transactions over the last 12 months, the measured volume of water dispensed into each 0.5-liter bottle last week at a water bottling plant, or the cost of each of the company's travel reimbursements submitted in November. The difficulty with populations, however, is that capturing all the data associated with a defined population is often not practical or even possible.

A *sample,* on the other hand, is a subset of measurements taken from a population. The purpose of a sample is to estimate a population through a smaller but representative collection of data. Examples of samples include the cycle time of 100 randomly selected credit card transactions from over the last 12 months, the measured volume of water dispensed into every 10th bottle at a water bottling plant, or the cost of all the travel reimbursements from a single employee. After you define the boundaries of a population, a sample is any subset of the full population data.

Statisticians usually use Greek letters to represent population parameters (μ for the average and σ for the standard deviation) and Roman letters for corresponding sample parameters ($\bar{x}$ for the average and s for the standard deviation; we cover these statistical calculations in detail in Chapter 9).

If you find a rare example where you're able to capture all the data for a population, the calculated statistics — such as the average — will exactly represent the population. If, however, the data you have are from a sample, you'll always have some amount of error between the calculated statistics of the sample and the exact statistics of its parent population.

Parameter Distributions from Multiple Samples: Using the Central Limit Theorem

What happens when you take repeated samples from the same population? Imagine flipping a coin ten times and counting the number of heads that you get. The laws of probability say that you have a 50-50 chance of getting heads on any single toss. So if you toss the coin ten times, you'd expect to get five heads, right?

Go ahead and pull a coin out of your pocket and try this experiment if you want. You may not get the expected five heads after flipping the coin ten times. You may get only three heads. Or maybe you get six. If you keep repeating the ten-flip experiment over and over again (you can think of each set of ten flips as a repeated sample from the population of all future flips of the coin), the distribution of the number of heads that you get in each set of ten flips will look something like Figure 16-1. After each experiment repetition (sample), the number of heads out of the ten flips was counted. The experiment was repeated 10, then 100, and finally 1,000 times.

This coin flip experiment is analogous to any situation where you take a sample of data from a population — like taking a sample of measurements from a process and calculating the average. Two important facts arise from Figure 16-1 that you can generalize to any sampling situation:

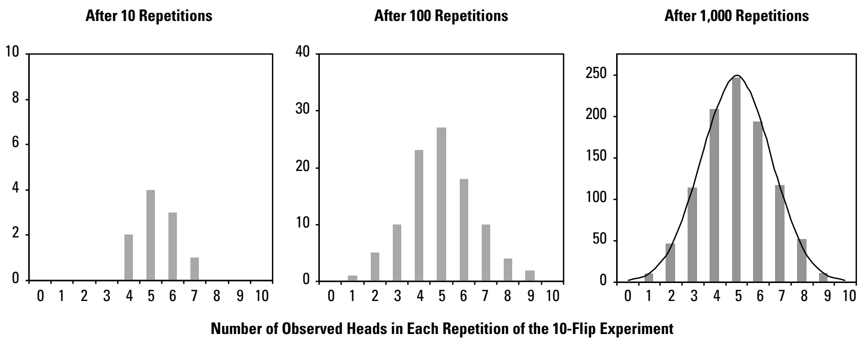


Figure 16-1: Results of a repeated, ten-flip coin experiment.

- **Repetitions of the measurement event produce different outcome results.** That is, the result is variable from sample to sample. In the coin-flipping experiment, not every repetition of the ten-flip series produced the expected five heads. The same is true if you repeatedly take a five-point average of the thickness of paper coming out of a paper mill.
- **This resulting measurement, or *sampling distribution,* is normally distributed (see Chapter 12).** The variation is also centered on the expected outcome. And the more repetitions you make, the closer and closer the sampling variation gets to a perfectly normal distribution.

Statisticians call repeated measurements of a characteristic or a process *samples*. So the variation that occurs in repeated sampling events they call its *sampling distribution.*

The sample measurements themselves aren't the only things that vary when you're dealing with repeated samples. Statisticians have refined and honed technical definitions of what is called the *central limit theorem.* Although each definition is equally mysterious, they all say the same basic thing: When you calculate statistics on a sample (such as the sample's average), repeating those calculations on another sample from the same population will always give you a slightly different result for the calculated statistic. Additionally, the collection of repeated calculated results will always have a distribution itself. This sampling variation follows a normal bell curve centered on the true variation of the underlying population. Further, the width of the sampling distribution depends on how many measurements you take in each sample (the sample size). The larger your sample size, the narrower the sampling variation.

Although statisticians often have a difficult time explaining the central limit theorem, its power and utility are nevertheless remarkable. The results of the central limit theorem allow you to predict the bounds of the future and to quantify the risks of the past.

Calculating Decision Risk: Confidence Intervals

Because samples are accessible (and populations generally aren't), samples are the primary data tool for understanding a business or process performance situation. But samples can never give you an exact measure of what is going on in the underlying population. They're inherently fuzzy! How sure can you be that your sample accurately enough reflects what is actually going on in the underlying population?

The key to objective decision-making lies in *confidence intervals*. They use the central limit theorem to quantify how much confidence you can place in any of your measurements or statistical conclusions from samples. (Head to the preceding section for info on this theorem.)

Don't confuse confidence in your measurements, the topic of this chapter, with measurement system capability, the topic of Chapter 14. The measurement confidence we talk about here doesn't address the capability of your system for acquiring measurements. Instead, *measurement confidence* assumes you have a perfect, ideal system for acquiring your measurements. This scenario should serve as another reminder of how important validating the capability of your measurement system is.

For example, say your factory has just produced 5,000 ballpoint pens. You want to know the average diameter of this population, so you randomly select 30 pens from the population, measure each of their diameters, and calculate the average to be 0.120 inches. (See Chapter 9 for details of calculating averages.) Suddenly, your boss rushes into your office and asks, "What's the average diameter of our latest pens? Our customer just called and said it will reject the whole batch if the average is higher than 0.125 inches!" Your boss anxiously awaits your response. What do you say? How confident are you in your calculated average?

The central limit theorem says that if you repeat your 30-sample measurement, you'll get a slightly different average. Your customer will, too, when checking its own sample. But how different will each calculation of the average be? Confidence intervals give you a way of quantifying how much variation will appear in repeated measurements and statistical calculations. Knowing how to create confidence intervals, you'll be able to tell your boss, "With 99.7 percent certainty, our average pen diameter will be within our customer's requirement."

Confidence intervals for means

You see averages every day. Unfortunately, very few of them are communicated with a confidence interval.

Making decisions with large samples

When your sample size has more than 30 data points, you can calculate the confidence around the true population average (μ) as

$$\mu = \bar{x} \pm Z \frac{\sigma}{\sqrt{n}}$$

where

- $\bar{x}$ is the average of the sample data.
- Z is the sigma value corresponding to the desired level of confidence you want to have.
- σ is the calculated standard deviation from your sample.
- n is the number of data points in your sample.

Figure 16-2 illustrates the confidence interval for μ.

From Figure 16-2, you can see that most sample average calculations are close to the real population average. In fact, 68 percent of calculated $\bar{x}$s are within

$$\pm \frac{\sigma}{\sqrt{n}}$$

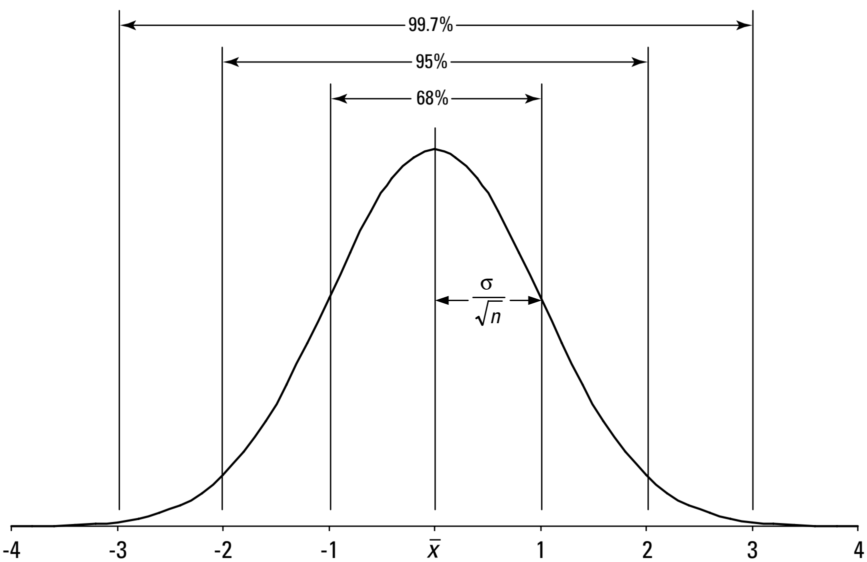


Figure 16-2: Sample distribution and confidence intervals for μ for various probability (Z) values.

of the real population average. Further, 95 percent of calculated $\bar{x}$s are within

$$\pm 2\frac{\sigma}{\sqrt{n}}$$

of the real population average. And 99.7 percent of calculated $\bar{x}$s are within

$$\pm 3\frac{\sigma}{\sqrt{n}}$$

of the real population average. This formula works any time you have more than 30 measurements in your sample.

Anytime you calculate a confidence interval, you also have an associated risk of being incorrect. This risk is simply the complement of the calculated confidence. So for a 95-percent confidence interval, you have a corresponding 5-percent risk of the actual population average being outside your calculated confidence interval.

The risk of incorrectly concluding that the population average is within your calculated confidence interval when it really isn't is called *alpha* (α) *risk.*

Making decisions with small samples

When you have only a few data points in your sample, you're not able to get an accurate estimate of the population standard deviation σ. With these small samples, statisticians replace variable σ with s to communicate that you only have an inaccurate estimate of the population standard deviation from your sample.

So when your sample has anywhere from 2 to 30 data points, you have to use a different factor in place of Z. Statisticians call this new factor for small-sized samples t. t is more conservative because your smaller sample size lessens the accuracy of your calculated value for the standard deviation. In fact, for each desired confidence level, t is adjusted depending on how many data points are in your sample. Table 16-1 provides values for t for selected confidence percentages and sample sizes.

Table 16-1 ***t* Values**

Confidence	*n = 2*	*n = 5*	*n = 10*	*n = 25*	*Z*
68%	1.837	1.142	1.059	1.021	1
95%	13.968	2.869	2.320	2.110	2
99.7%	235.811	6.620	4.094	3.345	3

Using *t,* the formula for the confidence interval around the true population average becomes

$$\mu = \bar{x} \pm t\frac{s}{\sqrt{n}}$$

where the value for *t* depends on your desired level of confidence and the number of data points in your sample.

Which is better? Comparing averages

Very often, you need to determine whether two or more items are different and, if so, by how much. Examples include the following:

- Are the operators of a process different?
- Do two alternative manufacturing processes lead to significantly different outputs?
- Is the gas mileage of Car A better than Cars B and C?
- Are the marketing collateral materials with color graphics really better at generating leads than black-and-white equivalents?

You can use confidence intervals for population averages (μs) to verify differences between any two or more versions of the same outcome. Here's how:

1. **Take samples from each of the different versions or conditions you're comparing.**
2. **Calculate the appropriate confidence interval for each different version or condition of the characteristic.**

   Remember, if your sample has fewer than 30 data points, you need to use the *t* formula to calculate the confidence interval. Also remember to use the same confidence level for each condition or version you're comparing.
3. **Graphically or numerically determine whether the confidence intervals of the different versions or conditions overlap at all.**

   If overlap does exist between any of the confidence intervals, you can say with your decided level of confidence that no difference exists between the overlapping versions.

   On the other hand, if you don't see any overlap, you can know right away that a difference does exist between the different versions of the output.

As an example, Figure 16-3 shows a graphical comparison of the 95-percent confidence intervals for the average items-per-hour output for three types of computer systems.

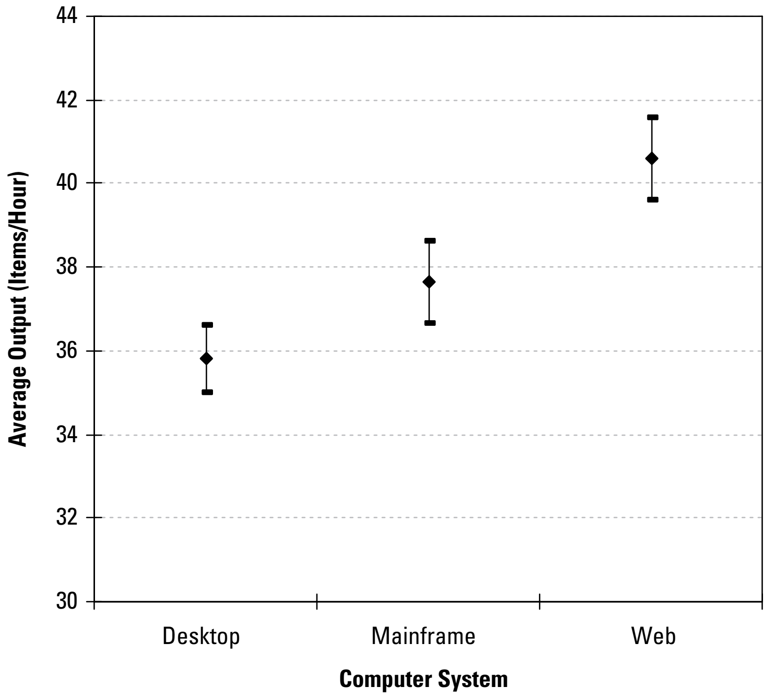


Figure 16-3: A graphical comparison of the confidence intervals for three different types of computer systems used in an invoicing process.

Graphically comparing the confidence intervals for the average performance clearly shows no overlap in the intervals. So with 95-percent confidence, you can say that the web computer system is better than the mainframe computer system (better on average by three items per hour) and that the web computer system is better than the desktop computer system (better on average by almost five items per hour). If you had seen an overlap between any of the three computer system options, you would have concluded (with 95 percent confidence) that no significant difference occurred between the overlapping versions.

Confidence intervals for standard deviations

Not surprisingly, your calculations of the standard deviation of a process or characteristic have sampling variability in them, just like your calculations of the mean do. That means that you should create confidence intervals for standard deviations, too. (Chapter 9 shows you how to calculate standard deviation.)

How much variation exists?

To construct a confidence interval around your calculated sample standard deviation, you have to use a new factor invented by statisticians called χ^2. (This factor is named after chi, the 22nd letter of the Greek alphabet, and is pronounced "kye squared.") Like the *t* value used to create confidence intervals for averages (see the earlier section "Making decisions with small samples"), the value of χ^2 depends on how many data points are in your sample — the more data points in your sample, the more confident your estimate. Another twist is that you have different values of χ^2 for the lower and upper limits of the confidence interval. Table 16-2 shows upper and lower values of χ^2 for common 1-, 2-, and 3-sigma confidence values.

Table 16-2 χ^2 Values

Confidence	n = 2	n = 5	n = 10	n = 25	Z
68%	1.987	6.599	13.088	30.833	1
	0.040	1.416	4.919	17.169	
95%	5.187	11.365	19.301	39.749	2
	0.001	0.460	2.628	12.225	
99.7%	10.273	17.800	27.093	50.163	3
	0.000	0.106	1.241	8.382	

Note: First value listed in each table cell is χ^2_{LOWER}. Second value listed in each cell is χ^2_{UPPER}.

You then use the χ^2 values from Table 16-2 with the following formula to calculate the confidence interval for a population standard deviation (σ) by using its sample standard deviation (s).

$$\sigma = \left[\sqrt{\frac{(n-1)s^2}{\chi^2_{LOWER}}}, \sqrt{\frac{(n-1)s^2}{\chi^2_{UPPER}}}\right]$$

As an example, suppose your sample of five data points leads to a sample standard deviation of 3.7. To create a 95-percent confidence interval for the population standard deviation, you use the values in Table 16-2 corresponding to a 95-percent confidence and $n = 5$. So $\chi^2_{LOWER} = 11.365$ and $\chi^2_{UPPER} = 0.460$. Plugging these values into the equation, you get

$$\sigma = \left[\sqrt{\frac{(5-1)3.7^2}{11.365}}, \sqrt{\frac{(5-1)3.7^2}{0.460}}\right]$$

or [2.195, 10.907]. Basically, this result means you can say that, with 95-percent confidence, you know that the real population standard deviation lies somewhere between 2.195 and 10.907.

Note: Confidence intervals for standard deviations are usually very wide unless you have a lot of data points in your sample. This large range occurs because an estimate of the standard deviation is always less accurate than an estimate of the average.

Which has less variation?

Sometimes, you need to compare the variability of two populations to find out whether one has more variation than the other. You do this comparison by creating a confidence interval for the ratio of the variances of the two populations. If the ratio confidence interval includes the value *1* within its limits, you know that the two populations have equal variability. If the confidence interval doesn't contain the value of *1* within its limits, you know that the two populations have different amounts of variation.

Constructing a confidence interval around this ratio of variances requires yet another statistical factor, *F,* whose value depends on three things: the desired level of confidence, the number of data points in the numerator distribution (n_1), and the number of data points in the denominator distribution (n_2). Table 16-3 is a list of *F* values for 95-percent confidence intervals and various sample sizes.

Table 16-3 — *F* Values for 95% Confidence

	$n_1 = 2$	$n_1 = 5$	$n_1 = 10$	$n_1 = 25$
$n_2 = 2$	161.446	224.583	240.543	249.052
$n_2 = 5$	7.709	6.388	5.999	5.774
$n_2 = 10$	5.117	3.633	3.179	2.900
$n_2 = 25$	4.260	2.776	2.300	1.984

You use the *F* values from Table 16-3 with the following formula to calculate the confidence interval for a ratio of variances:

$$\frac{\sigma_1^2}{\sigma_2^2} = \left[\frac{1}{F(n_2,n_1)} \frac{s_1^2}{s_2^2}, F(n_1,n_2) \frac{s_1^2}{s_2^2} \right]$$

As an example, suppose you have a ten-point sample from population *A,* and its variance $s_A^2 = 4$. Another population, called *B,* has a sample of five points, and its variance $s_B^2 = 7.5$. The 95-percent confidence interval for the ratio of σ_A^2 to σ_B^2 is calculated as

$$\frac{\sigma_A^2}{\sigma_B^2} = \left[\frac{1}{F(5,10)}\frac{s_A^2}{s_B^2}, F(10,5)\frac{\sigma_A^2}{\sigma_B^2}\right] = \left[\frac{1}{3.633}\frac{4.0}{7.5}, 5.999\frac{4.0}{7.5}\right] = \left[0.147, 3.199\right]$$

This confidence interval contains the value of *1* within its limits, so all you can say with 95-percent confidence is that no evidence indicates that the two populations have different variances. Like the confidence intervals for standard deviations in the preceding section, confidence intervals for variance ratios are usually very wide unless you have a lot of data points in your sample, because an estimate of the standard deviation is always less accurate than an estimate of the average.

Four out of five recommend: Confidence intervals for proportions

When you calculate the number of successes out of a certain number of attempts — like "four out of five dentists recommend sugarless gum" — you can write this proportion (*p*) mathematically as

$$p = \frac{y}{n}$$

where *y* is the number of successes and *n* is the total number of attempts or trials.

Calculating a proportion creates yet another sampling distribution. The resulting confidence interval around a calculated proportion is

$$p = \frac{y}{n} \pm Z\sqrt{\frac{(y/n)(1-y/n)}{n}}$$

So, as an example, if you wanted to be 90-percent sure of the calculated proportion for the four out of five dentists, you would calculate the confidence interval as follows:

$$p = \frac{4}{5} \pm 1.645\sqrt{\frac{(4/5)(1-4/5)}{5}} = \frac{4}{5} \pm 0.294$$

This result means that, with 90-percent confidence, the proportion of four out of five dentists really could be as small as one-half or as large as one.

In reality, proportions can never be less than zero or greater than one. So if your confidence interval for your proportion exceeds these natural limits, just adjust the confidence interval to the natural limit.

If you're comparing the difference between two proportions, such as

$$p_1 = \frac{y_1}{n_1}$$

and

$$p_2 = \frac{y_2}{n_2}$$

the confidence interval for this difference becomes

$$p_1 - p_2 = \frac{y_1}{n_1} - \frac{y_2}{n_2} \pm Z\sqrt{\frac{(y_1/n_1)(1-y_1/n_1)}{n_1} + \frac{(y_2/n_2)(1-y_2/n_2)}{n_2}}$$

To illustrate this confidence interval, imagine you're part of a company with two production lines. You suspect that your Toledo (T) plant produces a higher proportion of good items (yield) than your Buffalo (B) plant. You select samples of size $n_T = n_B = 300$ from each plant and find that the number of good items from the Toledo plant (y_T) is 213, while the number from the Buffalo plant (y_B) is 189. That means that a 95-percent confidence interval for the difference between the Toledo and the Buffalo yields is

$$\begin{aligned} p_T - p_B &= \frac{213}{300} - \frac{189}{300} \pm 2\sqrt{\frac{(213/300)(1-213/300)}{300} + \frac{(189/300)(1-189/300)}{300}} \\ &= 0.08 \pm 0.076 \end{aligned}$$

or, equivalently, [0.004, 0.156]. Because this confidence interval doesn't include zero, you can conclude — with 95-percent confidence — that the Toledo plant produces, on average, a higher proportion of good items than the Buffalo plant. Table 16-4 is a summary of all the confidence interval calculations you use in Six Sigma.

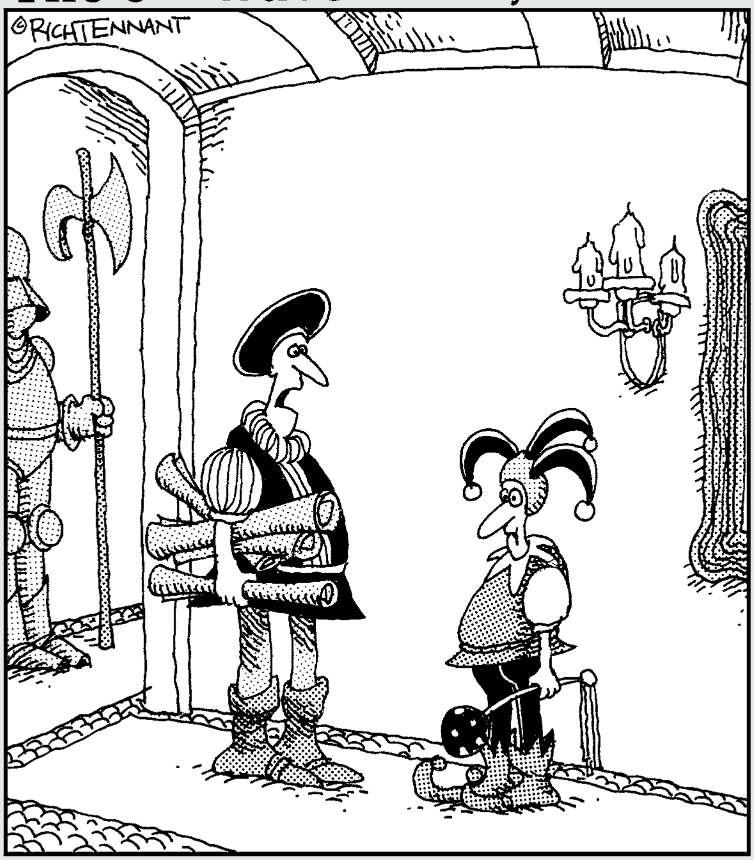
Table 16-4 Confidence Intervals

Name	***Equation***	***Look-Up Factor***
Average with large (> 30) sample size	$\mu = \bar{x} \pm Z \frac{\sigma}{\sqrt{n}}$	Z
Average with small (< 30) sample size	$\mu = \bar{x} \pm t \frac{s}{\sqrt{n}}$	t
Standard deviation	$\sigma = \left[\sqrt{\frac{(n-1)s^2}{\chi^2_{LOWER}}}, \sqrt{\frac{(n-1)s^2}{\chi^2_{UPPER}}} \right]$	χ^2
Ratio of variances	$\frac{\sigma_1^2}{\sigma_2^2} = \left[\frac{1}{F(n_2, n_1)} \frac{s_1^2}{s_2^2}, F(n_1, n_2) \frac{s_1^2}{s_2^2} \right]$	F
Proportion	$p = \frac{y}{n} \pm Z \sqrt{\frac{(y/n)(1-y/n)}{n}}$	Z
Difference of proportions	$p_1 - p_2 = \frac{y_1}{n_1} - \frac{y_2}{n_2} \pm Z \sqrt{\frac{(y_1/n_1)(1-y_1/n_1)}{n_1} + \frac{(y_2/n_2)(1-y_2/n_2)}{n_2}}$	Z

Part IV

DMAIC: Improving and Controlling

The 5th Wave — By Rich Tennant



"Sorry Cedric, the King cut my budget for additional fools. He said the project already had enough fools on it."

In this part . . .

With the root cause determined and verified, the work of Six Sigma turns to developing an effective improvement, putting that improvement in place, and then enacting measures to make sure the achieved improvements stay in place. The chapters in this part provide the critical tools needed to make your hard-won improvements permanent.

Chapter 17

Forecasting Future Performance

In This Chapter

- Quantifying relationships between variables
- Calculating and interpreting the correlation coefficient
- Fitting predictive $Y = f(X) + \varepsilon$ curves to data
- Checking the validity of fitted prediction curves

Part II of this book shows you how to launch an improvement project and identify the potential variables that influence a critical outcome. Part III covers tools and methods for analyzing the situation and determining which *X*s are actually critical and which are trivial.

But in this part, you're turning over a whole new leaf. With the critical few factors known, you're ready to begin devising improvements. In this chapter, we show you how to quantify potential improvement effects so you know how much improvement in the output you'll get for any given adjustment to the critical inputs. We also help you understand the relationships between the input variables and the critical outputs. Knowing the outcome of a potential improvement without spending the resources to test it out is the essence of Six Sigma improvement power!

Seeing the Correlation

Scatter plots (which we explain in Chapter 10) are a great way to visually discover and explore relationships between variables — both between *Y*s and *X*s and between *X*s and *X*s. In a scatter plot, you graph the values of one variable against paired values of another variable. As an example, Table 17-1 is a list of paired data for the curb weight (in pounds) of some common automobiles and their corresponding fuel economies (in miles per gallon).

Table 17-1 Automobile Curb Weight versus Fuel Economy

Make/Model	*Curb Weight (lbs.)*	*Fuel Economy (mpg)*
Toyota Camry	3,140	29
Toyota Sequoia	4,875	17
Honda Civic	2,449	35
Land Rover Discovery	4,742	16
Mercedes-Benz S500	4,170	20
VW Jetta Wagon	3,078	27
Chrysler 300	3,715	22
Chevrolet Venture	3,838	23
Hyundai Tiburon	2,940	27
Dodge Ram 2500 Quad	6,039	11

A data point for each automobile in the study is plotted in Figure 17-1. The scatter plot shows a negative relationship between the curb weight of the vehicle and its fuel economy — the heavier the car, the lower its fuel economy. The plot also shows that the relationship between the two variables is approximately linear, meaning that its shape approximately follows a straight line. Finally, you can see from the figure that the relationship between the variables is fairly strong, as evidenced by the tight clustering of the plotted data points around the drawn line approximating the relationship. But how do you put numbers to this relationship? You use *correlation,* which shows how closely two variables' relationship follows a linear pattern.

WARNING!

Correlation tells you only how linear the relationship between the variables is. It may miss more-complicated relationships where the variables follow a nonlinear pattern. Always include a graphical scatter plot when doing a correlation analysis. That way, you can visually check to make sure the variable relationship really is linear.

To quantify how linear the relationship is between two variables, you use the following formula to calculate the *correlation coefficient* (r):

$$r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{\sigma_x}\right)\left(\frac{y_i - \bar{y}}{\sigma_y}\right)$$

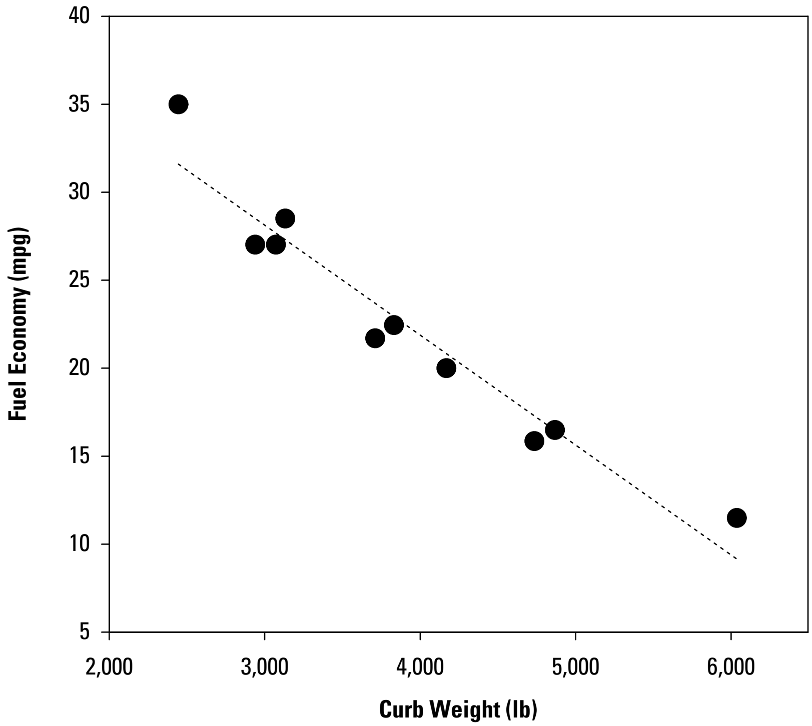


Figure 17-1: Scatter plot of vehicle curb weight versus fuel economy.

where

- n is the number of data pairs.
- x_i and y_i are the individual *x*-variable and *y*-variable measurements.
- $\bar{x}$ and $\bar{y}$ are the averages of the *X* and *Y* measurements, respectively.
- σ_X and σ_Y are the standard deviations of the *X* and *Y* measurements, respectively.
- Σ is a capital Greek letter telling you to add up all the $\left(\frac{x_i-\bar{x}}{\sigma_x}\right)\left(\frac{y_i-\bar{y}}{\sigma_y}\right)$ terms, from 1 to *n*.

The calculated correlation coefficient is always between –1 and 1. Remember:

- **The sign of *r* tells you the direction of the relationship between the variables.** If *r* is greater than zero (positive), that means that the variable relationship is positive; if the value of one variable increases, the other variable also increases. If *r* is less than zero (negative), the variable relationship is negative; if the value of the independent variable increases, the value of the dependent variable decreases, and vice versa.

- **The absolute value of *r* tells you how strong the relationship is.** The closer *r* gets to –1 or 1, the stronger the variable relationship is. An *r* equal to 1 or –1 indicates a perfect linear relationship, with all points being exactly on the line. An *r* close to 0 indicates that the data don't fit a linear model. For the automobile fuel economy example introduced earlier, the calculated correlation coefficient *r* is

$$r = \frac{1}{10-1}\sum_{i=1}^{10}\left(\frac{x_i - 3{,}899}{1{,}087}\right)\left(\frac{y_i - 23}{7}\right) = \frac{1}{9}(-8.738) = -0.971$$

An *r* of –0.971 verifies that the relationship between the two variables is indeed linear and is negative. Also, this *r* value is very close to –1, telling you that the relationship is very strong.

Correlation basically just confirms the existence of a linear relationship between two variables and quantifies how linear that relationship is. What correlation does *not* tell you is how much a given change in one variable changes a related variable. To get that kind of information, you need to become acquainted with some predictive tools.

Correlation doesn't equal causation. The fact that two variables correlate doesn't mean that one *causes* the other. For example, studies show that a person's reading comprehension ability (*Y*) is correlated with his or her height (*X*), so you may conclude that height *causes* reading comprehension. But if you think about it for a second, you realize that young children haven't yet developed cognition and reading skills. In the teenage years, physical growth continues along with maturation of mental and reading abilities. By the time you're a full-grown adult, your brain and mental abilities have fully developed. Thus, you can see that height is just an indirect indicator of overall maturation and growth (including cognitive abilities), not a direct cause of those abilities. So be very careful: Don't assume a causal link when you see correlation.

Getting a Handle on Curve Fitting

A step beyond correlation (see the preceding section) is curve fitting. In *curve fitting,* you actually determine the equation for the curve that best fits your data. Armed with this information, you know quantitatively what effect one variable has on another, which variables are significant influencers, and which ones are just in the noise. Finally, you know how much of the system behavior your equation does *not* explain.

In some rare cases, you know the exact details of the $Y = f(X) + \varepsilon$ equation relating the *X*s to the *Y* without having to do any curve fitting, either because you have a very mature understanding of the physics of your process or system or because you have some other source of knowledge. These situations are called *deterministic* because you know with certainty that setting the input *X*s to certain values always leads to the exact same value for the output *Y*, even when the process is repeated. For the vast majority of cases, however, you don't know the exact relationship between the *X*s and the *Y* or *Y*s due to the system's complexity and a human inability to address all the factors that truly exert influence on the output. Because of this natural limitation, repeating the same input values in the system doesn't always produce the same output performance. These situations are called *statistical.*

The goal of curve fitting is to develop an approximate equation that describes the system's or process's statistical behavior as much as possible. When you work to create an approximate equation for a system that has a single output *Y* and a single input *X,* this type of curve fitting is called *simple linear regression.* When you work to create an equation that includes more than one variable, it is called *multiple linear regression.*

Finding the line: Simple linear regression

In simple linear regression, you assume that each observed output point Y_i can be described by a two-part equation:

$$Y = \beta_0 + \beta_1 X + \varepsilon$$

The first part of this equation is $\beta_0 + \beta_1 X$. The second part is ε. Graphically, the decomposition of this equation is shown in Figure 17-2.

Time warping back to your high-school algebra days, you may recall that the $\beta_0 + \beta_1 X$ part of the equation for *Y* is just an equation for a straight line: β_0 by itself tells you at what value the fitted line crosses the *Y* axis, and β_1 tells you the line's slope. The ε part is a normal, random distribution with a center value equal to zero.

In simple linear regression, you mathematically determine values for β_0 and β_1 so that the resulting line fits your observed $X - Y$ data as closely as possible with the minimum amount of error. Then you determine how wide the ε portion needs to be so that it accounts for all the extra *Y* variation that the line doesn't already capture. You calculate β_0 and β_1 from the following equations:

$$\beta_1 = \frac{\sum (x_i - \bar{x}) y_i}{\sum (x_i - \bar{x})^2}$$

$$\beta_0 = \bar{y} - \beta_1 \bar{x}$$

where x_i and y_i are the paired data points and $\bar{x}$ and $\bar{y}$ are the calculated averages for all the *X* points and all the *Y* points, respectively.

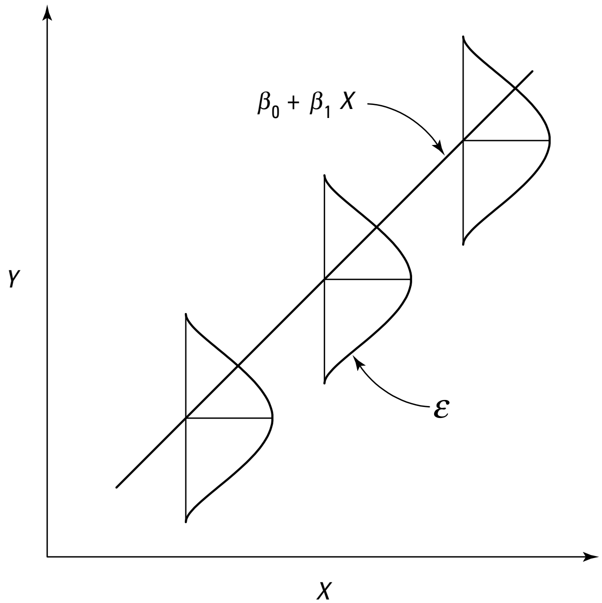


Figure 17-2: The simple linear regression model.

For the automobile weight versus fuel economy example we introduce in the earlier section "Seeing the Correlation," the calculated value for β_1 turns out to be –0.00624, and β_0 comes out to be 46.9. So the equation for the line that best fits the data is

$$\hat{Y} = 47.3 - 0.00632\ X$$

where $\hat{Y}$ represents the estimate or prediction for *Y,* not an actual observed value for *Y.* You're now armed with a powerful, predictive tool. If you find that a car you were interested in has a curb weight of 5,000 pounds, you can plug that *X* value right into your equation to predict the vehicle's fuel economy:

$$\hat{Y} = 47.3 - 0.00632\,(5{,}000) = 15.7\ \text{mpg}$$

All without ever test driving the car!

REMEMBER

When using your Six Sigma powers, be aware of a couple points of caution:

- **Be careful not to extend your predictions very far beyond the range of the data in your study.** For example, you don't want to use your equation to predict the fuel economy of a vehicle weighing 25,000 pounds, such as a locomotive. Vehicles in this weight class are so much heavier than the automobiles of the study that they use very different mechanisms and technology and don't fit the line. The general rule is not to extrapolate any predictions beyond the range of your study data.

- **Note that the derived equation for the line is missing the ε component.** The line predicts only the expected *average* performance. In reality, the actual performance level varies from the predicted value. This discrepancy is the effect of the ε component. For some situations, this random variation component dominates, leaving little room for effective predictions. In other cases, your derived line equation gets you very close to actual, real-world values.

Discovering residuals and the fitted model

Your next step is to understand and quantify the ε component of your regression equation. For each of the i data points in your study, you can calculate an error term e_i — how far off the predictive equation line is from the observed data. For example, referring to Table 17-1 earlier in the chapter, the data for the Toyota Camry shows that its curb weight is 3,140 pounds and its fuel economy is 29 mpg. But plugging an X value of 3,140 pounds into the derived regression equation, you get a predicted fuel economy of

$$\hat{Y} = 47.3 - 0.00632(3{,}140) = 27.49 \text{ mpg}$$

The difference between the observed and the predicted fuel economy is

$$e_1 = Y_1 - \hat{Y}_1 = 29 - 27.49 = 1.51 \text{ mpg}$$

You can calculate similar error e_i terms for each of the other data points in your regression study (in the case of Table 17-1, the nine other car models). These e_i terms are called *residuals* — or what's left over after using the predictive equation. The beginning assumption of the predictive linear equation is that it has a secondary ε part that is a normal, random distribution with a center value equal to zero. This variation is manifest in the residuals and is the bell-shaped variation we identify in Figure 17-2. The most efficient way to check your predictive linear equation's validity is graphically reviewing the residuals to make sure they're behaving as you've assumed. You may need to create up to four different graphical checks of the residuals:

- A scatter plot of the residuals e_i versus the predicted values from the derived equation
- A scatter plot of the residuals e_i versus the observed X data
- Additional scatter plots of the residuals e_i versus any other X variables that you didn't include in your equation
- A run chart of the residuals e_i versus the previous residuals $e_{i\text{-}1}$ if you collected your study data sequentially over time

In each of these graphical residual checks, you're looking for the following:

- The variation has no obvious patterns and is truly random, like a cloud of scattered dots.
- The residual variation is centered on the value of zero.

Figures 17-3, 17-4, and 17-5 are examples of residual-checking plots for the earlier automobile weight-fuel economy study.

Figures 17-3, 17-4, and 17-5 appear valid. In each case, the residuals show evidence of being truly random, normal, and centered over time on zero. You can now conclude that your derived linear predictive equation is valid.

REMEMBER

However, not all residual plots are valid. Figure 17-6 shows two examples of an inappropriate simple linear regression model. In Figure 17-6(a), the variation of the residuals isn't centered on zero. Instead, it shows a curved pattern. In Figure 17-6(b), the residual variation isn't consistent — lower values of variable *X* produce larger residual variation and then higher values of variable *X*.

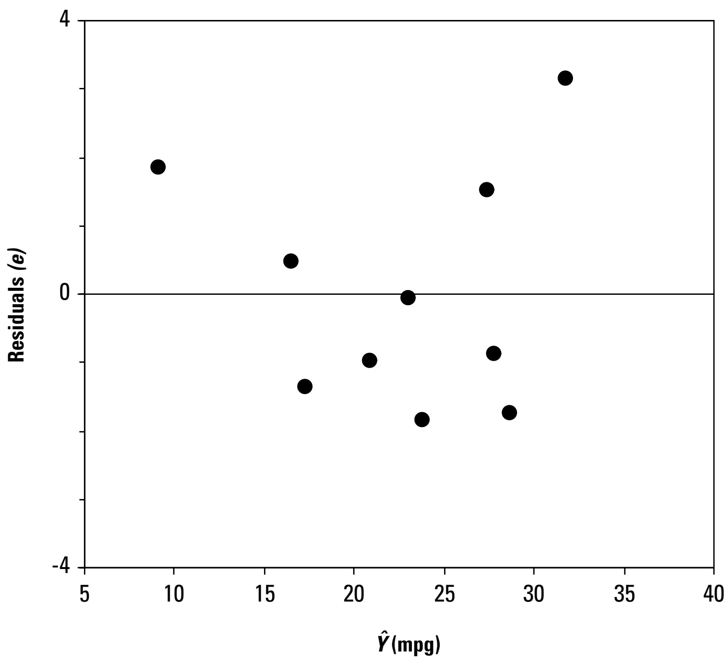


Figure 17-3: Residuals plotted versus the corresponding predicted values.

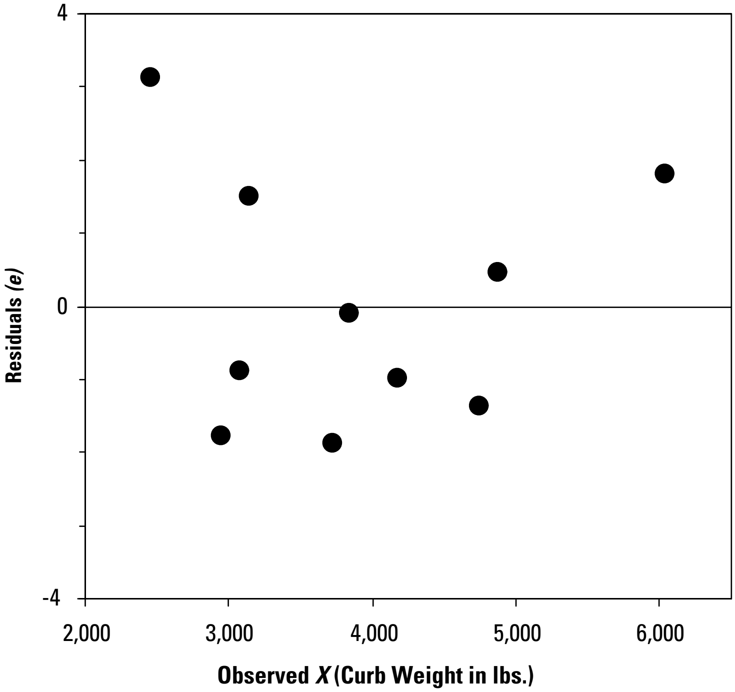


Figure 17-4: Residuals plotted versus the observed *X* variable of vehicle curb weight (lbs.).

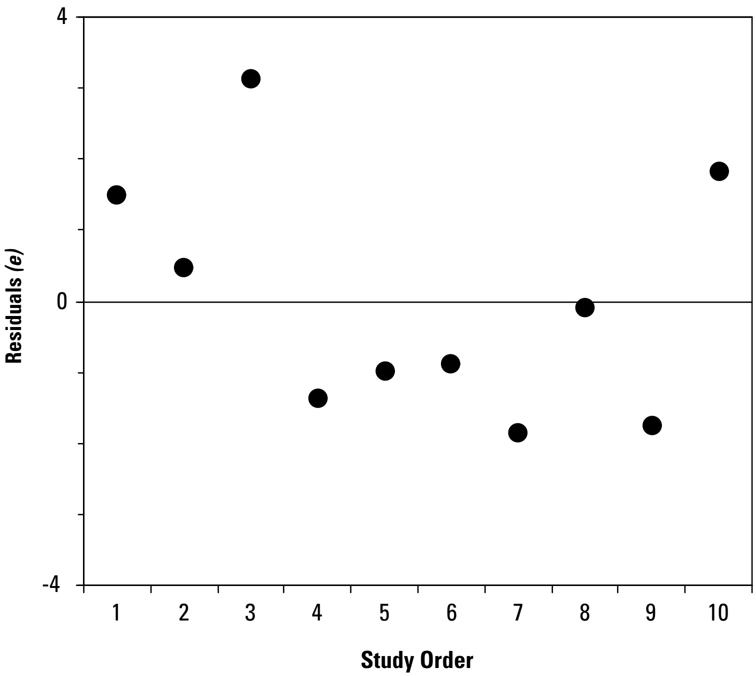


Figure 17-5: Residuals plotted in the order of the study data.

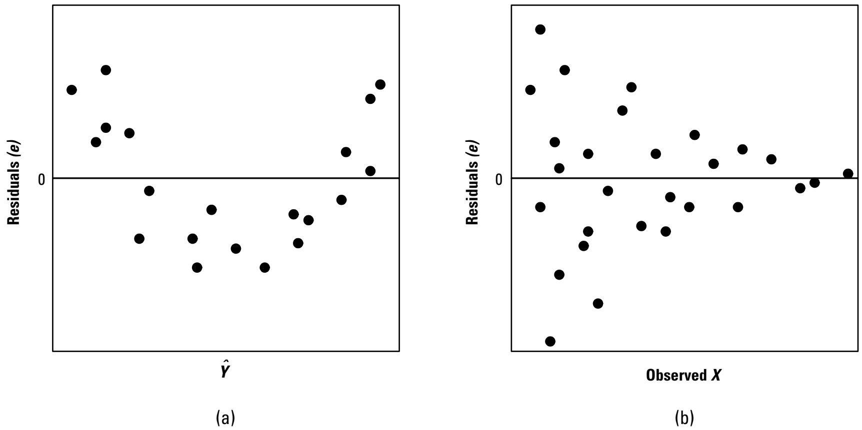


Figure 17-6: Examples of residual plots showing invalid behavior.

An added way to investigate how good your derived regression model is involves looking at the variation of the output variable *Y*. You do this new assessment on a squared error basis. The total sum of the squared error (*SSTO*) in the output variable *Y* can be written as

$$SSTO = \sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2$$

where Y_i are the *n* observed output values.

In a similar way, you can state the squared error from just the derived regression equation (SSR) as

$$SSR = \sum_{i=1}^{n}\left(\hat{Y}_i - \bar{Y}\right)^2$$

where $\hat{Y}_i$ are the predicted estimates for the *n* data points.

Finally, you can express the squared error from the remaining ε variation (*SSE*) as

$$SSE = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2$$

Together, these three squared error terms can be related with the simple sum

$$SSTO = SSR + SSE$$

You can do three important tests with these squared error terms:

- **Calculate the coefficient of determination, R^2, for your predictive model.** The *coefficient of determination* is simply the ratio of the squared regression error (*SSR*) and the total squared error (*SSTO*), like this:

  $$R^2 = \frac{SSR}{SSTO}$$

  What R^2 tells you is how much of the total observed variation is determined or explained by your linear model. For a business setting, you want this number to be 80 percent or higher. This result means that the unexplained variation ε accounts for the remaining 20 percent or less.

  With a high R^2 value, you can know that your predictions will be close — and not dominated by the unexplained variation. For the automobile curb weight versus fuel economy study introduced earlier in this chapter, the R^2 value is

  $$R^2 = \frac{424.2}{450.1} = 0.94$$

  Ninety-four percent of the observed variation is explained by your derived linear model. That leaves only 6 percent that is unexplained and left to random chance.

- **Quantify the unexplained ε variation in terms of its standard deviation.** The ε value is an inherent part of your predictive linear equation, so you need a way to figure out how big its variation is.

  You can calculate an estimate of the standard deviation ($\hat{\sigma}_\varepsilon$) of the ε distribution by using the surprisingly simple equation

  $$\hat{\sigma}_\varepsilon = \sqrt{\frac{SSE}{n-2}}$$

  This estimate comes in handy when you want to mimic what may happen in reality. You use your derived linear model to predict the average or expected performance of the output, $\hat{Y}$, and then add to it a random number generated from the ε distribution — with a mean of zero and standard deviation equal to $\hat{\sigma}_\varepsilon$. In this way, you can simulate what would happen if your process or characteristic were repeated over and over again.

  For the automobile curb weight versus fuel economy study, you can estimate the standard deviation of the unexplained variation as

  $$\hat{\sigma}_\varepsilon = \sqrt{\frac{25.9}{10-2}} = 1.80 \text{ mpg}$$

- **Perform an F test to quantify your confidence in the validity of your regression model.** Another test of validity for your derived linear equation is to statistically compare the variation explained by your regression model to the unexplained variation. Yet another way to mathematically represent the variation in the regression model is by an estimate of its variance

  $$\hat{\sigma}^2_{REG} = SSR$$

You may also already know — from the test in the preceding bullet — that

$$\hat{\sigma}_{\varepsilon}^{2} = \frac{SSE}{n-2}$$

Creating a ratio of $\hat{\sigma}_{REG}^{2}$ to $\hat{\sigma}_{\varepsilon}^{2}$ is just like the confidence intervals covered in Chapter 16 for comparing the size of two different distributions. So if

$$\frac{\hat{\sigma}_{REG}^{2}}{\hat{\sigma}_{\varepsilon}^{2}} \geq F(2, n-1)$$

you can say with 95-percent or 99-percent confidence — whichever level of confidence you select from the *F* table in Chapter 16 — that your derived predictive model is, in fact, valid.

For the automobile curb weight versus fuel economy study, if you want to be 99-percent confident with your $n = 10$ data points, the *F* test of the variances becomes

$$\frac{424.2}{25.9} = 16.4 \geq 11.259 = F(2,9)$$

Because the calculated ratio value of 16.4 is greater than the critical 99-percent *F* value of 11.3, you can conclude with 99-percent confidence that your derived model is valid.

Practicing tools for fitting lines

Simple linear regression is becoming a common activity. Anyone with Microsoft Excel, for example, can take data from an *X* and a *Y* variable and almost immediately create a scatter plot of the two. Then with just a couple of clicks, the program automatically derives the fitted line for your data. If you have Excel, try this process on the automobile weight versus fuel economy study introduced in this chapter:

1. **Enter the data from Table 17-1 into Excel as two columns of data — one for the curb weight *(X)* data and another for the fuel economy *(Y)* data.**
2. **Select the entered data in the spreadsheet and create what Excel calls an *XY* (scatter) plot.**
3. **Right-click on the plotted data in the graph and select Add Trendline from the menu that pops up; select the Linear option and click OK.**

   The best fit line with the correctly calculated parameters is automatically added to your graph!

   If you double-click on this fitted line, you see options to display the equation for the line and to display the coefficient of determination R^2. You can see the results of these display options in Figure 17-7.

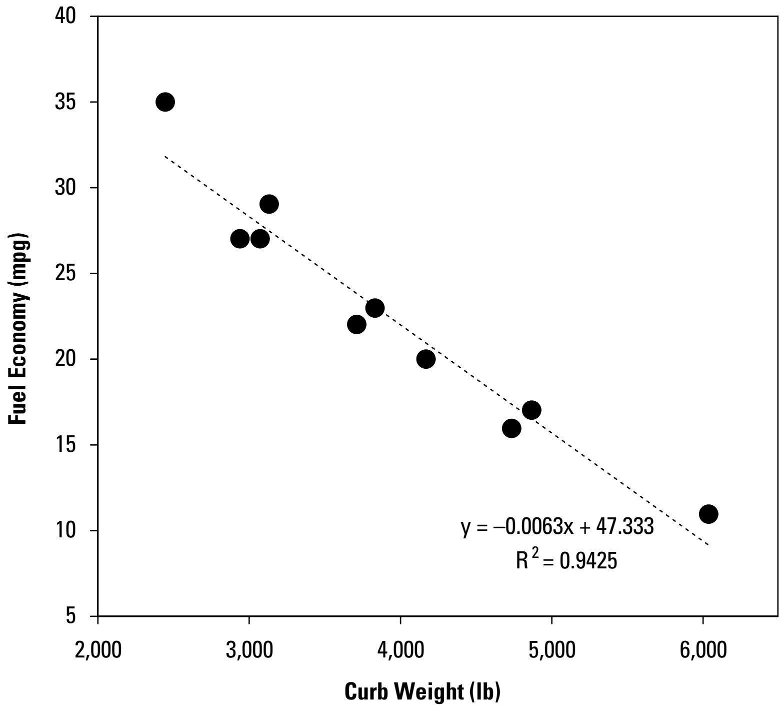


Figure 17-7: A simple linear regression model automatically fitted by Microsoft Excel.

In addition to Excel, Minitab, JMP, and other statistical analysis software tools provide tremendous detail and make simple linear regression almost fun! See Chapter 22 for more on these analytical software tools.

Moving on to multiple linear regression

The preceding sections show you how to generate and validate a predictive model linking a single *X* to a *Y*. But what about all the situations where more than one *X* influences a *Y?* After all, that kind of situation is more common than a single influencing variable is. When you work to create an equation that includes more than one variable — such as $Y = f(X_1, X_2, \ldots, X_n)$ — you use *multiple linear regression.*

The general form of the multiple linear regression model is simply an extension of the simple linear regression model (see the earlier section "Finding the line: Simple linear regression." For example, if you have a system where X_1 and X_2 both contribute to *Y*, the multiple linear regression model becomes

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_{11} X_1^2 + \beta_2 X_2 + \beta_{22} X_2^2 + \beta_{12} X_1 X_2 + \varepsilon$$

This equation features five distinct kinds of terms:

- β_0: This term is the *overall effect.* It sets the starting level for all the other effects, regardless of what the X variables are set at.
- $\beta_i X_i$: The $\beta_1 X_1$ and $\beta_2 X_2$ pieces are the *main effects* terms in the equation. Just like in the simple linear regression model, these terms capture the linear effect each X_i has on the output Y. The magnitude and direction of each of these effects are captured in the associated β_i coefficients.
- $\beta_{ii} X_i^2$: $\beta_{11} X_1^2$ and $\beta_{22} X_2^2$ are the *second-order* or *squared effects* for each of the Xs. Because the variable is raised to the second power, the effect is quadratic rather than linear. The magnitude and direction of each of these second-order effects are indicated by the associated β_{ii} coefficients.
- $\beta_{12} X_1 X_2$: This effect is called the *interaction effect.* This term allows the input variables to have an interactive or combined effect on the outcome Y. Once again, the magnitude and direction of the interaction effect are captured in the β_{12} coefficient.
- ε: This term accounts for all the random variation that the other terms can't explain. ε is a normal distribution with its center at zero.

The equation for multiple linear regression can fit much more than a simple line; it can accommodate curves, three-dimensional surfaces, and even abstract relationships in *n*-dimensional space! Multiple linear regression can handle about anything you throw at it. The process for performing multiple linear regression follows the same pattern that simple linear regression does:

1. **Gather the data for the *X*s and the *Y*.**
2. **Estimate the multiple linear regression coefficients.**

   When you have more than one X variable, the equations for deriving the βs become very complex and very tedious. You definitely want to use a statistical analysis software tool to calculate these equations automatically for you. The βs just pop right out. Otherwise, go buy a box of number 2 pencils and roll up your sleeves!
3. **Check the residual values to confirm that they meet the upfront assumptions of the multiple linear regression model.**

   WARNING!

   Checking that the residuals are normal is critically important. If the variation of the residuals isn't centered on zero and the variation isn't random and normal, the starting assumptions of the multiple linear regression model haven't been met, and the model is invalid.
4. **Perform statistical tests to see which terms of the multiple linear regression equation terms are significant (and should be kept in the model) and which are insignificant (and need to be removed).**

Some terms in the multiple regression equation aren't significant. You find out which ones by performing an *F* test for each term in the equation. When the variation contribution of an equation term is small compared to the residual variation, that term won't pass the *F* test, and you can remove it from the equation. (Flip to "Discovering residuals and the fitted model" earlier in the chapter for more on *F* tests.)

Your goal is to simplify the regression equation as much as possible while maximizing the R^2 metric of fit. Generally, simpler is always better. So if you find two regression equations that both have the same R^2 value, you want to settle on the one with the fewest, simplest terms.

Usually, the higher order terms are the first to go. There's just less chance of a squared term or an interaction term being statistically significant.

5. **Calculate the final coefficient of determination R^2 for the multiple linear regression model.**

   Use the R^2 metric to quantify how much of the observed variation your final equation explains.

TIP

With good analysis software becoming more accessible, the power of multiple linear regression is available to a growing audience. Many more sophisticated statistical analysis software tools even have automated algorithms that search through the various combinations of equation terms while maximizing R^2.

Chapter 18

Designing, Conducting, and Analyzing Experiments (DOE)

In This Chapter

- Looking at the advantages of planned experimentation
- Examining experimental considerations and terminology
- Exploring the 2^k full factorial experiments

The point of Six Sigma is improvement; after you reach the improvement stage in the DMAIC road map, you explicitly synthesize the improvements and/or reconfigure your system or process for the better. Six Sigma offers extremely powerful tools to aid you in your improvement efforts, and chief among these is experimentation. In Six Sigma, you design an experiment, carry that experiment out, and then follow it up with analysis to uncover previously hidden knowledge.

Design of Experiments (or *DOE* for short) has always been at the technical heart of Six Sigma. And as necessity is the mother of invention, so the field of DOE has matured due to the need to understand and then improve the world around you. This chapter gives you the lowdown.

Seeing the Improvement Power of Six Sigma Experiments

How do you achieve improvement? The spark of improvement comes from a curious mind trying to figure out what makes things tick.

Achieving better understanding through experiments

In an *observational study* (covered in Chapter 15), you simply act as an outside observer, recording data as they happen and trying to gain understanding from careful review of the world around you. As an observer, you just let the *X*s (inputs) of the system or process you're working on take whatever values they do. And as the process plays out, you record the corresponding process output *Y* values.

Experiments, on the other hand, are different from observational studies. In experiments, you actively control and modify the process being studied; you purposely set and control the values that the *X*s have instead of just letting the *X*s take on whatever values they happen to.

Experiments offer a greater level of insight and knowledge than observational studies do. Think of the many observational studies performed for decades in fields like medicine, education, economic policy, diet, and so on. Dozens upon dozens of observational studies added only incremental knowledge to these areas. But when you purposefully control the factors, the amount of specific knowledge you get out of an experiment almost always exceeds what you gain from observational studies. For that reason, designing and analyzing experiments — in spite of the complexity of the topic — has always been one of the core pillars of Six Sigma breakthrough improvement.

Every experiment in Six Sigma is targeted at better understanding the $Y = f(X) + \varepsilon$ relational foundation between the inputs and outputs of the process or system being improved. The insights you gain from experimentation include the following:

- Knowing which input *X*s have the most significant effects on the output *Y* and which *X*s are insignificant
- Formulating and quantifying the mathematical relationship between the significant *X*s and the output *Y*
- Discovering where to set the values of the significant *X*s so that they combine to produce the optimal output value of *Y*
- Statistically confirming that a change or improvement has been made to a process or system

REMEMBER

Few activities in Six Sigma offer as much insight and change horsepower as experiments do. That's because properly designed experiments reveal, quantify, and confirm the underlying $Y = f(X) + \varepsilon$ relationship of a process or system.

Getting schooled on the terms

The field of planning and analyzing experiments is much older than Six Sigma; you probably studied experiments and variables in science class as a kid long before Six Sigma was on your radar screen. In case you last heard the terms associated with setting up experiments in elementary school, here's what you need to know:

- **Response:** *Response* is the term used for the output of the process that you investigate in the experiment. In Six Sigma terms, the response is synonymous with the Y in the $Y = f(X) + \varepsilon$ equation. The whole point of the experiment is to figure out how the Xs combine to affect the response, or Y.
- **Factors:** The input characteristics, or variables you purposely control during the experiment, are called experimental *factors.* Sometimes, they're also called *conditions, variables,* or simply *inputs.* In all cases, the experimental factors are the Xs in the Six Sigma $Y = f(X) + \varepsilon$ equation.
- **Levels:** In your experiment, you choose two or more values for each of the experimental factors. These values are called the *levels* for that factor. Planning your experiment includes deciding how many levels you need to use for each factor.
- **Replication:** Processes and systems have variation. Part of experimentation is repeating part or all of an experiment to understand how much variation actually exists. These types of repetitions are called *replications.* Deciding what part of your experiment you need to replicate and how many replications to perform is part of developing your experiment plan.
- **Runs:** Every experiment is made up of a series of *runs*. Each experimental run consists of a unique, predetermined set of values for each of the factors. You then conduct the process or system through one cycle with those input values and record the output.

The end game of Six Sigma experiments

You've heard that knowledge is power. Six Sigma experiments are a confirmation of that statement. The power of Six Sigma experiments lies in their ability to formulate, quantify and validate the $Y = f(X) + \varepsilon$ relationship of a process or system. Knowing the form and details of $Y = f(X) + \varepsilon$ for a system, you literally have a window into the past, present, and — most importantly — the future.

After wrapping up an experiment, you have in your hands a $Y = f(X) + \varepsilon$ equation that identifies each critical input X and quantifies its influence on the output Y. For example, if you're working on a marketing plan to improve brand awareness (that's the output Y), a Six Sigma experiment provides an equation that tells you which type of advertisements — newspaper, radio, TV, Internet, and so on — and how many of each type to run (the input *X*s) to reach a specified improvement goal. Or if you're managing the production of plastic seals that must meet a minimum tear strength requirement (the *Y*), after proper experimentation, you have an equation that tells you exactly where to set the mold press temperature (X_1), how much pigment to add (X_2), and the correct operating temperature of the mold press (X_3). In all cases, whether they involve continuous or attribute data, successful experimentation reveals detailed, specific knowledge of which input *X*s influence the output *Y* — and by how much.

With this level of system or process knowledge, your operational focus immediately switches from passively watching the output and hoping for success to actively monitoring and controlling identified key inputs, knowing that your purposeful management and control of these inputs will always lead to the desired process outcome. This point is where you open the door to the new world of breakthrough performance.

Looking Before You Leap: Experimental Considerations

Trial and error — tinkering with the input knobs of a process or system — is temptingly simple. Everyone has a desire to jump in and quickly fix a problem. In the long run, though, carefully planning your experiments almost universally leads you to a quicker and better solution. So how should you approach experimentation? Where do you start? The following sections review some common experimentation philosophies and describe why Six Sigma experimentation is so effective.

The trial-and-error approach

Many people approach experimentation by rolling up their sleeves and jumping into an unstructured exploration of the experimental variables and their resulting output: Basically, they randomly tweak the knobs, adjust the settings, and observe the results. Often, judgment and intuition are the basis for steering the exploration and interpreting the findings. However, this unstructured, haphazard approach rarely increases knowledge; fiddling with the settings without any rhyme or reason makes identifying the source of any change difficult. Every once in a while, you may get lucky, but this approach is unreliable.

The one-factor-at-a-time approach

At the other end of the spectrum is a structured approach: Isolate a single input variable and study its effect on the output across a range of values while carefully holding all other factors constant. Then repeat this meticulous scan for each of the input variables.

The downfall of this method is twofold:

- **It's inefficient and expensive.** Conducting scans for the high and low values of each input variable leads to a huge number of experimental runs. Unless you have only one variable in your system, this approach becomes unwieldy and wastefully expensive.
- **Its results are often misleading.** When you isolate individual variables, you automatically negate the possibility of two or more factors combining to affect the outcome. But these types of interactions are an unavoidable part of reality. The danger of this approach is that you draw unfounded conclusions from your experiment — or miss important information altogether.

  Think of baking a cake. A delicious-tasting outcome (the *Y*) is a function of several input *X*s — amount of flour, number of eggs, oven temperature, baking time, and so on. Obviously, the right value for the variable of "baking time" depends on the setting for "oven temperature." How hot the oven is and how long you leave the cake in the oven are two input variables that interact with each other. One-factor-at-a-time experiments don't uncover this essential relationship.

TIP

Use the one-factor-at-a-time approach when you have a process or system with a single input variable only. This approach works with a single-*X* system because such a system has no possibility of an interaction effect.

The boil-the-ocean approach

The power of designed experiments is intoxicating. Be careful not to get carried away, though. You may be tempted to try to solve everything in one fell swoop, using a big, well-designed super-experiment. But putting all your eggs into one experimental basket has some definite drawbacks:

- **Determining inputs:** Creating a single super-experiment based only on the knowledge you have *before* the experiment begins requires that you include all the variables that you suspect are contributing to the situation. This tactic always leads to a long list of potential *X*s and therefore always results in a long, expensive, unwieldy experiment.

- **Controlling factors:** As you carry out a large super-experiment over a protracted period of time, you run a greater chance of unknown factors creeping in, confounding the experimental conditions and results.
- **Lacking prior knowledge:** With no prior knowledge, you can't easily know what values and ranges to assign to each experimental *X* input.
- **Running out of money:** Conducting an experiment takes time and money. If something goes wrong in your one super-experiment, or if new information is revealed that requires a change to your initial assumptions, you may be up a creek if you've already consumed your experimental budget and resources.

The Six Sigma approach: Multitasking and progressing

With all the drawbacks of the trial-and-error approach, the one-factor-at-a-time approach, and the boil-the-ocean approach (see the preceding sections), you may be wondering whether a solid strategy for experimentation even exists. Lucky for you, we have just that. Six Sigma uses a reliable approach to experimentation that

- Efficiently accumulates information about a process or system
- Provides valid insights, including knowledge regarding variable interactions
- Quantifies the amount of knowledge discovered about a system as well as the amount of knowledge that remains unknown (the ε)

The experimental approach you use in Six Sigma incorporates the best practices from the various disciplines of science. Over the years, scientists have developed experiment plans that return a vast amount of knowledge in a very efficient way. The key elements of the Six Sigma approach include

- **Planning out the experiment before you conduct it:** "Look before you leap" is a mantra of every good experimenter. Careful planning always increases the value of your experiment results while minimizing the amount of work and money you have to invest.
- **Exploring the effect of more than one input variable at a time:** This strategy allows you to be efficient while capturing unsuspected and sometimes hard-to-find interaction effects.
- **Minimizing the number of required runs in your experiment:** You may be surprised how much you can get out of a small number of properly planned experimental runs.
- **Replicating key experiment conditions to assess variation:** A part of every experiment is understanding how much of your system's or

process's behavior is *deterministic* (the result of a specific cause) and how much is random variation.

- **Accounting for known and unknown factors that you aren't directly including in your experiment:** You can never take everything into consideration in your experiment. However, Six Sigma offers ways to keep these nuisance factors from clouding the results of your experiment.

In addition to accomplishing these goals, the Six Sigma experimentation method also follows a progressive and iterative approach:

- **Screening experiments:** The whole point of this first stage is to quickly verify which factors have a significant effect on the output. When you first start investigating a process or system, your experiments are designed to handle a large number of factors or variables because you identify all the possible *X*s that may be influencing the output *Y*. But not all of those inputs actually affect the output, so you screen them out.
- **Characterizing experiments:** When you've screened out the unimportant variables, your experiments focus on characterizing and quantifying the effect of the remaining critical few inputs. These characterization experiments reveal what form and what magnitude the critical factors take in the $Y = f(X) + \varepsilon$ equation for your process or system.
- **Optimization experiments:** After characterizing your process or system, the final step is to conduct *optimization experiments* to find the best settings of the *X*s to meet your *Y* goal. Your goal may be to maximize or minimize the value of the output or to hit a certain target level. More often, your goal is simply to minimize the amount of variation in the output *Y*.

Because each of these experiment types has a very different purpose, the forms and plans of the experiments you conduct at each stage are also different. Figure 18-1 shows the progressive and iterative approach used in Six Sigma experiments.

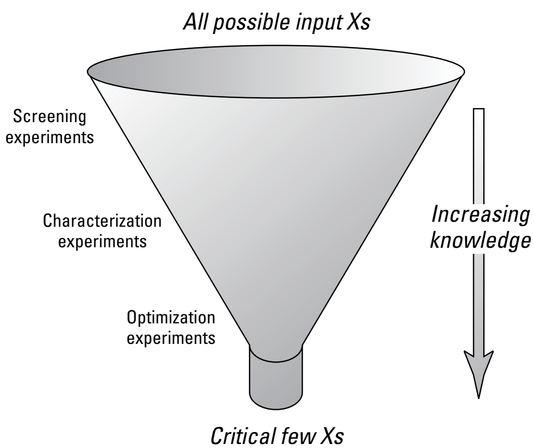


Figure 18-1: The progressive and iterative path of Six Sigma experiments.

Setting up 2^k Factorial Experiments

Designing and analyzing experiments is a topic large enough for a whole *For Dummies* book by itself. To get you quickly up to speed, however, the following sections show you how to plan, conduct, and analyze the most common type of experiment in Six Sigma — the *2^k factorial* (pronounced "two to the *k*"). You can easily adapt 2^k factorial experiments to provide screening, characterization, or optimization information. Along the way, we also give you insights into other types of experiment designs and variations used in Six Sigma.

Planning your experiment

Like in almost all other endeavors, time spent in planning is rewarded with better results in a shorter period of time. Planning 2^k factorial experiments follows a simple pattern: choosing the factors you want to experiment with, establishing the high and low levels for those factors, and creating the coded design matrix.

Selecting the experiment factors

The first thing to do in your planning is identify the input variables, the *X*s, that you'll include in your experimental investigation. The factors you include should all be potential contributors to the output *Y* you're investigating and should be ones that previous analysis have indicated are critical. How many factors you want to include in your experiment guides you in choosing the right experimental design. 2^k factorial experiments work best when you have between two and five *X*s.

If you have over five *X*s in your experiment, full 2^k factorial experiments become relatively inefficient and can be replaced with pared down versions called *fractional factorials,* or with other screening designs. One good strategy is to include all potential *X*s in a first screening experiment — even the ones you're skeptical about. You then use the analysis of the experiment results to tell you objectively, without any guessing, which variables to keep pursuing and which ones to set aside. Remember, in Six Sigma, you let the data do the talking.

TIP

Experience with experiments verifies the *Pareto principle* we introduce in Chapter 14 — that even if you include dozens of contributing factors in your experiment, only a small number of these *X*s have a significant effect on the output response. When you initially have more than four or five factors, your experiment purpose is to screen out the "trivial many" factors from the "critical few." After that, you then run characterization experiments to provide the detailed knowledge about the remaining critical few.

TECHNICAL STUFF

Plackett-Burman experiment designs are an advanced method you may hear about for efficiently screening dozens of potential *X*s. Although they don't reveal all the detailed knowledge provided by a 2^k factorial design, Plackett-Burman experiments quickly identify which experimental variables are *active* in your system or process. You then follow these screening studies up with more detailed characterization experiments.

Set the factor levels

2^k factorial experiments all have one thing in common: They use only two levels for each input factor. (That's what the "2" in 2^k stands for. The k represents the number of factors included in your experiment.) For each X in your experiment, you select a high and a low value that bound the scope of your investigation.

For example, suppose you're working to improve an ice cream carton filling process. Each filled half-gallon carton needs to weigh between 1,235 and 1,290 grams. Your Six Sigma work up to this point has identified ice cream flavor, the time setting on the filling machine, and the pressure setting on the filling machine as possible critical Xs to the Y output of weight. For each of these three factors, you need to select a high and a low value for your experiment. With only two values for each factor, you want to select high and low values that bracket the expected operating range for each variable. For the ice cream flavor variable, for example, you may select vanilla and strawberry to book-end the range of possible ice cream consistencies. Table 18-1 provides a summary of the selected experiment variables and their values.

Table 18-1 Variable Values for the Ice Cream Carton Filler Experiment

Variable	*Symbol*	*Low Setting*	*High Setting*
Ice cream flavor	X_1	Vanilla	Strawberry
Fill time (seconds)	X_2	0.5	1.1
Pressure (psi)	X_3	120	140

2^k experiments are intended to provide knowledge only *within* the bounds of your chosen variable settings. Be careful not to put too much credence on information inferred outside these original boundaries.

Exploring experimental codes and the design matrix

With the experiment variables selected and their low and high levels set (see the preceding sections), you're ready to outline the plan for the runs of your experiment. For 2^k factorial experiments, you have 2^k number of unique runs, where k is the number of variables included in your experiment. For the ice cream carton filler example, then, you have $2^3 = 2 \times 2 \times 2 = 8$ runs in the experiment because you have three input variables. For an experiment with two variables, you have $2^2 = 2 \times 2 = 4$ runs, and so on.

Each of these 2^k experimental runs corresponds to a unique combination of the variable settings. In a full 2^k factorial experiment, you conduct a run or cycle of your experiment at each of these unique combinations of factor settings. In a two-factor, two-level experiment, the four unique setting combinations are with

- Both factors at their low setting
- The first factor at its high setting and the second factor at its low setting
- The first factor at its low setting and the second factor at its high setting
- Both factors at their high setting

These groupings are the only ways that these two factors can combine. For a three-factor experiment, eight such unique variable setting combinations exist.

TIP

A quick, shorthand way to create a complete table of an experiment's unique run combinations is to create a table called the *coded design matrix.* Make a column for each of the experiment variables and a row for each of the 2^k runs. Then, using –1s as a code for the low variable settings and +1s as a code for the high settings, fill in the left-most variable column cells with alternating –1s and +1s. Repeat the process with the next column to the right, this time with alternating *pairs* of –1s and +1s. Fill in the next column to the right with alternating *quadruplets* of –1s and +1s, and so on, repeating this process from left to right until, in the right-most column, you have the first half of the runs marked as –1s and the bottom half listed as +1s. Table 18-2 shows the coded design matrix for a three-factor experiment, such as the ice cream carton filler.

Table 18-2 Coded Design Matrix for a Three-Factor Experiment

Run	X_1	X_2	X_3
1	–1	–1	–1
2	+1	–1	–1
3	–1	+1	–1
4	+1	+1	–1
5	–1	–1	+1
6	+1	–1	+1
7	–1	+1	+1
8	+1	+1	+1

Remember that these three factors are coded values in the table; when you see a –1 under the X_1 column, it really represents a discrete value, such as "vanilla" in the ice cream experiment; a +1 really represents the other value, like "strawberry."

Conducting your experiment

With your experiment well planned, the act of carrying it out is easy — it's like falling off a log. You just have to roll up your sleeves and get into the scientific trenches. The following sections show you how.

Randomizing: Safeguard against unknown nuisance factors

Despite your best efforts, external factors beyond the control of your selected experiment variables may creep in and influence the outcome of your experiment. These influences are factors (called *nuisance factors*) that you haven't foreseen, but they have the potential to blur the clarity of your analysis and insights. For example, in the ice cream carton filling process discussed in "Planning your experiment," a rise in the ambient factory temperature while you're conducting the experiment may affect the experiment outcomes and lead you to believe it's a real effect from your selected experimental factors. One way to compensate for these unknown nuisance variables is to *randomize* the order of your experimental runs. Doing so spreads out the potential for nuisance effects evenly and fairly over all of the experimental runs and preserves the validity of your results.

TIP

Always randomize the order of your experiment runs to reduce the risk of extraneous variables skewing the results of your analysis. Also, randomize your experiment materials, your personnel, and your equipment. The idea is to guarantee that only the effect of your selected factors is purposely concentrated during your experiment.

Blocking: Safeguard against known nuisance factors

When you know the source of nuisance variation, you can purposely include this nuisance effect in *all* your experimental runs. In this way, you guarantee that the nuisance factor won't bias only a portion of your experimental settings. In the ice cream carton filling example, you may decide to perform each experimental run at the same time each day. This way, the influences from different times of day are blocked from impacting only some of the experimental runs.

TIP

A catchy phrase may help you remember the roles of randomizing and blocking in your experiments: Block what you can and randomize against what you can't block. (Check out the preceding section for more on randomizing.)

Performing the experiment and gathering the data

Running the experiment is the fun part. All you have to do is follow your experimental plan, like the one shown in Table 18-3 for the ice cream carton filler project.

In Table 18-3, we've added a column to the coded design matrix after the Run column, showing the random order in which the experimental runs are conducted. We've also added a column on the far right to capture the outcome Y variable for each experimental run and assigned specific variables to the X values.

Table 18-3 Plan and Results for the Ice Cream Carton Filler Experiment

Run	*Order*	*X_1: Flavor*	*X_2: Time*	*X_3: Pressure*	*Y*
1	7	–1	–1	–1	1,238
2	2	+1	–1	–1	1,252
3	5	–1	+1	–1	1,228
4	8	+1	+1	–1	1,237
5	3	–1	–1	+1	1,223
6	6	+1	–1	+1	1,234
7	1	–1	+1	+1	1,238
8	4	+1	+1	+1	1,250

Analyzing your experiment

The purpose of analyzing your experiment is to take the experiment results and piece together the $Y = f(X) + \varepsilon$ puzzle for your process or system. How much effect does X_1 have on Y? What mathematical form does this relationship take on? These are the questions that your analysis answers. In the following sections, we give you the lowdown on analyzing your Six Sigma experiment.

Calculating and visualizing the main effects

A *main effect* is the quantitative influence a single experiment factor has on the response Y. Each factor in your experiment will have a main effect. For example, how much effect does ice cream flavor by itself — going from vanilla to strawberry — have on the resulting filled weight of the carton?

The main effect of the X_1 ice cream flavor factor is the average response of the experiment runs with X_1 at its high or strawberry setting minus the average response of the experiment runs with X_1 at its low or vanilla setting. You can find the related values for the ice cream example in Table 18-3. Runs 2, 4, 6, and 8 are where X_1 is at its high setting. Runs 1, 3, 5, and 7 are where X_1 is at its low setting. So you can write the main effect of ice cream flavor (called E_1) mathematically as

$$E_1 = \frac{Y_2 + Y_4 + Y_6 + Y_8}{4} - \frac{Y_1 + Y_3 + Y_5 + Y_7}{4}$$
$$E_1 = \frac{1{,}252 + 1{,}237 + 1{,}234 + 1{,}250}{4} - \frac{1{,}238 + 1{,}228 + 1{,}223 + 1{,}238}{4}$$
$$E_1 = 1{,}243.25 - 1{,}231.75$$
$$E_1 = 11.5$$

Figure 18-2 shows the main effect of ice cream flavor graphically. You can see that as the ice cream flavor changes from vanilla to strawberry, the carton weight changes by 11.5 grams.

To calculate the main effect E_2 of fill time on the filled carton weight Y, you can leverage the coded setting values for factor X_2 in Table 18-3. Call these coded values $c_{2,1}$, $c_{2,2}$, and so on through $c_{2,8}$, for each of the experimental runs. Another way to write the equation for the main effect of fill time, then, is

$$E_2 = \frac{c_{2,1}Y_1 + c_{2,2}Y_2 + c_{2,3}Y_3 + c_{2,4}Y_4 + c_{2,5}Y_5 + c_{2,6}Y_6 + c_{2,7}Y_7 + c_{2,8}Y_8}{4}$$
$$E_2 = \frac{(-1)\,1{,}238 + (-1)\,1{,}252 + (+1)\,1{,}228 + (+1)\,1{,}237 + (-1)\,1{,}223 + (-1)\,1{,}234 + (+1)\,1{,}238 + (+1)\,1{,}250}{4}$$
$$E_2 = \frac{-1{,}238 - 1{,}252 + 1{,}228 + 1{,}237 - 1{,}223 - 1{,}234 + 1{,}238 + 1{,}250}{4}$$
$$E_2 = 1.5$$

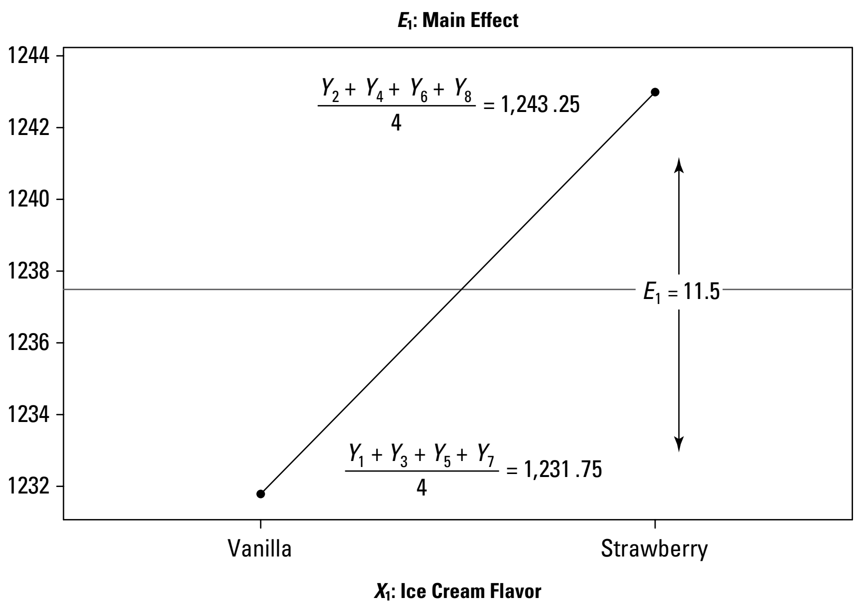


Figure 18-2: Main effect E_1 on carton weight due to the ice cream flavor.

which gives a main effect of fill time of 1.5 grams.

Then using the coded setting values for X_3 — $c_{3,1}, c_{3,2}, \ldots, c_{3,8}$ — you can use the same procedure to calculate the main effect of pressure E_3:

$$E_3 = \frac{-1{,}238 - 1{,}252 - 1{,}228 - 1{,}237 + 1{,}223 + 1{,}234 + 1{,}238 + 1{,}250}{4}$$

$$E_3 = -2.5$$

with the main effect of pressure being –2.5 grams.

In fact, you can leverage the coded setting values to create the following generalized equation to compute *any* effect in a 2^k full factorial experiment:

$$E_i = \frac{1}{2^{k-1}} \sum_{j=1}^{2^k} c_{i,j} Y_j$$

where k is the number of experiment factors and i designates which effect you're calculating.

Figure 18-3 shows all three main effects on a single plot for comparison.

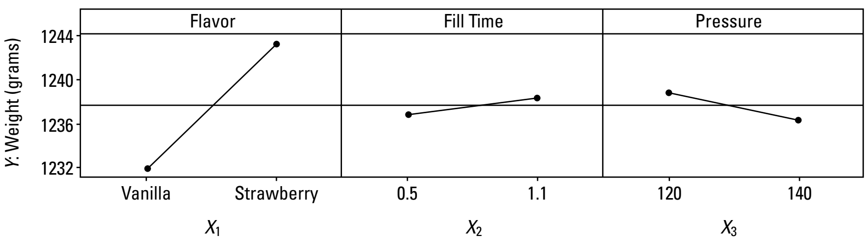


Figure 18-3: Graphical comparison of main effects for the ice cream carton filling example.

Visually, you can easily see that X_1, the flavor of the ice cream, has the largest main effect on the filled weight of the cartons.

Picturing and determining the interaction effects

As we note earlier in the chapter, one input variable interacting with another is always a possibility. To find out whether your experiment has interacting variables, you perform a series of calculations that indicate how strongly your variables influence each other.

Say you want find out how your flavor and fill time variables impact each other in the recurring ice cream example. Label the interaction effect between ice cream flavor (X_1) and fill time (X_2) as E_{12}. You then create a new column of coded setting variables that represents the interaction of factors X_1 and X_2 by multiplying the coded values of X_1 and X_2 together for each experiment run. For example, $c_{12,1} = c_{1,1} \times c_{2,1}$, $c_{12,2} = c_{1,2} \times c_{2,2}$, and so on up through $c_{12,8} = c_{1,8} \times c_{2,8}$. Table 18-4 shows the new coded setting values for the two-variable and the three-variable interactions possible in the ice cream carton filler experiment.

Table 18-4 Interaction Coded Variables for the Ice Cream Carton Filler Experiment

Run	c_1	c_2	c_3	c_{12}	c_{13}	c_{23}	c_{123}	Y
1	–1	–1	–1	+1	+1	+1	–1	1,238
2	+1	–1	–1	–1	–1	+1	+1	1,252
3	–1	+1	–1	–1	+1	–1	+1	1,228
4	+1	+1	–1	+1	–1	–1	–1	1,237
5	–1	–1	+1	+1	–1	–1	+1	1,223
6	+1	–1	+1	–1	+1	–1	–1	1,234
7	–1	+1	+1	–1	–1	+1	–1	1,238
8	+1	+1	+1	+1	+1	+1	+1	1,250

With the coded values for the interaction effects, you can now use the general formula we outline in the preceding section to calculate each of the possible two-variable interaction effects. For example, the interaction effect between ice cream flavor (X_1) and fill time (X_2) is calculated as

$$E_{12} = \frac{1}{2^{k-1}} \sum_{j=1}^{2^k} c_{12,j} Y_j$$

$$E_{12} = \frac{(+1)1{,}238 + (-1)1{,}252 + (-1)1{,}228 + (+1)1{,}237 + (+1)1{,}223 + (-1)1{,}234 + (-1)1{,}238 + (+1)1{,}250}{4}$$

$$E_{12} = \frac{1{,}238 - 1{,}252 - 1{,}228 + 1{,}237 + 1{,}223 - 1{,}234 - 1{,}238 + 1{,}250}{4}$$

$$E_{12} = -1.0$$

or –1.0 grams effect when the X_1 and the X_2 factors are combined.

Using the same procedure, you can calculate interaction effects for E_{13} and E_{23}. You should get values of 0.0 grams and 14.0 grams, respectively. Figure 18-4 shows all three two-variable interaction effects.

In the grid layout of Figure 18-4 for the $X_2 - X_3$ interaction, you can see that the plotted effect lines have very different slopes. This graphical clue lets you know that E_{23} is very strong. The plotted effect lines for $X_1 - X_2$ and $X_1 - X_3$, however, have very similar slopes. Their calculated interaction effects, E_{12} and E_{13}, are rather small.

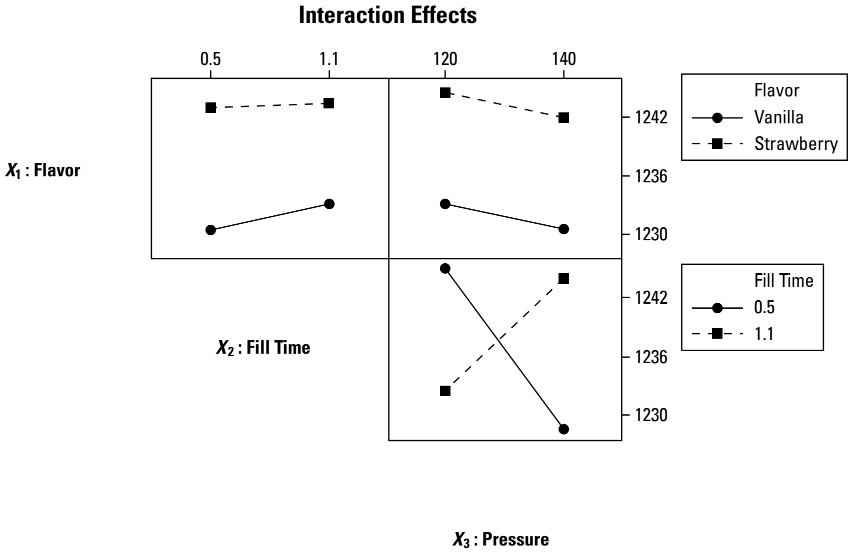


Figure 18-4: Two-factor interactions in the ice cream carton filler example.

For a three-factor experiment, you need to compute one more interaction effect: the possible interaction when all three variables are combined (E_{123}). This calculation may sound tricky, but it's not, because you're using the coded setting values and the same general formula for calculating the effects:

$$E_{123} = \frac{1}{2^{k-1}} \sum_{j=1}^{2^k} c_{123,j} \, Y_j$$

$$E_{123} = \frac{-1{,}238 + 1{,}252 + 1{,}228 - 1{,}237 + 1{,}223 - 1{,}234 - 1{,}238 + 1{,}250}{4}$$

$$E_{123} = 1.5$$

or 1.5 grams effect when all three factors are combined.

Figuring out which effects are significant

Even though you can calculate all the main and interaction effects of the variables, they likely aren't all significant or necessary. The Pareto principle (see Chapter 14) tells you that a relatively small subset of all the possible effects explains the vast majority of the output responses. So how do you know which effects to hold on to and which ones to cast aside?

If the factors you select for your experiment have no impact on the outcome *Y*, the calculated main and interaction effects will just be random — they'll be normally distributed and centered around zero. But if any one of the effects is significant, it'll depart from the random cluster of the rest.

The easiest way to detect this departure is graphically, by plotting all the calculated effects against a line representing a normal distribution. If a plotted effect doesn't fit this line, you know that it's significant and not part of the random noise.

To create this graph for the ice cream carton filler example, you list all the calculated effects in rank order from smallest to largest and write down the rank *i* next to each effect. In case of ties, like between E_2 and E_{123}, you assign the average rank to the tied effects. You can see this setup in Table 18-5.

Table 18-5 Creating the Normal Scores for the Ice Cream Carton Filler Example

Effect	*Value*	*Rank (i)*	*P*	*Z*
E_3	–2.5	1	0.071	–1.465
E_{12}	–1.0	2	0.214	–0.792
E_{13}	0.0	3	0.357	–0.366
E_2	1.5	4.5	0.571	0.180
E_{123}	1.5	4.5	0.571	0.180
E_1	11.5	6	0.786	0.792
E_{23}	14.0	7	0.929	1.465

As an intermediate step, you have to calculate the expected probability for each rank. This probability is called *P* and is in the fourth column of Table 18-5. The formula calculating the *P* for each row in the table is

$$P_i = \frac{i - 0.5}{2^k - 1}$$

So for the E_{13} effect, its expected probability, *P,* is

$$P_i = \frac{3 - 0.5}{2^3 - 1} = \frac{2.5}{7} = 0.357$$

The final step in creating the values of Table 18-5 is looking up the *Z* value for each intermediate *P* value. Using a look-up table for *Z,* you can see that the *Z* score corresponding to the *P* of 0.357 on E_{13} is –0.366. Having filled in all the values of Table 18-5, you now simply plot the calculated *Z* value against each of the corresponding effect values. You can see this diagram for the ice cream carton filler example in Figure 18-5.

Looking at Figure 18-5, you can see that effects E_1 and E_{23} are obviously very different from the rest of the effects. Although E_1 and E_{23} aren't centered around zero and clearly don't fit the expected normal probability line, all the others do.

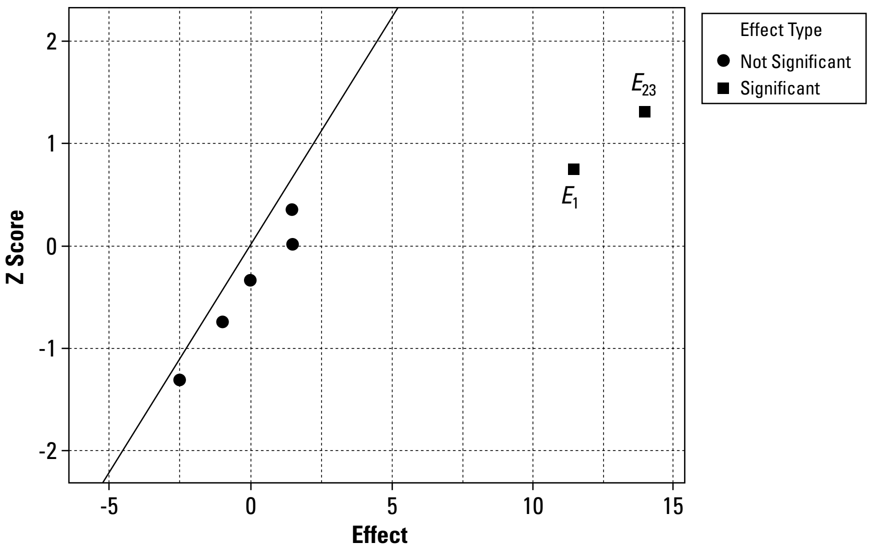


Figure 18-5: Normal probability plot for all effects of the ice cream carton filler example.

The more complicated a potential interaction is, the less likely it is to be significant in reality. Very often, for example, two-factor interaction effects are found to be significant. Much less often, three-factor interactions are determined to be important. Uncovering a legitimate interaction effect that includes four or more factors is a real rarity. The more complicated an interaction effect is, the more skeptical you should be about it being real.

With just an eight-run experiment, you've determined that only two effects significantly affect the performance of the ice cream carton filler. The first is the type or flavor of ice cream being produced. Also, the combined, interactive effect of filler time and pressure definitely impacts performance. But filler time and pressure acting by themselves don't have a significant effect.

This kind of revelation is the power of Six Sigma. Instead of guessing or fumbling in the dark for the answer, you let the data and the analysis show what's important and what isn't. In return, you're the improvement hero!

Considering the general form of the equation

2^k factorial experiments not only reveal which factors affect the output Y but also allow you to understand the form of the $Y = f(X) + \varepsilon$ equation for the system or process you're improving. At the onset, a 2^k experiment investigates the possibility of all main and interaction effects being significant. (Subsequent analysis shows you which ones you can safely ignore.)

Picture in your mind a general $Y = f(X) = \varepsilon$ equation with a term for each main effect, a term for each interaction effect, and an overall offset effect. For a three-factor system (such as the ice cream carton filler example), this general equation takes the following form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3$$

In this general equation, each combination of the input X variables has a multiplier coefficient represented by β (the Greek letter beta). The little subscripts at the lower right of each β tell you which effect it corresponds to. These βs are often called coefficients.

A two-factor system would have a general equation of

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2$$

while a four-factor system would include additional terms for all the three-variable and four-variable interactions.

The β_0 term in all these equations represents the overall level of the process or system you're working on. No matter what you do to the setting of any of the system variables, the system will take on at least this value. That's why it's often called an *offset* or *constant* term.

Defining your $Y = f(X) + \varepsilon$ equation

For the system or process you're working on, the only terms of the general equation you need to hang on to are the ones that correspond to the effects you've found to be significant. For example, in the ice cream carton filler process, only the ice cream flavor X_1 and the filler time-pressure interaction X_2X_3 effects were found to be significant. That leads to a simplified equation form of

$$Y = \beta_0 + \beta_1 X_1 + \beta_{23} X_2 X_3$$

But what are the values of the βs? Finding these values is easier than you may think. The value for the offset β_0 is simply the computed average for all the 2^k experiment runs. For the ice cream carton filler example, the average output Y for the eight experiment runs is 1,237.5, so

$$\beta_0 = 1{,}237.5$$

The β value for all other significant factors is found by dividing the corresponding effect value in half. That means that

$$\beta_1 = \frac{E_1}{2} = \frac{11.5}{2} = 5.75$$

$$\beta_{23} = \frac{E_{23}}{2} = \frac{14.0}{2} = 7.0$$

The β coefficients are half the effect value because the effect value is calculated over a span of +1 to –1 for the variable. That's an effective distance of two, not one. Therefore, to get back to the right equation coefficient, you have to divide the calculated effect value by two.

With these coefficients calculated, you can write the $Y = f(X) + \varepsilon$ equation for the ice cream carton filler system:

$$Y = 1{,}237.5 + 5.75\,X_1 + 7.0X_2X_3$$

Armed with this equation, you can now go out to the ice cream production line and immediately correct the problem situation of this example.

Suppose that the weight of the filled ice cream cartons is required to be between 1,225 and 1,280 grams. If you're producing a batch of vanilla ice cream, you can plug that coded value into the equation ($X_1 = -1$), and then plug in various coded values for X_2 and X_3 to calculate what your fill time and pressure settings should be on the ice cream filler machine. When you switch over to making strawberry ice cream, you can then pull out your equation again and know exactly how to alter your fill time and pressure settings to maintain the correct filled carton weight.

Be careful to plug only *coded* values into your derived $Y = f(X) + \varepsilon$ equation.

You've Only Just Begun: Looking at More Topics in Experimentation

2^k full factorial experiments give you a powerful jump-start into the world of improvement through DOE. But really, they're just the tip of the iceberg. As you gain experience, you want to discover how to address more advanced topics.

- **Curvature:** The assumption of 2^k experiments is that the effects of your experimental factors are linear. Although this idea is often a good first approximation, a line often doesn't fit your process or system. For those cases, you need to design your experiment to reveal the curved nature of the reality of your situation. This redesign usually involves including more than two levels for each of your experimental factors.
- **Replications:** If you repeat your experiment, you get slightly different results. Variation, as always, is a part of everything — including your experiment. Repeating runs of your experiment (called *replications*) allows you to estimate how much of the observed variation in your process or system is explained by $Y = f(X)$ and how much remains unexplained, the ε.

- **Analysis of variance (ANOVA):** Almost all experiments involve exploring, investigating, and comparing the sources of observed variations. ANOVA is an advanced method that allows you to categorize and quantify all the various sources of variation.
- **Robustness:** The ability of a process or system to perform consistently in the face of variation is called *robustness.* Taguchi and other experiment designs allow you to investigate and optimize your process or system so that it's as immune as possible to the ravages of variation.
- **Response surface methods (RSM) and optimization:** The purpose of many experiments is to find out the best values to set the input variables at. A whole branch of the field of DOE focuses on designing and analyzing experiments to find the local or global optimal operation settings.
- **Fractional factorial experiments:** You can adapt 2^k full factorial experiments to more efficiently search through a large number of experimental factors. What you give up in increasing the number of experimental factors is analytical accuracy. Fractional factorial experiments teach how and where to adapt your experiment to get the most out of your search efforts.

Chapter 19

Standardizing on Improvement

In This Chapter

- Getting long-term results with control planning
- 5S-ing for sustained improvement
- Mistake-proofing for the future with Poka-Yoke
- Using your old friend FMEA to establish the right level of control
- Setting up and following standards to make your awesome new process last

A solution that isn't sustained over the long term has little value. That kind of solution can make you feel good for a little while, but if the problem doesn't stay solved, you end up being frustrated with the experience. The Control phase (the *C* in DMAIC) helps you make sure the problem stays fixed and, if done properly, provides you with additional data to make further improvements to the process.

In this chapter, you find an abundance of easy-to-use and readily available Six Sigma tools and techniques to ensure that your problem remains solved for the long term. These tools range from documented plans and strategies to common-sense approaches for mistake-proofing a process.

Satisfying the Need for Control Planning

Six Sigma emphasizes the Control phase because previous attempts at improving quality and business performance repeatedly demonstrated that process behavior is complex and fragile and that hard-earned gains slip away if the process is left to itself. A *process* is a system of events, activities, and feedback loops. A well-designed process exhibits inherent self control, while a poorly designed process requires frequent external control and adjustment to meet requirements. Some people use the terminology *tampering with the process* to describe such adjustments.

TIP

A process with built-in control acts like a self-adjusting heating and cooling system in a house: The system automatically maintains a comfortable temperature at all times. A process without inherent control is like having to get up from the couch to manually turn the heat on and off every time you get too cold or too hot. That process results in a lot of variation, and excessive variation creates waste.

In the Six Sigma control phase, your action in developing a control plan — and the knowledge (the reference documentation and the organizational memory) that you gain from it — virtually guarantees you that the improved performance you've worked so hard to achieve will stick. Before Six Sigma came along, developing process controls tended to be like trying to boil the ocean. Organizations would often go to herculean efforts to have an exhaustive plan for every process and every detail of every process, regardless of the importance of the process. It was like trying to eat the proverbial elephant in one bite! Six Sigma, however, gives you the ability to pick out the most important processes and to identify the input and output variables of the process that matter most (effectively eating the elephant one bite at a time). This prioritization changes the control effort from a broad-swathed flashlight to a focused laser beam. Developing a control plan for a Six Sigma project is not only a much easier alternative but also an absolutely essential activity.

REMEMBER

$Y = f(X) + \varepsilon$ shows the inputs that must be controlled (see Chapter 3 for details on this equation). The outputs can be monitored only to see whether control has or hasn't been achieved. Accordingly, a Six Sigma control plan has two main aspects:

- *Process monitoring* of outputs uses a tool called a *process management summary.* The objective of the process management summary is to enable the visibility, review, and action for all critical process outputs in an organization.
- *Process control* of inputs uses a tool called a *process control plan.* The objective of the process control plan is to create systematic feedback loops and actions to assure the process has inherent, automatic control. With a good process control plan, you can change people, equipment, materials, and production rates without significantly altering the performance quality of the process. The following sections get into more details on these two tools.

The process management summary

Use the process management summary to collect all the critical-to-quality outputs, or CTQs, for a process, a department, a division, or even an entire company. (You can see an example summary in Figure 19-1.) Roll up the summary to whatever level your organization needs for monitoring, reviewing, and taking action to assure acceptable process and business performance. Each time a Six Sigma project is completed, add that project's CTQs to the summary.

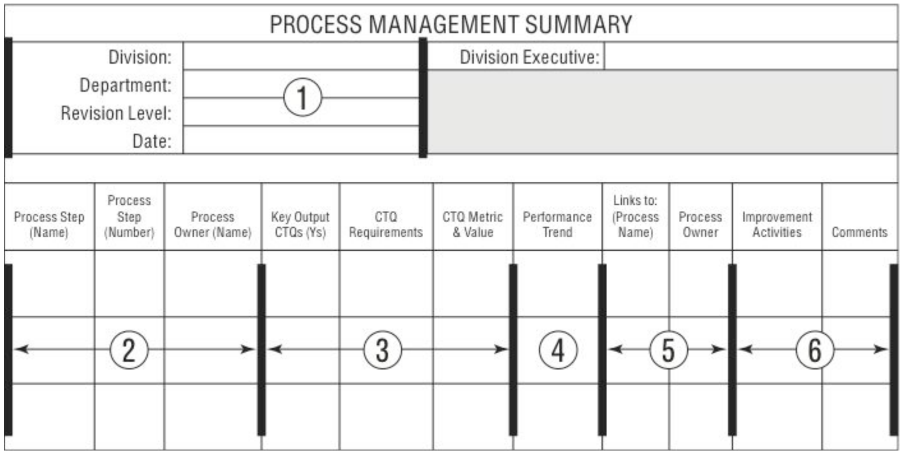


Figure 19-1: Six Sigma process management summary.

In this example, the administrative section of the summary (Section 1) is where you identify the organizational areas involved, plus the revision level and date of the information. The summary's purpose is captured in the main body (Sections 2 through 6), where you provide enough information for anyone to readily see the current status of the CTQs, how they relate to downstream processes, and what actions, if any, are currently being taken.

The process control plan

The process control plan is your companion to the process management summary; you can see a sample in Figure 19-2. Use the process control plan to focus on the *X*s — the inputs to the process. The inputs, by definition in the formula of $Y = f(X) + \varepsilon$, are the critical *X*s that are determined from the Six Sigma project. But you can place process outputs, the *Y* (the CTQs), on a process control plan, too. When done correctly, the process control plan creates a complete picture of all possible inputs, outputs, and activities for a single process.

The administrative section of the process control plan (Section 1) is where you provide key information for identifying the process, including the owner. It also includes revision control information. Section 2 is a larger space for you to write an operational definition of the control plan. The information in this field helps people understand why the process exists — that is, what its value proposition is — and helps put the control activities into proper context. In Section 3, identify what is specifically being controlled. Use Section 4 to specify the spec limits or other requirements and the key performance metrics and values. People can look to this section to see quickly how well the process is performing and how the control activities are going.

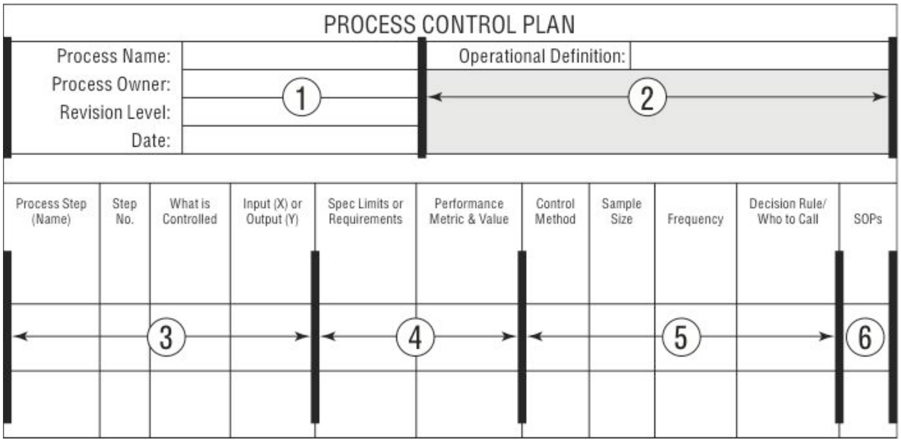


Figure 19-2: Six Sigma process control plan.

Section 5 is where the rubber meets the road. This section is where you identify the control methods and measures and the actions you want taken if the process goes out of control. The control methods may include checklists, mistake-proofing methods, statistical process controls, or any other appropriate procedures. Control methods likely include the use of automated data collection and process intelligence technologies. Note that in this section, you also specify the required sample sizes and the frequency of sampling in order to provide the proper feedback to the process. This feedback is important, just like it is when you're driving a car. If you don't have the right amount of feedback at the right time to keep your car going down the center of the road, you may suddenly find yourself in the ditch. The same is true for keeping a process on track.

Also include in Section 5 the action(s) you want to be taken if the controlled parameter doesn't meet its requirements or stay within its specification limits. This action is analogous to an in-case-of-emergency plan — it's what to do and who does it. A sense of emergency always exists when an input *X,* an output *Y,* or a CTQ goes out of control! In Section 6, list the names of any governing documents for the process and any standard operating procedures (SOPs). With a good process control plan in place, you're ready to hand your project off to the process owner and process workers, highly confident that they can sustain the improvement your Six Sigma efforts have made.

REMEMBER

Creating a process control plan requires you to really think through what needs to be done, but it's worth the effort. Without a good control plan in place, your Six Sigma project isn't complete.

5S: Housekeeping for Sustained Improvement

High-performing processes and workplaces are always characterized by organization and cleanliness. Think of a race car pit crew, where every tool is positioned to shave off tenths of a second, or of a hospital operating room, where cleanliness and instrument precision can be the difference between life and death.

Now, you're probably not a pit crew mechanic or a surgeon. But if the process you have improved is important to your business, you need to keep that process environment in tiptop shape. The foundation of this maintenance is basic housekeeping — the kind your mother may admire: cleaning and organizing the area where the process occurs to rid it of distractions and obstacles. The whole point is to reduce or keep out waste, and the method that helps you with that is called *5S*.

The process behind 5S began decades ago in Japan as a means of immediately engaging frontline process teams in the daily work of improvement. Just this practice alone brought immediate incremental improvement to processes. Regularly revisiting the 5S method maintained the improvements over the long term. The *S*s are English equivalents of five Japanese words that capture the sequence and actions of the method. The actions build on each other, so you need to conduct them in sequence. Otherwise, you get a reconfigured process that misses its optimal condition.

TIP

In Six Sigma vernacular, you can use *5S* as an adjective ("How did your 5S event go?") or as a verb ("See you later; I'm going to go 5S my cubicle.") The five sequential elements of 5S are

1. **Sort.** The first step is to go through all equipment and materials and determine what must be retained at the worksite. Only essential tools, aids, equipment, and so on are allowed to remain. When you find something that doesn't belong, return it to the correct person or department or simply get rid of it. Put a red tag on these items and get proper authorization before scrapping, selling, or recycling them.
2. **Straighten.** After Step 1, all you have left at the worksite are essentials. You must now give each of these a single, proper place. You've heard the saying, "A place for everything, and everything in its place." That's exactly what we're talking about. Be creative in establishing places for things so that returning an item to where it belongs is natural or easy.

It's like creating a "shadow board" for tools, with a silhouette for each tool that makes knowing where to put the tool back a cinch. In that way, anyone working in the area can find what they need and know where to put it when they're done so that it's ready for its next use. And if an essential tool is absent, that fact is immediately apparent.

3. **Scrub.** To help maintain the order you've created, thoroughly clean everything remaining at the worksite. The time and money spent on polishing or repainting, if needed, will be returned many-fold in more-positive employee attitudes and greater productivity, an increased ability to detect equipment problems, fewer contamination and defects, and improved safety.
4. **Standardize.** Where possible, make worksites consistent. All workstations for a particular job should be identical so that someone from another worksite can immediately step in and productively run the process if necessary. Think of the value business travel hotels add by standardizing the layout, the furniture, and other amenities across all their locations. That fosters a familiar environment for their guests and increases their guests' productivity (not to mention the hotel staff's).
5. **Sustain.** This final step means to put a schedule and system in place for maintaining and refreshing the 5S-ed worksite. The actions of 5S are everyone's job, not just the janitor's or cleaning crew's.

Note: Because everyone in a company is involved in 5S and because the approach includes so many similar elements, many companies now include their safety programs as part of their 5S efforts. Usually, these companies tack "safety" onto the end of the list of *S*-words and call the process *6S*. Here are some important points to consider about 5S:

- **5S is intensely visual.** It involves labels, colors, shadow boards, taped-off placement lines, and everything else that provides instant identification for what belongs where or in what order. Making 5S visual makes it simple and effective.
- **The work of 5S is inherently local.** What a process needs differs from task to task and from area to area. So keep the boundaries of a 5S effort divided into these small regions and then repeat the 5S steps in other areas if you want to expand the effort.
- **5S is just as important for office areas as it is for production or manufacturing.** Office workers benefit greatly when shared copy and office supply areas are 5S-ed. Conference rooms that are 5S-ed add value to each successive meeting held in them.
- **Management plays a key role in 5S.** Not only can managers participate in 5S events, but they can also regularly audit or review areas of 5S performance. Both of these actions add important credibility and momentum.

REMEMBER

5S sometimes runs counter to an individual's work style, but that excuse should never be a deterrent from doing the right thing. A surgeon may have sloppy drawers at home, but in the operating room, he's required to have the discipline to join in the improvement and standardization.

Mistake-Proofing with Poka-Yoke

Mistake-proofing, or *Poka-Yoke* (pronounced POH-kuh YOH-kay) as it's known in Japan, is an action you take to remove or significantly lower the opportunity for an error or to make the error so obvious that allowing it to reach the customer is almost impossible. Figure 19-3 depicts both of these approaches.

Poka-Yoke is one of the simplest tools to master; it's very consistent with the fundamental aims and philosophy of Six Sigma, and it has wide applicability in manufacturing, engineering, and transactional processes. Poke-Yoke involves creating actions that are designed to eliminate errors, mistakes, or defects in everyday activities and processes. Poka-Yoke starts with an understanding of the cause-and-effect relationship of a defect, followed by a remedy that eliminates the occurrence of the mistakes that lead to that defect. Poka-Yoke solutions can include the addition of a simple physical feature, the creation of a checklist, a change in the sequence of operation, a highlighted field on a form, a software message that reminds the operator to complete a task, or any other way of helping to totally reduce or eliminate mistakes.

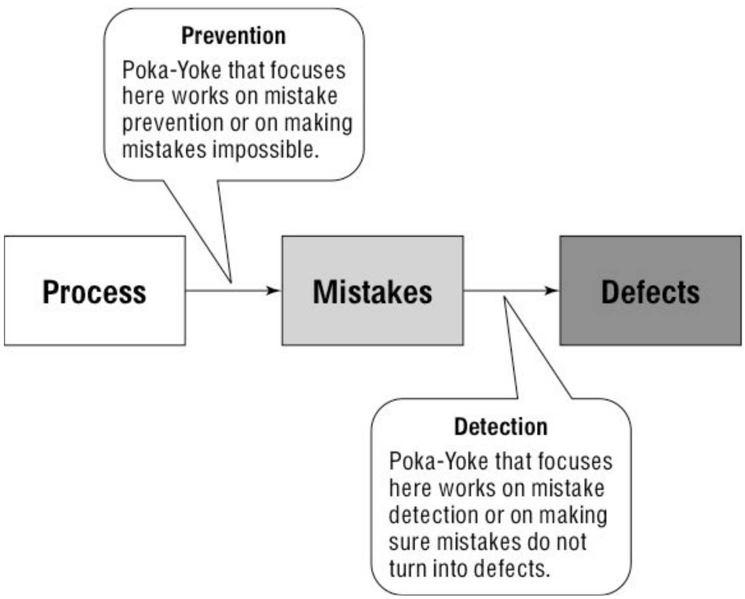


Figure 19-3: Applying Poka-Yoke for the prevention and detection of defects.

You can find a number of everyday examples of Poka-Yoke. Look at the connector on a cellphone charger. Its shape prevents you from connecting it in the wrong place or turning it incorrectly, damaging your phone. Or remove the gas cap and look at the gas filler tube on your car. It's designed so that you can put only the right kind of gas into your car. Poka-Yoke is also an ideal form of control for transactional processes. Some examples include the following:

- Computer data entry forms won't let you advance until all the information is input correctly.
- Checklists are used so items aren't inadvertently missed.
- Process workflow is automatically routed and executed.

The objective of the Control phase is to establish measurement points for the critical *X*s and other significant parameters of the process to assure that the CTQs are predictable and meet established requirements. Different levels of control have different levels of effectiveness.

TECHNICAL STUFF

The most effective form of process control is sometimes called a *Type-1 corrective action.* This control prevents the error condition from ever occurring, which is the primary intent of the Poka-Yoke method. The second-most effective control is called a *Type-2 corrective action.* This control detects when an error occurs and stops the process or shuts down the equipment so that the defect can't move forward. It's the detection application of Poka-Yoke.

Leveraging FMEA as a Control Tool

In Chapter 8, we introduce you to failure mode effects analysis (FMEA). FMEA is also part of the Control phase because of its power in helping you identify and right-size control actions for your DMAIC project.

One of the three scores given to each identified failure mode in FMEA is for its detectability. You determine the detectability score by reviewing how effective your control measures are at preventing or detecting the failure mode's associated cause. When you arrive at the Control phase of your DMAIC project, you must open your FMEA and check the condition of each control for identified failure modes. During your earlier FMEA work, you probably devised control methods for prioritized risks. Now you must ask, "Are the controls for the most significant risks in place? What's their status? Have they been validated as being as effective as needed? How will these controls be maintained?"

The answers to this review of your FMEA provide a comprehensive and extremely valuable plan to keep your improvements intact. We recommend you keep a current version of your FMEA close to the process. In that way, everyone in the process has timely access to valuable information about the risks of the process and how to control each of those risks.

Setting and Following Standards

Taking measures to enable and encourage a process to follow a *standard* — a standard sequence, a standard method of handling, a standard set of equipment settings, and so on — must become the norm if you want to keep performance at an improved level. And your organization's management must change the culture so that employees view these standards as process essentials to be embraced and even honored rather than as restrictive shackles that may be okay to resist.

Process standards — embodied in both the work of creating them and in the discipline to adhere to them later — demonstrate respect for people. You honor and respect those who work in a process when you put measures in place that allow them to more easily perform their work correctly. As a worker in a process, you show respect for people when you follow provided guidelines carefully, knowing that those who provided them did so conscientiously in an effort to help you. On the other hand, you actually disrespect people when you hand them an improved process with an absence of standards for consistent operation or when you disregard work instructions and automatically assume you know a better way.

The setting and following of standards ends up forming the foundation of continuous improvement. Few things are more essential. With standards in place, processes and products that have been improved stay that way, and process workers can rely on a basis for consistent high performance; then their intellects and capacities are freed to look for further improvements.

Chapter 20

Maintaining Gains through Statistical Process Control

In This Chapter

- Understanding statistical process control
- Selecting the right control chart for your situation
- Analyzing and interpreting control charts
- Creating control charts for continuous and attribute data

Statistical process control (SPC) is a century-old toolset that involves using statistics to monitor and control the variation in processes. In Six Sigma, you use SPC first and foremost to stabilize out-of-control processes, but you can also use it as a follow-on to monitor the consistency of product and service processes. As such, SPC is a hallmark of the DMAIC Control phase.

In this chapter, you become familiar with the underlying statistical concepts upon which SPC is founded, as well as with the recipes for constructing critical control charts. You also see how to correctly interpret the control charts you produce and how to select the right chart for your Six Sigma work from the host of available possibilities.

Getting to Know Control Charts

The primary SPC tool is the *control chart* — a graphical tracking of a process input or an output over time. In the control chart, these tracked measurements are visually compared to decision limits calculated from probabilities of the actual process performance. The visual comparison between the decision limits and the performance data allows you to detect any extraordinary variation in the process — variation that may indicate a problem or fundamental change in the process.

The different types of control charts are separated into two major categories, depending on what type of process measurement you're tracking: continuous data control charts and attribute data control charts. Here is a list of some of the more common control charts used in each category in Six Sigma:

- **Continuous data control charts:**
  - Averages and ranges ($\bar{X} - R$)
  - Averages and standard deviations ($\bar{X} - S$)
  - Individual values and moving ranges ($I - \overline{MR}$)
- **Attribute data control charts:**
  - *p* chart
  - *u* chart

The control chart you choose is always based first on the type of data you have and then on your control objective. The control chart decision tree in Figure 20-1 aids you in your decision. Check out the sections "Setting Up Control Charts for Continuous Data" and "Making Control Charts for Attribute Data" in this chapter to find out how to create each chart, respectively.

The general step-by-step approach for the implementation of a control chart is as follows:

1. **Define what needs to be controlled or monitored.**
2. **Determine the measurement system that will supply the data.**
3. **Establish the control charts.**
4. **Properly collect data.**
5. **Make appropriate decisions based on control chart information.**

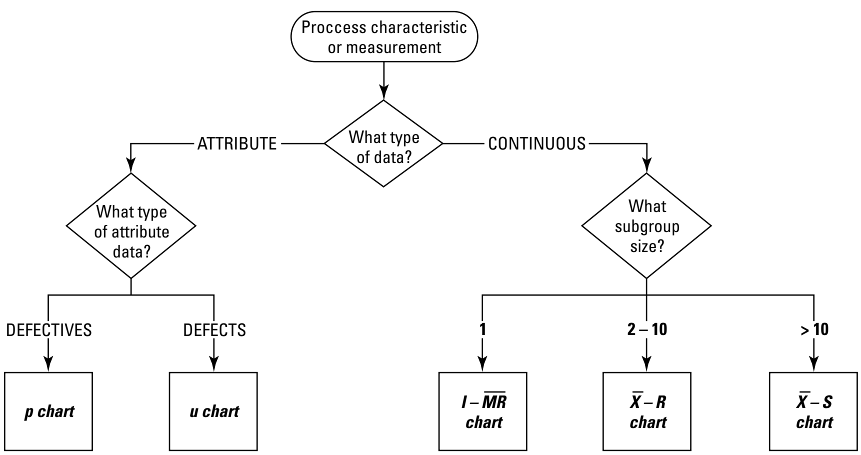


Figure 20-1: Control chart decision tree.

Control charts provide you information about the process measure you're charting in two ways: the *distribution* of the process and the *trending* or change of the process over time. You use control charts to

- Provide a simple, common language for discussing the behavior and performance of a process input or output measure
- Control the performance of a process by knowing when and when not to take action
- Reduce the need for inspection
- Understand and predict process capability based on trends and other performance insights
- Determine whether changes made to the process are having the desired result
- Provide an ongoing, continual view of the performance of the process
- Create a repository of data for follow-on improvement activities

Monitoring the process

What gets measured gets managed. Deciding what to measure and manage in Six Sigma is determined by your Define, Measure, Analyze, and Improve (DMAI) project activity before you get to the Control phase (check out the chapters in Parts II, III, and IV for more on how to measure and manage with DMAIC). Simply stated, what you monitor with control charts are the critical input *X*s and the output CTQs (the *Y*s) you discover in your project. These are the movers and shakers in your process that align to the needs of your customer. In the control phase, you monitor the outputs — the CTQs — and you control the inputs, the critical *X*s. When done properly, this monitoring allows you to consistently reap the fruits of your efforts.

Control charts are two-dimensional graphs plotting the performance of a process on one axis, and time or the sequence of data samples on the other axis. These charts plot a sequence of measured data points from the process. You can also view the sequence of points as a distribution. Figure 20-2 demonstrates how a distribution can be displayed from a sequence of data points.

Control charts have the following attributes determined by the data itself:

- **An average or centerline for the data:** It's the sum of all the input data divided by the total number of data points.
- **An upper control limit (UCL):** It's typically three process standard deviations above the average.
- **A lower control limit (LCL):** It's typically three process standard deviations below the average.

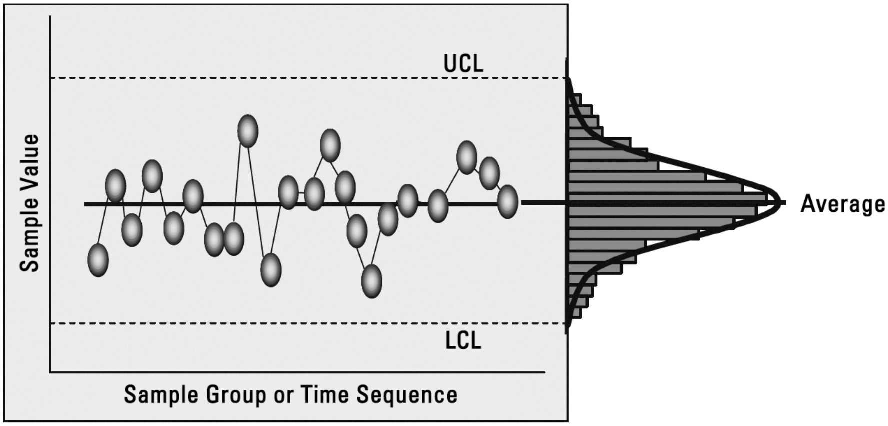
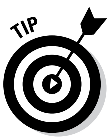


Figure 20-2: Data points and distributions.

Understanding control limits

You may ask, "What is the significance of a control limit, and where does it come from?" The simplicity of control limits, coupled with their powerful implications, will surprise you. Control charts use *probability* (the likelihood of an event occurring) expressed as control limits to help you determine whether an observed process measure would be expected to occur (in control) or not expected to occur (out of control), given normal process variation.



The likelihood that a specific event or measurement value will occur is the ratio of the number of times that event or measurement value occurs compared to the total number of times all other possibilities occur. This formula is demonstrated using Figure 20-3, which is a population of data that contains 100 data points plotted in a *histogram* (see Chapter 10).

In Figure 20-3, 25 data points out of 100 have a value of 50. You then estimate that the probability of getting an event with a value of 50 is 25 out of 100, or 25 percent. Similarly, the probability of getting an event with a value of 52 is approximately 13 percent, and for values of 55 and above, the probability is much lower. Figure 20-4 plots the data from the histogram in Figure 20-3 in a chronological sequence as a control chart for individual measurements.

The upper control limit of 58.7 is three standard deviations above the average. The lower control limit of 41.3 is three standard deviations below the average. Plus or minus three standard deviations from the mean includes 99.7 percent of all the data in a normally distributed population. Therefore, you have a 99.7-percent probability that a process data point will fall between these two limits. That means you have only a 0.3-percent chance that a measurement will be above the UCL or below the LCL.

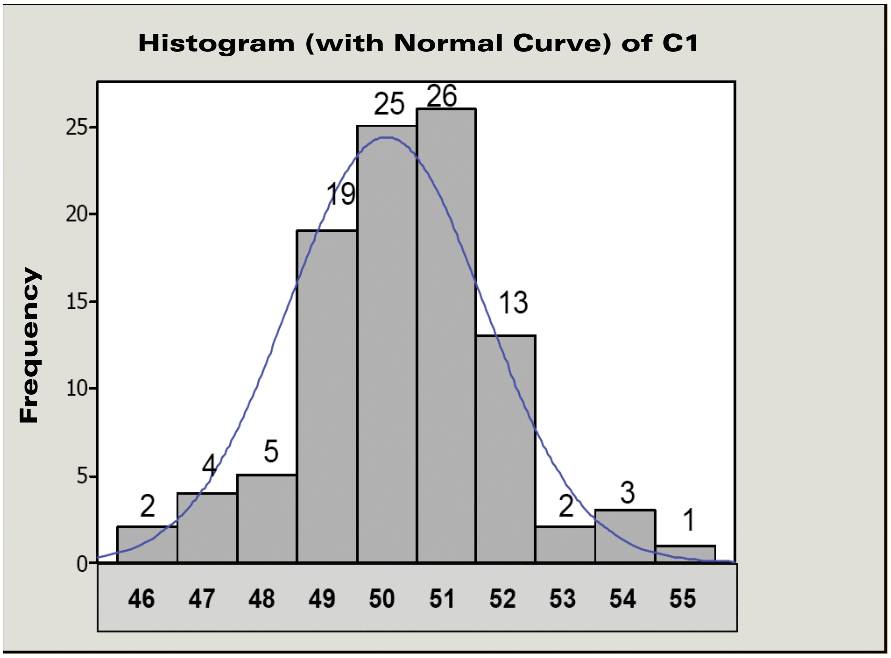


Figure 20-3: Probability of an event happening.

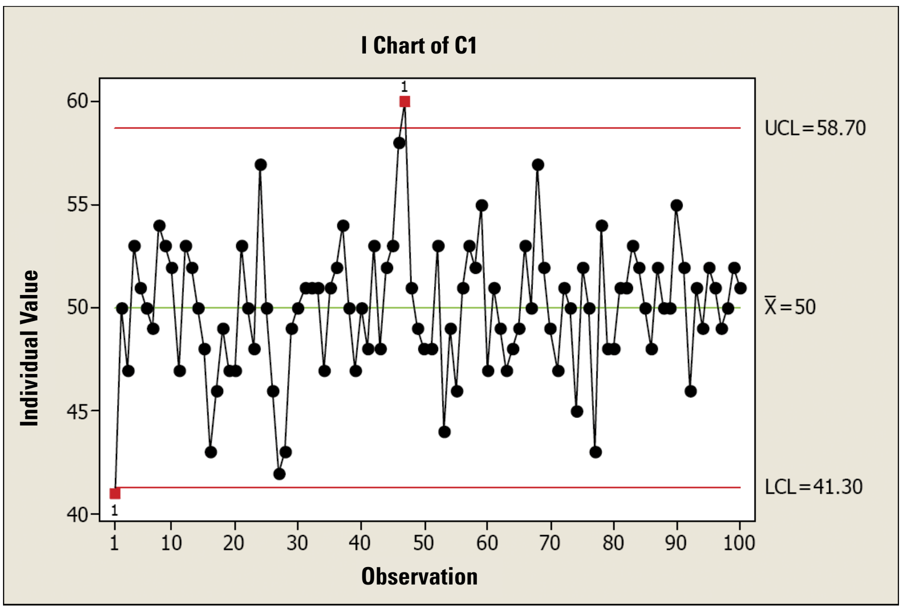


Figure 20-4: Control chart for individuals.

In the early 20th century, Walter Shewhart, one of the founders of the modern quality movement, formalized the ideas used in control charts. He defined that, if a measurement falls within plus or minus three standard deviations of its average, it is considered "expected" behavior for the process.

If a measurement falls within plus or minus three standard deviations of its average, it's considered "expected" behavior for the process and thus is a common cause variation (see Chapter 9). *Common cause variation* results from the normal operation of a process and is based on the design of the process, process activities, materials, and other process parameters.

However, if a data point falls outside of the control limits, something special has happened to the process. In other words, something out of the ordinary has caused the process to go out of control. This situation is known as *special cause variation* (also discussed in Chapter 9), meaning that, based on the behavior of the process up to that point, the probability of that situation occurring is less than 0.3 percent. A measurement with such a low probability suggests that special circumstances affected the process. This simple, quantitative approach by using probability is the essence of all control charts.

Using control charts to keep processes on track

If you apply control charting as a part of your process control plan, you can use the control chart itself to trigger action or to leave things as they are based on what the control chart tells you. *Sample data,* also called *subgroup data,* is collected from the process characteristic (an input or an output) in which you're interested. The process must be allowed to operate normally while you're taking a sample.

WARNING!

If you give the process you're charting out-of-the-ordinary care or any special treatment, the information from the control chart is invalid. You must allow the process to act as it normally does while you're creating a control chart for it.

How often you sample depends on how sensitive you want your chart to be to detect trends or other special-cause patterns in the process behavior. At first, err on the side of taking samples very often, and then, if the process demonstrates that it's stable and in control, you can take samples less often. (*Stable and in control* means that the sample observations are normally distributed around the average and lie within the control limits; the sequence of measurements doesn't show any trends or shifts in centering.)

TIP

A process should be left as it is if it's stable and predictable (in control) and capable of meeting customer requirements (see Chapter 13). If special cause variation occurs, however, you must investigate what caused this extraordinary variation and find a way to prevent it from happening again. Some form of action is always required to make a correction and to prevent future occurrences.

After you have collected a minimum of 25 subgroups of data (with two to five measurements in each subgroup), you can calculate the statistics and control limits by hand (which we describe how to do later in this chapter) or by using a software tool such as Minitab or JMP (see Chapter 22). If you already have historical data, including this data in the analysis is useful to form a strong baseline of information.

Never confuse control chart limits with specification limits! Specification limits — such as the USL and LSL we introduce in Chapter 2 — represent the voice of the customer. Control charts, however, represent only the voice of the process, something totally different. Discovering how the process performs naturally, apart from whatever its specifications may be, is the purpose of control charts. Another way of stating this distinction is that control charts determine only whether the process is stable and predictable. They don't tell you whether the process is capable of meeting customer requirements. To assess a process's capability, refer to Chapter 13. Always resist the temptation to interpret control chart limits as specifications and avoid overlaying specification limits onto your control charts.

Detecting patterns, shifts, and drifts

Besides control chart points that lie beyond the control limits, other visual patterns can tell you that something out of the ordinary is happening to your process. These other patterns also indicate special cause variation (see the earlier section "Understanding control limits").

Detecting special cause patterns, shifts, and drifts in a control chart is similar to detecting out-of-the-ordinary behavior in a pair of dice. The probability of rolling a *7* with two dice is 6 in 36, or about 17 percent. That's because you have 6 possible ways to roll a *7* with two dice, out of a total of 36 possible outcomes. What is the probability of rolling a *7* twice in a row? The combined probability is 17 percent (0.17) multiplied by 17 percent (0.17), or 2.8 percent (0.028). The probability of rolling a *7* three times in a row is $0.17 \times 0.17 \times 0.17$, or about 0.46 percent. So if you see someone roll a *7* three times in a row, that probability is small enough that you can safely conclude something out of the ordinary must be going on (like loaded dice!). You use this same thinking to detect patterns, trends, and shifts in control charts.

Dividing the distance between the control limits and the process average into three equal zones, as shown in Figure 20-5, you can use the following rules to detect special causes of variation:

- Any one point beyond either control limit
- Two out of any three consecutive points in Zone A, and all three on the same side of the process average
- Four out of any five consecutive points in Zone B or A, and all five on the same side of the process average
- Fifteen points in a row in Zone C, on either side of the process average

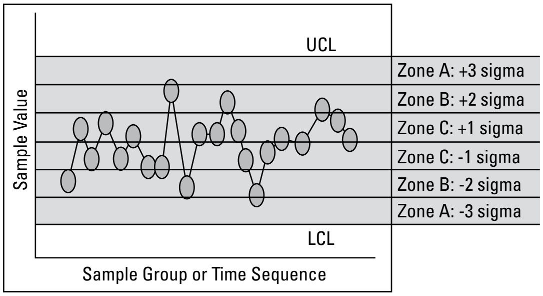


Figure 20-5: Control chart zones.

Table 20-1 shows a handful of additional rules for visually detecting whether special causes are acting on the process characteristic being charted.

Table 20-1 Tests for Special Causes for Rules One through Six

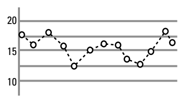
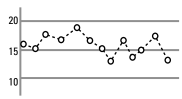
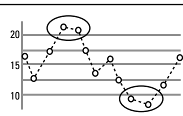
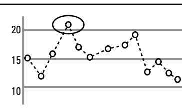
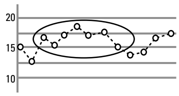
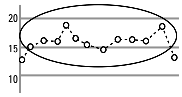
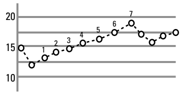
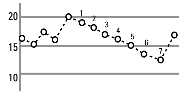
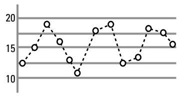
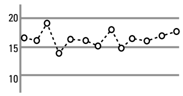
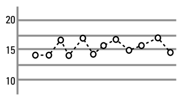
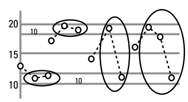
Chart	*Description*	*Example 1*	*Example 2*	*Interpretation*
Stable and predictable	Chart points don't form a particular pattern, and they do lie within the upper and lower control limits.			Indicates that the process is stable, not changing. Only common cause variation is affecting the process.
Beyond control limits	One or more chart points lie beyond the upper and lower control limits.			Alerts you that a special cause has affected the process. Investigate to determine the source of the special cause.

Chart	*Description*	*Example 1*	*Example 2*	*Interpretation*
Run	Chart points are on one side of the centerline. The number of consecutive points on one side is the "length" of the run.			Suggests that the process has undergone a permanent change. May require you to compute new control limits for the shifted process.
Trend	A continued rise or fall in a series of chart points (seven or more consecutive points in the same direction).			Indicates a special cause with a gradual, cumulative effect. Investigate possible special cause sources.
Cycle	Chart points show the same pattern changes (for example, rise or fall) over equal periods of time.			Indicates a special cause with a cyclical, repetitive effect. Investigate possible special cause sources.
Hugging	Chart points are close to the centerline or to a control limit line.			Suggests a possible error in data subgrouping or selection. Verify validity of sampling plan and/or investigate possible special cause sources.

When you detect any one of these listed patterns (well, other than Stable and predictable), you know that something out of the ordinary has happened in the process input or output you're charting.

Collecting data for control charts

You must collect data for control charts in a way that avoids a distorted or inaccurate view of the process performance — whether overly optimistic or too bleak. Using rational subgroups is a common way to assure that this distortion doesn't happen.

A *rational subgroup* is a small set of measurements in which all the items in the subgroup are produced under as similar conditions as possible, typically within a relatively short time period — short enough that special causes are unlikely to occur within the subgroup. In this way, rational subgroups enable you to accurately distinguish special cause variation from common cause variation.

TIP

Make sure that your subgroup measurements are randomly selected and don't unfairly favor any specific operating condition. For example, don't take subgroups from only the first shift's production if you're analyzing performance across multiple shifts. Or don't look at only one vendor's material if you want to know how the overall process, across all vendors, is really running. Finally, don't concentrate on a single time of the day, such as just before the lunch break, to collect your subgroup measurements.

Rational subgroups are usually small, typically consisting of three to five measurements. Make sure that rational subgroups consist of measurements that were produced as closely as possible to each other, especially if you want to detect patterns, shifts, and drifts. For example, if a machine drills 30 holes a minute and you want to create a control chart of hole size, a good rational subgroup may consist of four consecutively drilled holes.

TIP

If your process consists of multiple machines, operators, or other process activities that produce streams of the same process characteristic you want to control, use separate control charts for each of the process streams.

Setting Up Control Charts for Continuous Data

Continuous control charts refer to control charts that display performance of process input or output measurements that are *continuous data* — data where decimal subdivisions have meaning (see Chapter 9 for an explanation of data types). Using control charts to control the input *X*s to a process is referred to as *statistical process control,* or SPC.

You can also use continuous control charts to monitor output CTQs, the important process output characteristics. When you use control charts this way, you call it *statistical process monitoring,* or SPM. You find two categories of control charts for continuous data: charts for controlling the location of the process average and charts for controlling the width of the process variation. Generally, the two categories are combined in paired, side-by-side charts.

The typical pairing of continuous control charts used in Six Sigma are

- Individual and moving range $(I - \overline{MR})$ chart
- Averages and ranges $(\bar{X} - R)$ chart
- Averages and standard deviations $(\bar{X} - S)$ chart

Table 20-2 summarizes the important parameters of each type of continuous control chart.

Table 20-2 Continuous Data Control Chart Summary

Control Chart	*Subgroup Size(n)*	*Centerline*	*Control Limits*
Individuals and moving range $(I-\overline{MR})$	1	$\bar{X} = \frac{X_1+X_2+\cdots+X_k}{k}$	$UCL_x = \bar{X} + E_2\overline{MR}$
			$LCL_x = \bar{X} - E_2\overline{MR}$
		$\overline{MR}_i = \lvert X_{i+1} - X_i \rvert$	$UCL_{MR} = D_4\overline{MR}$
		$\overline{MR} = \frac{MR_1+MR_2+\cdots+MR_{k-1}}{k-1}$	$LCL_{MR} = D_3\overline{MR}$
Average and range $(\bar{X} - R)$	2–10	$\bar{\bar{X}} = \frac{\bar{X}_1+\bar{X}_2+\cdots+\bar{X}_k}{k}$	$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\bar{R}$
			$LCL_{\bar{x}} = \bar{\bar{X}} - A_2\bar{R}$
		$\bar{R} = \frac{R_1+R_2+\cdots+R_k}{k}$	$UCL_R = D_4\bar{R}$
			$LCL_R = D_3\bar{R}$
Average and standard deviation $(\bar{X} - S)$	> 10	$\bar{\bar{X}} = \frac{\bar{X}_1+\bar{X}_2+\cdots+\bar{X}_k}{k}$	$UCL_{\bar{x}} = \bar{\bar{X}} + A_3\bar{S}$
			$LCL_{\bar{x}} = \bar{\bar{X}} - A_3\bar{S}$
		$\bar{S} = \frac{S_1+S_2+\cdots+S_k}{k}$	$UCL_S = B_4\bar{S}$
			$LCL_S = B_3\bar{S}$

Where k is the number of subgroups and

Sample Size (n)	A_2	A_3	B_3	B_4	D_3	D_4	E_2
2	1.880	2.659	0	3.267	0	3.267	2.659
3	1.023	1.954	0	2.568	0	2.574	1.772
4	0.729	1.628	0	2.266	0	2.282	1.457
5	0.577	1.427	0	2.089	0	2.114	1.290
6	0.483	1.287	0.030	1.970	0	2.004	1.184
7	0.419	1.182	0.118	1.882	0.076	1.924	1.109
8	0.373	1.099	0.185	1.815	0.136	1.864	1.054
9	0.337	1.032	0.239	1.761	0.184	1.816	1.010
10	0.308	0.975	0.284	1.716	0.223	1.777	0.975

Individuals and moving range chart ($I - \overline{MR}$)

You use the individuals *(I)* and moving range $\left(\overline{MR}\right)$ control chart when you have continuous data and each subgroup consists of only a single, individual measurement. These charts are very simple to prepare and use. Figure 20-6 shows the *individuals chart,* where the individual measurement values are plotted, with the centerline being the average of the individual measurements. The *moving range chart* shows the range between two subsequent measurements. The centerline is simply the average of these between-point moving ranges.

In many situations, opportunities to collect data are limited, or gathering the data into subgroups simply doesn't make practical sense. Perhaps the most obvious of these cases is when each individual measurement is already a rational subgroup. This situation may happen when each measurement represents one batch, when the measurements are widely spaced in time, or when only one measurement is available in evaluating the process. Such situations include destructive testing, monthly inventory turns, monthly revenue figures, and chemical tests of a characteristic in a large container of material. All these situations indicate a subgroup size of one.

TECHNICAL STUFF

The formula to calculate the control limits is based on the average moving range, which is the variation from one point to the next. The control limits are estimated statistically from these moving ranges.

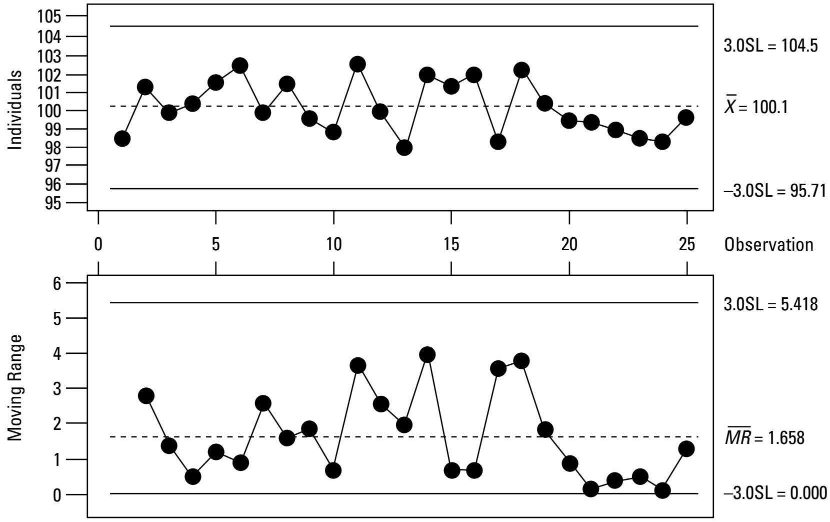


Figure 20-6: Individuals and moving range chart ($I - \overline{MR}$ chart).

The $I - \overline{MR}$ chart in Figure 20-6 shows the individual measurements in the upper chart of the pair and a moving range in the lower half, which allows you to examine the process location and variation width at the same time.

WARNING!

Because the $I - \overline{MR}$ chart is dealing with individual measurements, it's not as sensitive as the $\bar{X} - R$ or $\bar{X} - S$ chart in detecting process changes (see the two following sections).

Averages and ranges chart ($\bar{X} - R$ chart)

You use an $\bar{X} - R$ control chart when you have continuous data with subgroups of two to ten measurements each. It primarily monitors and controls the stability of the process characteristic's average value. The $\bar{X}$ chart plots the average values of each of a number of the small-sized subgroups. The averages of the process subgroups are collected in sequential, or chronological, order from the process. The $\bar{X}$ chart, together with its paired R chart shown in Figure 20-7, is a sensitive method for identifying assignable causes of product and process variation. Because it relies on rational subgroups, it provides great insight into the process characteristic's short-term variation.

As with all the paired control charts for continuous data, the $\bar{X}$ and the R charts are most effective when they're used together as a matched pair. That's because each chart individually shows only a portion of the information concerning the process characteristic. The upper chart shows how the process average changes. The lower chart shows how the variation of the process changes.

The R chart must show that the process variation width is stable and in control before you can properly interpret the $\bar{X}$ chart. That's because the control limits for the $\bar{X}$ chart are calculated from the observed variation in the ranges. When the R chart isn't in control, the control limits on the $\bar{X}$ chart will be inaccurate and may falsely indicate an out-of-control condition when none really exists.

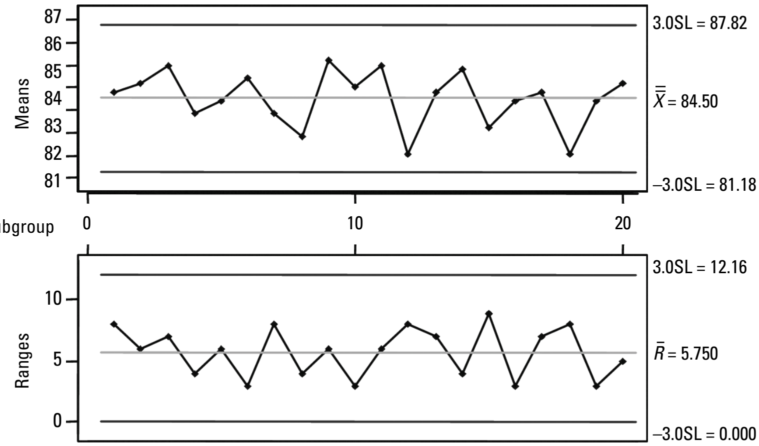


Figure 20-7: Averages and ranges chart ($\bar{X} - R$ chart).

Averages and standard deviation chart ($\bar{X} - S$)

The $\bar{X} - S$ chart is constructed similarly to the $\bar{X} - R$ chart, but rather than ranges, it plots the standard deviation of each subgroup. The calculation for the control limits on the $\bar{X} - R$ chart uses only two data points, the highest and lowest value. The calculation for the control limits on the $\bar{X} - S$ chart uses all the data. The $\bar{X} - S$ chart is, therefore, a more accurate indicator of process variation. The $\bar{X} - S$ chart is also very sensitive to small changes in the process average.

Use the $\bar{X} - S$ chart when the size of your subgroups is ten measurements or greater, and the $\bar{X} - R$ when it's less than ten. You should consider using this chart for processes with a high rate of production, when data collection is quick and inexpensive, or when you need increased sensitivity to variation.

An $\bar{X} - S$ chart is less sensitive than the $\bar{X} - R$ chart in detecting special causes of variation that result in only a single value in a subgroup being unusual.

Making Control Charts for Attribute Data

Attribute data is data that can't fit into a continuous scale but instead is chunked into distinct *buckets,* like small/medium/large, pass/fail, acceptable/not acceptable, and so on (see Chapter 9 for a detailed discussion of attribute and continuous data). Although monitoring and controlling products, services, and processes with more sensitive continuous data is preferable, sometimes continuous data simply isn't available, and all you have is less-sensitive attribute data. But don't despair, because certain control charts are designed specifically for attribute data to draw out startling information and allow you to control the behavior of your process.

With knowledge of only two attribute control charts, you can monitor and control process characteristics that are made up of attribute data. The two charts are the *p* (proportion nonconforming) and the *u* (non-conformities per unit) charts. Table 20-3 summarizes the important parameters of these charts. Like their continuous counterparts, these attribute control charts help you make control decisions. With their control limits, they can help you capture the true voice of the process.

Table 20-3 Attribute Data Control Chart Summary

Control Chart	*Subgroup Size (n)*	*Centerline*	*Control Limits*
Proportion defective (p chart)	Variable (usually > 50)	For individual subgroups: $p_i = \frac{\text{number of defective}}{n_i}$	$UCL_i = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$
		Overall: $\bar{p} = \frac{\text{total number of defective}}{n_1 + n_2 + \cdots + n_k}$	$LCL_i = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$
Number of defects per unit (u chart)	Variable	For individual subgroups: $u_i = \frac{\text{number of defects}}{n_i}$	$USL_i = \bar{u} + 3\sqrt{\frac{\bar{u}}{n_i}}$
		Overall: $\bar{u} = \frac{\text{total number of defects}}{n_1 + n_2 + \cdots + n_k}$	$LSL_i = \bar{u} - 3\sqrt{\frac{\bar{u}}{n_i}}$

Picture a bowl of soup. If you found ten flies in it, you'd deem it unacceptable. What if you found only one fly? You'd still call it unacceptable. Data from cases like this one, where something wrong — whether big or small, few or many — causes you to deem the entire item unacceptable, are called *defectives.* Any one or more things make the entire situation bad. If you're charting defectives attribute data (pass/fail, go/no-go, acceptable/unacceptable), you use a *p* chart.

Now picture a bowl of soup with three flies in it. This bowl has three *defects.* Some attribute data for control charts is defect data — the number of scratches on a car door, the number of fields missing information on an application form, and so on. If you're counting and keeping track of the number of defects on an item, you're using defect attribute data, and you use a *u* chart to perform statistical process control.

WARNING!

Although the words sound almost identical, it's critically important to know what type of attribute data you have: defectives (pass/fail) data or defect (count) data. If you get this distinction wrong, your subsequent control chart will be completely invalid.

Note: *p* charts for defectives data are based on a binomial distribution. *u* charts for defects data are based on the Poisson distribution.

The p chart for attribute data

The *p* chart plots the proportion of measured units or process outputs that are defective in each subgroup. The sequential subgroups for *p* charts can be of equal or unequal size. When your subgroups are different sizes, the upper and lower control limits aren't constant, horizontal values — they will look uneven, as exhibited in Figure 20-8. But the same rules for interpreting the control chart remain — the control limits just move from subgroup to subgroup. You find the proportion of defectives for each subgroup by dividing the number of defectives observed in the subgroup by the total number of defectives measured in the subgroup.

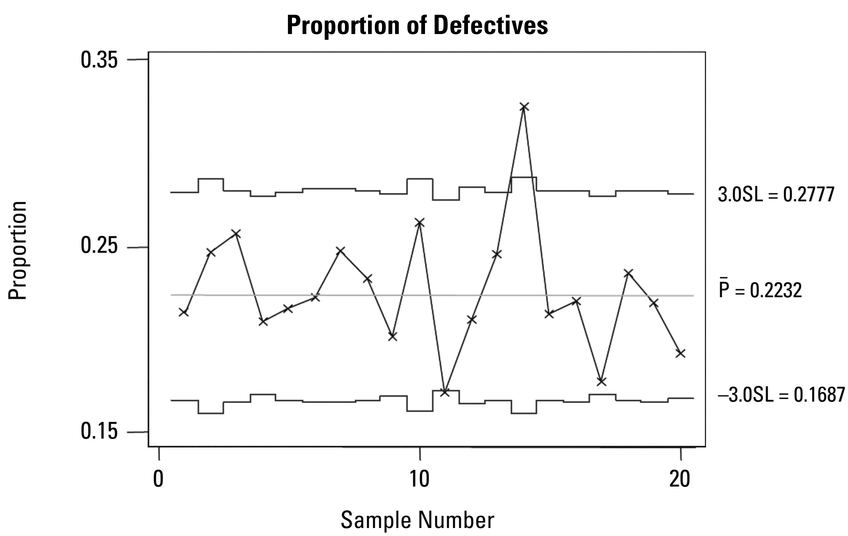


Figure 20-8: *p* chart for proportion defective.

A common application of a *p* chart is when you have percentage data, and the subgroup size for each percentage calculation may be different from one subgroup to the next — for example, the number of patients that arrive late each day for their dental appointments or the number of forms processed each day that have to be reworked due to mistakes or oversights (defects). In both of these examples, the total size of the subgroups measured may vary from day to day.

p charts are generally used where the probability of a defective is low — usually less than 10 percent. So to be effective, the subgroup size needs to be large enough to register one or more defectives. You also need to consider the length of time that a subgroup represents: Long periods of time can make pinpointing a specific cause difficult.

TIP

Remember, just as with continuous control charts, you need to be alert for other indicators of special cause variation in addition to just exceeding the control limits. The presence of unusual patterns, such as runs or trends, even if all the points are within the control limits, can be evidence of instability or an out-of-the-ordinary change in performance.

The u chart for attribute data

Like with the *p* chart, the *u* chart doesn't require a constant subgroup size. The control limits on the *u* chart vary with the subgroup size and therefore may not be constant.

Counting the number of distinct defects on a form is a common use of the *u* chart. For example, errors and missing information on insurance claim forms (defects) are a problem for hospitals. As a result, every claim form has to be checked and corrected before being sent to the insurance company.

One particular hospital measured its defects per unit performance by calculating the found number of defects per unit for each day's processed forms. Figure 20-9 demonstrates the hospital's defects per unit performance on a *u* chart.

Each point on the chart in Figure 20-9 represents the average defects per claim form for that subgroup. Points higher on the chart represent a greater number of defects per unit. The centerline, calculated at 1.870, indicates an overall average process performance of 1.87 defects per form.

Subgroup	Subgroup size	Defects
1	53	101
2	64	80
3	59	115
4	52	127
5	65	99
6	60	57
7	56	99
8	49	109
9	53	100
10	59	121
11	66	113
12	65	156
13	58	142
14	55	114
15	57	147
16	55	113
17	61	109
18	60	115
19	68	98
20	65	92

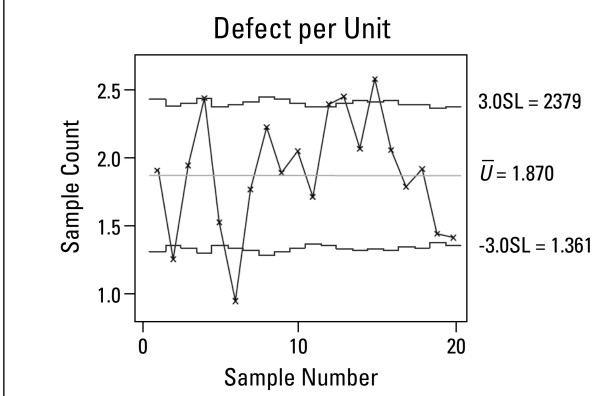


Figure 20-9: *u* chart for insurance claim forms.

Part V

Looking at the Six Sigma Technology Tool Landscape

The 5th Wave — By Rich Tennant

"This chart doesn't give us any information. I just like it because it looks like the Seattle skyline."

In this part . . .

Simply put, you can't do Six Sigma without tools. This part provides an overview of the technical and managerial tools you can use to apply Six Sigma at your company.

Chapter 21

Eyeing Process Characterization and Optimization Technologies

In This Chapter

- Understanding the platforms and protocols of technology tools
- Recognizing the capabilities and limitations of manual tools and techniques
- Examining various levels of computerized Six Sigma technology

The fundamental tenets and tools of Six Sigma are naturally independent of how you apply them. They are conceived in the abstract world of mathematics and logic. Consider a histogram, a cause-and-effect matrix, or a run chart — even now, as you read this, you can see these in your mind's eye. Picture a curve, for example, representing the distribution of how long it takes travelers to drive from Salt Lake City to Phoenix — a normal distribution, of course. Is the curve you picture drawn by hand? Is it on the back of a napkin or a nice piece of graph paper, or do you picture seeing it on a computer screen or high-definition TV monitor? Chances are the answer is none of the above. You just "see" it. That's because the concept and values of that distribution exist independent of how they're captured, analyzed, and viewed.

Imagine that you're in Salt Lake City and you're thinking of driving to Phoenix, so you call a few friends who've recently made the trip and ask them how long it took. You might jot down their times on a piece of scrap paper, quickly look at the range, and estimate the mean in your head. You're done; that's all it took. You wouldn't have entered them into a spreadsheet and calculated the precise mean and standard deviation. You would have naturally corrected for the fact that Verna and Jerome like to shop at all the Navajo art shops, while James has a new Porsche. But that's about it.

Now imagine you've been asked to provide estimates to travel agencies, trucking firms, and a nostalgic Route-66 car club. The scrap-paper approach doesn't seem so appropriate now: Not only do you need to collect more data; you need to analyze it for road types and weather and traffic conditions. Meanwhile, the trucking firms follow different processes and routes and have very different goals and targets than the car clubs. At this point, you're more likely envisioning Google Maps, Yelp for restaurants, Trip Advisor for motels, perhaps some computerized selection criteria, and a variety of tables and curves showing means and ranges — all available through the Internet.

In both cases, you've conceptually used the same methods, but the required depth of precision and range of applications is vastly different, so the tools are as well. The capabilities you bring to bear on the definition, measurement, analysis, and planning for variation and control reach from paper and pencil to space-age computing power.

In this chapter, you read about the different technologies you can use to characterize and optimize processes. You see how to analyze them in Chapter 22 and manage them in Chapter 23.

Understanding the Platforms and Protocols

From the no-tech world of pencil-and-paper process maps to the high-tech universe of real-time run-charts served onto tablet displays from manufacturing plants in faraway continents, you now have a wide range of technology platforms and protocols at your disposal.

Paper and pencil

Sometimes, nothing is quite as fast and easy as just grabbing a pencil or pen and a piece of paper and drawing a quick picture or entering info on a printed form. It's a great way to get images and ideas out of your head or to capture information from an event or occurrence. It's fast, cheap, and requires little training and minimal equipment.

Nearly everyone has drawn boxes and lines on a piece of paper or whiteboard to represent organization charts, information flow, or process steps. And anyone that's visited a doctor or dentist has filled out paper forms. Admittedly, the drawings are usually pretty crude and the handwriting barely legible, but it's fast — fast enough for you to keep moving and for ideas and information to flow. That's the best part about it — and it's often the drawback of computer-aided tools, which can be slow and cumbersome enough that you spend more time in the mechanics of creation or capture instead of the creation or capture process. Plus, there's the cost of the equipment.

In this high-technology, fast-moving world, don't fully discount the value and applicability of what you may call the low-tech tools. The simplicity and ease of use have a time and place. But don't kid yourself, either; today's world has little tolerance for isolated, random, nonstandardized information that can't be easily moved, shared, and leveraged. Manual tools have applicability, but that applicability is limited.

Looking at desktops and laptops

We're guessing you probably have a desktop or laptop computer. These devices all share a common architecture: Data and programs are stored locally on disk drives; the computer's processor runs applications; keyboards enable you to enter data and control programs; and graphical displays provide visuals. Most of the application programs utilized in Six Sigma throughout the DMAIC cycle — including those for process design, characterization, analysis, and control, as well as project management software and all manner of other utilities — were designed for this architecture.

Most Six Sigma desktop/laptop software programs run only on the PC-Windows platform and aren't compatible with the Apple OSX operating system. Check with the software vendor before you buy to be sure the program you want runs on your computer.

Everyone became comfortable having their data and programs on their computers, but the desktop/notebook approach naturally limits the sharing of information and collaboration. You can e-mail files and access data from servers, but that's a far cry from collaboration. Although the evolution is underway as we write this — programs and data are moving to the Cloud — in the meantime, the overwhelming majority of computer tools used in the definition, measurement, analysis, improvement, and control of processes over the vast history of Six Sigma projects have been performed on desktop and laptop computers.

Upgrading to smartphones and tablets

With the advent of cloud computing and high-bandwidth access to the Internet, lugging the data and processing power of traditional computers around with you is no longer necessary. All you need is access and the entry and display capability, and you can utilize integrated systems and information in the Cloud to accomplish your tasks. So increasingly, smartphones and tablets are effective tools for the Six Sigma practitioner.

Expanding to enterprise-class options

The world's a big place; it's way too big to fit on your PC. Yes, you can perform local projects and crunch the data on your laptop. But after you step beyond your immediate project, workgroup, or operating environment, you need more. To address projects of broader scope and scale, larger challenges, and extended value streams, you need *enterprise-class* technology — technology meant for collaboration among geographically distributed teams; the orchestration of processes that span organizations; information living in corporate databases; and the flow of goods and information across extended supply chains.

Moreover, enterprise-class systems are more independent of the user's platform — that is, they run from centralized environments and let you utilize whatever device you have, whether it's a PC, Mac, or something else. Increasingly, centralized systems such as ERP (Enterprise Resource Planning), CRM (Customer Relationship Management), or BPM (Business Process Management) can be hosted outside of corporate datacenters, in the Cloud, or delivered through a model known as *software as a service,* or SaaS.

Knowing When Going Manual Makes Sense (And Doesn't)

Most people use computers to do their work, and Six Sigma is naturally computational and collaborative, so manual tools have limited use. But with all the computer programs available — and the need for accuracy, sharing, and control — some situations support using a pen or marker, for a couple of reasons:

- **It's fast and free-form.** Whether you're describing what you understand a current process looks like or designing a new process, it's a quick way to put your ideas out there — especially if you don't have more sophisticated tools handy.
- **It's inexpensive.** You don't need a computer, software, or training — or even electricity — to draw a process map with a pencil and paper. With a ruler, template, and graph paper, you can draw pictures of processes.

You can make fast progress utilizing selected tools in manual mode. Mostly, these apply in the early-stage or more qualitative situations.

- **Affinity diagrams:** *Affinity diagrams* are the output of group collaboration and brainstorming sessions (see Chapter 8). These sessions are often best conducted in off-site casual settings, and the tool of choice is the sticky note: It's fast and portable. You need to copy and organize the info into a spreadsheet or table later, but these manual diagrams are a natural way to start.
- **Fishbone (Ishikawa) diagrams and CT (critical-to) trees:** Save time by brainstorming causal factors by hand *before* you start making pretty charts in a drawing tool. Head to Chapter 8 for details on fishbone diagrams.

- **Data entry:** Some circumstances, such as spontaneous conditions and environments, favor manual data capture. For example, quick updates on a shop floor or in a meeting may best be initially captured on a whiteboard. (But we still can't figure out why medical offices make people fill out paper forms.)
- **Instructions**: Many environments are well-suited to handwritten instructions for controlling behaviors and keeping processes in control. Shop-floor instruction boards are often handwritten; pit-crew instructions to race-car drivers are on handwritten boards.

Because the discipline in hand-drawn processes lies solely with the person drawing them, they're especially susceptible to being wrong. Someone's description of a current process is likely to be incomplete or inaccurate. Icons drawn to represent process tasks, decision points, data, storage, and so on may not follow conventions. (We outline the conventions for process mapping in Chapter 7.) People often leave out exception branches or improperly represent systems or information. So watch out: If you're beyond the quick-idea phase and you find yourself drawing processes or value stream maps (see Chapter 7) manually, the only acceptable reason is that you're constrained by the expense of computerized tools — relatively modest as it may be. If you're in an organization with the staff and systems to support computer-supported standardized process mapping, step up to it.

Along those lines, you should avoid doing several classes of activity by hand:

- **Tables and matrices:** A QFD (quality function deployment) house-of-quality table, a C&E (cause-and-effect) matrix, or any other matrixed data — these items all belong in a computerized spreadsheet or relational data table. You can find more on C&E matrices in Chapter 11.
- **Input forms:** Data input on paper just begs for error; you can't *Poka-Yoke* (mistake-proof) any of the entries, and someone else has to translate and enter the data later anyway. Fix it at the source. (Chapter 19 gives you the lowdown on Poka-Yoke.)
- **Process diagrams:** As we note in Chapter 7, the language and controls of process mapping are complex and specific. A protocol called the Business Process Modeling Notation (see `www.bpmn.org`) governs the many aspects of process mapping. And this chapter covers so many of the process drawing and process mapping computer tools available that you really have no excuse to be drawing processes by hand anyway.

Every Six Sigma tool is supported by multiple software products (see the following sections). You're not forced to do any of it by hand.

Using Basic Desktop Tools

Whether you buy a computer as a consumer or have one issued to you at work, the machine typically comes with a set of general-purpose tools preinstalled for you. Because these tools are readily available on most practitioners' machines, folks automatically apply them to Six Sigma initiatives — for better or for worse. In this section, we show you how the most common desktop software applies to Six Sigma.

Getting a handle on the Office suite

The suite of general-purpose programs that come standard on most computers includes word-processing, spreadsheets, presentations, and drawing. First marketed by Microsoft under the Office brand, people often substitute Microsoft's product names for the general-purpose tools. But different providers offer different tools, as we outline in Table 21-1.

Table 21-1 General-Purpose Desktop Computing Tools

Provider	*Suite*	*Documents*	*Spreadsheets*	*Presentations*
Microsoft	Office	Word	Excel	PowerPoint
Google	Docs	Documents	Spreadsheets	Presentations
Apple	iWork	Pages	Numbers	Keynote
Open Source	OpenOffice	Writer	Calc	Impress

Although the providers are competitors, most of these products fully read and interact with the complimentary product from the other providers.

Reading documents

You regularly use computer-based document programs like Word in Six Sigma for defining projects and writing business cases, reports, and problem and objective statements (see Chapters 5 and 6). Most organizations create reference templates or have libraries of past examples for you to use to help ensure consistency and comprehensiveness.

Creating spreadsheets

Six Sigma practitioners extensively use spreadsheet tools like Excel, mostly for performing analysis; we cover details of this usage in Chapter 22. But spreadsheets are great for other tasks as well:

- Capturing and organizing process metrics for characterization, optimization, and even presentation
- Easily creating simple forms in a spreadsheet
- Building matrices (such as C&E) and tables (such as QFD) and displaying information (plots and graphs)

Spreadsheet data files can be easily stored and shared and, like with documents, you can create templates and example references. Note, however, that spreadsheets have limitations.

REMEMBER

Spreadsheet data are stored in what's called *flat files* — a simple file structure that's just rows and columns. But real-world data usually are related in multiple ways; the standard for defining relational data is the *Structured Query Language* (SQL), the construct governing database systems such as Oracle and Sybase. Accessing data from SQL databases into flat-file spreadsheets involves precision extract procedures and mapping algorithms that are typically outside the realm of most casual spreadsheet users. You'll need technical assistance.

Prepping presentation packages

Six Sigma managers make full use of presentation packages like PowerPoint as a communications tool — more on this topic in Chapter 23. But many people inappropriately utilize presentation software as a process mapping tool. Yes, you can draw boxes, circles, and arrows in PowerPoint, but that's just drawing, and it suffers from most of the same drawbacks as doing it by hand. (You can find those pitfalls in the earlier section "Knowing When Going Manual Makes Sense [And Doesn't].") Instead, use presentation tools for the more appropriate purpose of communicating with the people you're working with.

Process mapping with Visio

Microsoft Visio has been included as a standard desktop computer program on PC desktops and laptops for many years. It also runs in the Mac environment. As such, most Six Sigma practitioners use it to draw process maps and flow diagrams, and most instructors teach process mapping with it.

Microsoft has built an array of flowcharting icons and tools into Visio that makes drawing process maps easy, as you can see in Figure 21-1. You can also set process steps into swim lanes (which we cover in Chapter 7) and draw the flows horizontally or vertically.

Numerous add-ons and third-party extensions are also available that provide even more functionality and capabilities. Many of these extend the drawing and mapping features, while others let you import and export data with external data sources. The most important options for Six Sigma practitioners are the extensions that elevate Visio from a simple drawing tool to a more enterprise-compatible process mapping tool through BPMN: the ability to export the process description to process execution engines. Without this enhancement, Visio is just a drawing tool.

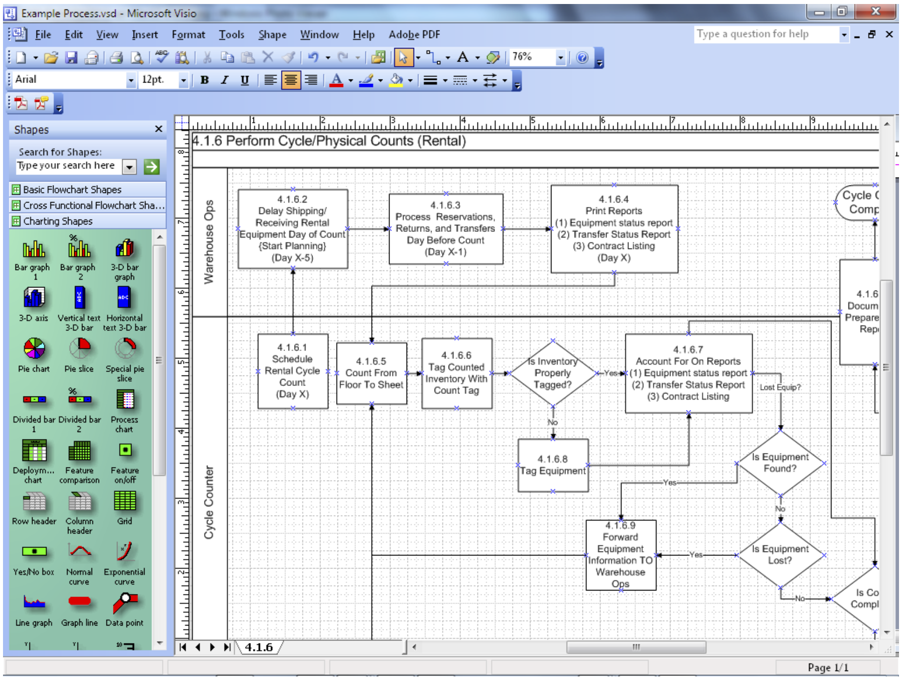


Figure 21-1: Flowcharting with Microsoft Visio.

Perusing Process Intelligence Tools

Most of the time, your Six Sigma project is charged with improving an existing process. You're not beginning with a blank page; your work is based on the current process. So before you charge off and just start designing the world's greatest new process, you must characterize and understand the existing process by using process intelligence tools.

Process intelligence tools help you capture the state, condition, and definition of the current process. They're often used along with enterprise-class tools (more on this topic later in the chapter) because you must capture information from existing systems and points of measure, and doing so requires integration capabilities and access to corporate systems. But the individual tools of the process intelligence toolkit are specific:

- **Process capture:** Process capture begins manually: affinity diagrams, interpretations of reference designs, and structured interviews with key participants. From there, you build a model of the as-is process by using modeling tools such as Visio (see the preceding section). To validate and refine your model, use tools such as ARIS to attach to your existing network environment and generate a process flow picture based on the transaction activity in your systems.
- **Process characterization:** Gain insight into your existing process by capturing the key metrics associated with the as-is process model. Process characterization tools include the system of instrumentation as well as the storage, processing, and display of the results. (Figure 21-2 shows a sample process intelligence display board.) These results include data aggregated over time that indicate trends and can generate histograms (see Chapter 10) down to the performance and condition of single instances of the process — such as the condition of an existing order.

Process intelligence tools are continuous improvement tools. You use them the first time you characterize a process so that your analysis and design leads to the improved process state you're seeking. You then use them to maintain the improved process — keep it in control (see Chapter 20). And you use them to indicate where to pursue the next round of improvement.

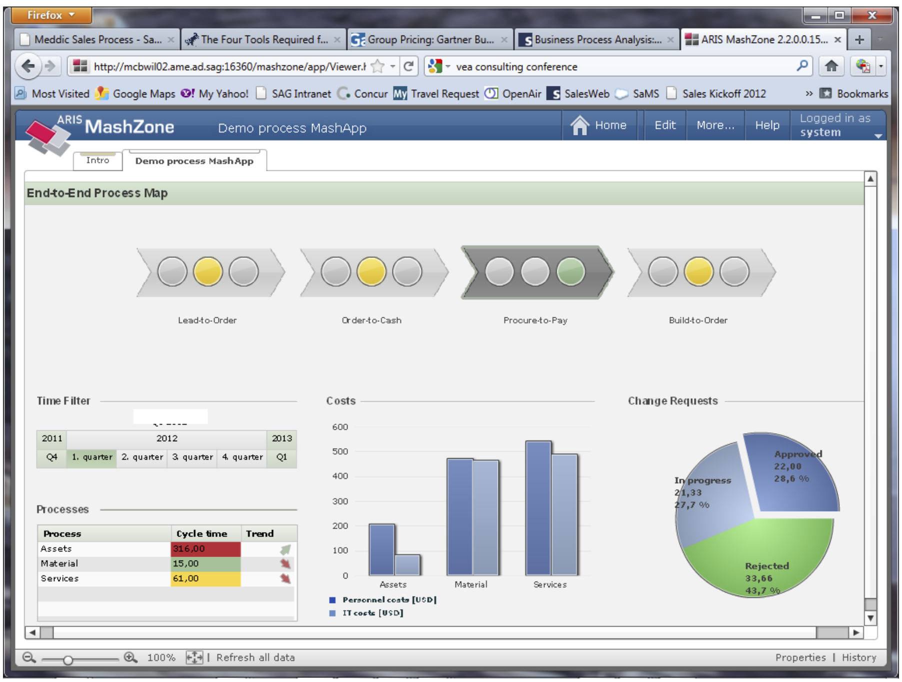


Figure 21-2: A process intelligence display board.

Diving into Desktop Process Mapping Technology

You have no excuse for not developing your processes professionally because a wide assortment of software tools for mapping, designing, and simulating processes is available to Six Sigma practitioners. These resources are known as *process mapping, business process management* (BPM), or sometimes *flowcharting software.* Dozens of viable offerings are available in the marketplace, but they're not at all the same, so you need to choose the software package that's right for you. Look for the combination of features and functionality that best fit your needs.

REMEMBER

Most desktop process mapping programs began as — and still offer — tools that ran only on PC-Windows environments. This setup may be sufficient for your immediate needs, but many of the vendors are evolving their offerings and now run on multiple platforms and even as cloud/SaaS offerings accessible from any platform. Look at the platform options as you consider which package is right for you.

Most process mapping software tools provide similar features: menus, charting icons, swim lanes, and so on. And over time, most of the vendors have imitated and included whichever new drawing and mapping features were offered by the other providers. With the advent of the BPMN standard in 2004, the modeling features and functions are now even more capable — and similar.

The most important feature of any process modeling package is that it's more than just an easy-to-use drawing tool. In a process modeling package, each object represents something real: A task box is a real task with attributes; it's not just a rectangle. Similarly, a flow arrow is a flow; a decision branch has logic; swim lanes represent organizations. Each of these objects (per the BPMN standard) has specific definitions that are real, meaningful, and can be interpreted by analysis programs and process execution engines.

Very few of the modeling tools just model. Because you need to do more, they do more. We provide additional detail about this extra functionality in the following section because all the enterprise-class providers offer the full range of capabilities. But even tools at the desktop level contain common features beyond modeling:

- Simulation, both visual and statistical, with generated or real data
- Network management, configuration management, and collaboration
- Value stream mapping and other Lean features
- Integration with analytics engines such as Minitab and JMP
- Report generation (need to feed those PowerPoint presentations!)

TIP: Look for BPMN-compatibility from your process modeling tool. This way, the process models adhere to industry standards, ensuring a degree of accuracy and completeness. Further, you can export them, and other applications and utilities can simulate, execute, and measure process performance.

Exploring Enterprise-Class Technology

At the top of the heap — in capability, features, and scale — are the tools and technologies designed for “the enterprise.” No, we’re not talking about the spaceship from *Star Trek* (that’s even more advanced!); this *enterprise* is your full-scale operation. If you’re a manufacturer, the enterprise includes your company, your supply chain, and your customer network. If you’re a government entity, it’s your entire agency, its supply chain, and your constituents. Enterprise-class technology scales to handle the operations of up to thousands of employees, partners, suppliers, and customers; it conducts millions or even billions of transactions each day and utilizes large databases and hundreds or even thousands of applications and transaction systems, spread potentially across the globe.

All the best manual efforts and the applied capabilities of desktop toolsets can’t address and resolve enterprise-class challenges. If your process spans departments, people, organizations, systems, and databases, you must apply enterprise-class technology to characterize and optimize that process. At this level, the technology tools are in BPM systems (see the preceding section).

Process characterization and optimization tools at the enterprise-level are designed to let you operate within and across your information technology universe while exercising the individual tools of your Six Sigma projects. An enterprise-level modeling tool is still a modeling tool, but it’s part of a suite that includes not only process design but also systems design, process orchestration, process execution, and process intelligence — all integrated into the extended information technology enterprise.

Chapter 22

Tools for Performing Six Sigma Analysis

In This Chapter

- Identifying the different types of technology you can apply to Six Sigma analysis
- Understanding how and when to apply analytics technology
- Listing some of the more popular statistics packages

Computers were made to help us crunch numbers — and they're extremely good at it. Analyzing a process in detail is an exercise in number-crunching, so from the beginning, Six Sigma analysis has been a computer-intensive discipline. As a rule, practitioners resolve all the equations and expressions described in Part III with the help of computers and computers' younger brother, the calculator. You can crank out some simple expressions and graphs by hand, but even the most elementary graphical analyses quickly exceed manual abilities as the data volumes and expressions multiply.

With the right analytical software, you can deftly create accurate and detailed plots; calculate cause and effect; analyze failure modes; determine degrees of normality; calculate throughput yields, defect rates, Z-scores, and process capabilities; conduct multi-factorial experiments; perform linear regressions; and implement blindingly accurate statistical process control. In short, you can easily put all the tools of Six Sigma right to work.

Tackling Technology for Analytics

If someone asked you to find the mean of three numbers, you'd likely do the math in your head. If the list went to 10 numbers and some of them had decimal places, you'd reach for a pencil and paper. At 30 numbers, you're ready to break out the calculator, even though the calculation process — find the sum and divide by the number of entries — is the same. But by the time you had 1,000 numbers and needed to find the median, mode, and standard deviation as well, plus make a histogram plot, you'd be reaching for a computer (and probably a specialized software program, too).

This example illustrates the wide range of technology applied to analytics. Your choice of technology — from no-tech to high-tech — is a matter of selecting the proper equipment for the size and scope of the problem at hand. The same analytical and control tools and algorithms we describe in Parts III and IV apply to situations large and small.

Six Sigma isn't a purely computational discipline. You're solving complex problems in applied business settings, which call for ideas, reasoning, and intuition. Answers to these types of problems aren't purely quantitative; computers aren't a substitute for thinking.

Making room for manual computations

Considering the low cost and high availability of calculators and computers, you would be wasting time and risking error unnecessarily by performing anything other than the most rudimentary calculations by hand. But perspective, objectivity, and sanity checks are all manual. Find those points of critical balance alongside the technology-enabled calculations. The professional Six Sigma practitioner uses technology as an aid, not a crutch. Perform qualitative computations manually — and regularly.

Holding out for hand-held calculators

Don't dismiss the lowly calculator: The portable hand-held electronic calculator has come a long way since it was first introduced in the 1970s. Today, you can just about carry a statistics valet in your pocket. The Texas Instruments TI-30X performs more than 50 statistical functions and costs less than $10. The TI-89 programmable graphing calculator performs advanced algebra, calculus, matrix, and statistical functions, plus animations, 3-D graphics, and contour plots. There's even a *For Dummies* book about it (*TI-89 Graphing Calculator For Dummies* by C.C. Edwards [Wiley]). You can buy the calculator *and* the book for under $150. Casio and HP have similar offerings.

Opting for online calculators

With Internet access, an extensive suite of free online calculators is available to help you perform nearly any function. Sites such as `www.math.com`, `www.calculator.com`, `www.metacalc.com`, and `www.ecalc.com` essentially emulate the pocket calculator interface, and they also provide help in the form of advice and examples.

As a Six Sigma practitioner, you can go to `www.stattrek.com` to calculate distributions or to `www.sqconline.com` to calculate acceptance handling, process capability, and controls. Even a few universities are in the game;

check out Vassar's statistical computation website at `faculty.vassar.edu/lowry/VassarStats.html` or the online stats calculator at Saint John's University at `www.physics.csbsju.edu/stats/Index.html`.

In addition, members of the Six Sigma industry have contributed online tools to help you calculate DPMO, sigma score, sample size (see Chapter 13), and confidence intervals (refer to Chapter 16). (Many of these online "calculators" are actually sophisticated web-based application programs, but even the more advanced hand-held calculators are programmable and therefore not quite a normal "calculator," either).

Looking at the local computer

Six Sigma came to rise in the mid-1990s, just about the same time as the personal computer went fully mainstream. This coincidence resulted in a plethora of analytical programs and utilities for Six Sigma that run on the PC. And as the cottage industry in Six Sigma instruction boomed, training and education programs utilized PC-based analysis tools as the platform of choice, further ingratiating the PC as the analytical computation device for the Six Sigma industry.

However, this model is changing as technology evolves. Programs that first ran only on the PC now run in networked environments, as the online calculators we describe in the preceding section, or as full software-as-a-service (SaaS) cloud applications. The end unit device — that thing you touch or hold — no longer needs to carry the data or even the processing capability around with it. A smartphone or tablet can run a lightweight application or even just a web browser and capture and display the information for you while the rest is crunched and managed elsewhere.

Using Standard Spreadsheets

Microsoft Excel and its counterparts enable anyone with a desktop, laptop, or notebook computer to perform a wide variety of statistical calculations. (Flip to Chapter 21 for a look at the various spreadsheet programs available.) As a result, the Six Sigma professional performs considerable analyses with these standard spreadsheet programs. Most Green Belt projects can get by with a level of analysis performed by spreadsheets, but Black Belt projects ultimately require more specialized capabilities. Here are a few spreadsheet highlights:

- Spreadsheets can hold and manipulate relatively large two-dimensional data files — up to 2^{16} (65,536) rows by 2^{8} (256) columns.
- Extensive analytical functions are included: ANOVA, correlation, covariance, descriptive statistics, regression, *t*-tests, and more (refer to Part III for more on these analytical functions).

- Spreadsheet programs include charting and plotting capabilities, such as histograms, scatter plots, and bar charts (which we cover in Chapter 10); spider charts; polar plots; and even rudimentary 3-D surface plots.
- Other users and programs can seamlessly exchange and read the data files created by spreadsheet programs.

As useful as spreadsheet programs are, they're still general-purpose tools, so their utility has its limits. Because you can program expressions and generate *macros* (mini programs), you can technically perform just about any function on a data set in a spreadsheet — if you work at it enough. But doing everything with a spreadsheet isn't worth it, because many better options are available to you, either as add-on extensions or as dedicated programs (see the following section for more on specialized statistical analysis tools).

The first major PC-based spreadsheet program, *Lotus 1-2-3*, was a breakthrough, and its huge popularity contributed significantly to the adoption of the personal computer in corporate environments. Competitors arose quickly, and as the power and sophistication of the PC evolved rapidly, statisticians and analysts no longer needed to use mainframes or corporate minicomputers to perform their work. By the mid-1990s, Excel was shipping as part of the Office Suite with nearly every PC and Mac.

Taking on Bigger Projects with Specialized Statistical Analysis Tools

The number one tool in the Six Sigma practitioner's belt is the statistical analysis package. It's the single most-used tool, and it's critical to advancing the Six Sigma project from the M (measurement and characterization) phase through A and I (analysis and improvement) and getting you into the C (control) phase. Chapter 5 explains that during the Six Sigma project lifecycle, you transform a practical problem into a statistical problem, solve that problem, and then transform the statistical solution back to a practical one. The stats package is the enabler that takes you through that transformation. No self-described Six Sigma professional would be without one. The following sections break down various types of stats packages.

Stats packages are complex and sophisticated technology tools that work wonders with numbers. They're so capable and have so many features and functions that you risk losing yourself in them. Remember the goal of Six Sigma is process improvement. Avoid analysis-paralysis and know when to say when with your stats package.

Sampling spreadsheet add-ons

Over the years, practitioners created macros and add-ons specific to performing Six Sigma analysis for spreadsheet programs like Excel. They were — and in some cases still are — posted on dropboxes and e-mailed among members of the community. These offerings became so broadly used and useful that several firms emerged to bundle them up into add-on programs. You simply install one of these programs, and it supercharges your spreadsheet into a stats package.

Programs such as SigmaXL, QETools, SPCforExcel, and StatTools integrate seamlessly with your spreadsheet program. In most cases, the integration enables your spreadsheet with new menu functions and toolbars. The programs also offer developer kits that let you build even more custom or specialized procedures.

These packages are designed to work only with specific programs, such as Excel. Check with the vendor to ensure compatibility with your spreadsheet program of choice.

Perusing dedicated statistics packages

You can use hundreds of established statistics packages as a Six Sigma practitioner. Most have their roots in university science or engineering programs, and many are open-source products that are the result of university projects. The commercial packages tend to be more general purpose, while the open-source packages are often slanted to some specific area of statistical analysis or field of application. As a rule, open-source software is typically written in a language that can be compiled and run on any platform. Conversely, many of the proprietary packages were designed for a single platform, although over time, most vendors support the more popular operating systems.

Of the many stats packages available, several are Six Sigma-specific, organized and aligned with features specific to performing Six Sigma analyses. These packages often combine the analytics capabilities with features that support other phases of the DMAIC cycle, as well as project and process management tools (more on these in Chapter 23). The following sections introduce the major players.

The point of all your Six Sigma analysis is to determine how best to improve a process so you can implement those improvements and then keep the improved process in control. For this reason, business process management (BPM) software helps connect the outcomes of analyses and visualization to systems of execution and control.

Minitab

Minitab is the most popular stats package for Six Sigma. In its 16th release as of this printing, Minitab is the leading provider of software for Six Sigma education as well as Six Sigma improvement projects; you find Minitab at the heart of analytics activity within most corporate Six Sigma programs. Figure 22-1 shows a sample Minitab statistics display.

Minitab is a complete, full-featured statistical software package, including basic statistics, graphics, regression, ANOVA, DOE, SPC, MSA, multivariate analysis, nonparametrics, simulation, and more. It comes with online training, tutorials, and help and includes hundreds of sample data sets, report-generation, and a function to export to Word and PowerPoint. It's available in seven languages; more than 4,000 colleges and universities use it to teach statistics. You can read more about Minitab at `www.minitab.com`. ***Note:*** Minitab is strictly a Windows application.

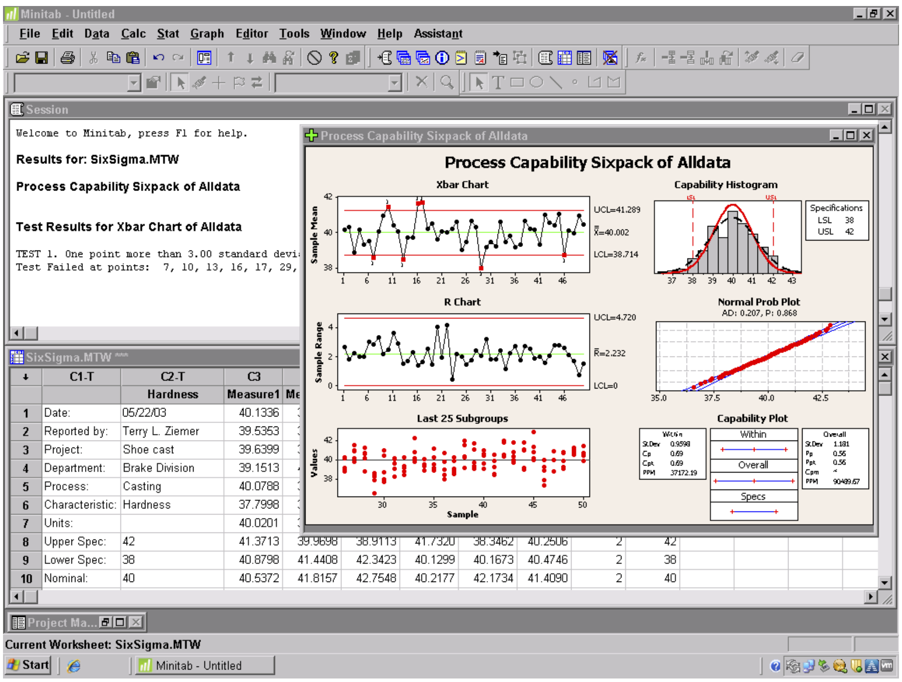


Figure 22-1: Minitab Statistics summary page.

JMP

JMP (pronounced *jump*) from the prestigious SAS Institute is also used extensively in Six Sigma. JMP is much more than statistical analysis, and it has a particular emphasis on visualization. Beyond reports and static graphs, JMP enables a dynamic interaction with data — the ability to see patterns and spot trends in broad-based, complex data sets. JMP is enterprise-class software. You can see an example JMP statistical display page in Figure 22-2. JMP runs on Windows, Apple/OSX, and Linux environments and has both 32-bit and 64-bit editions.

Now in its 10th release, JMP includes a family of products, including JMP Pro, with more advanced analytics, data mining, and predictive models. In addition, JMP has specialized products for clinical testing and genomics. Check out `www.jmp.com` for more info about JMP.

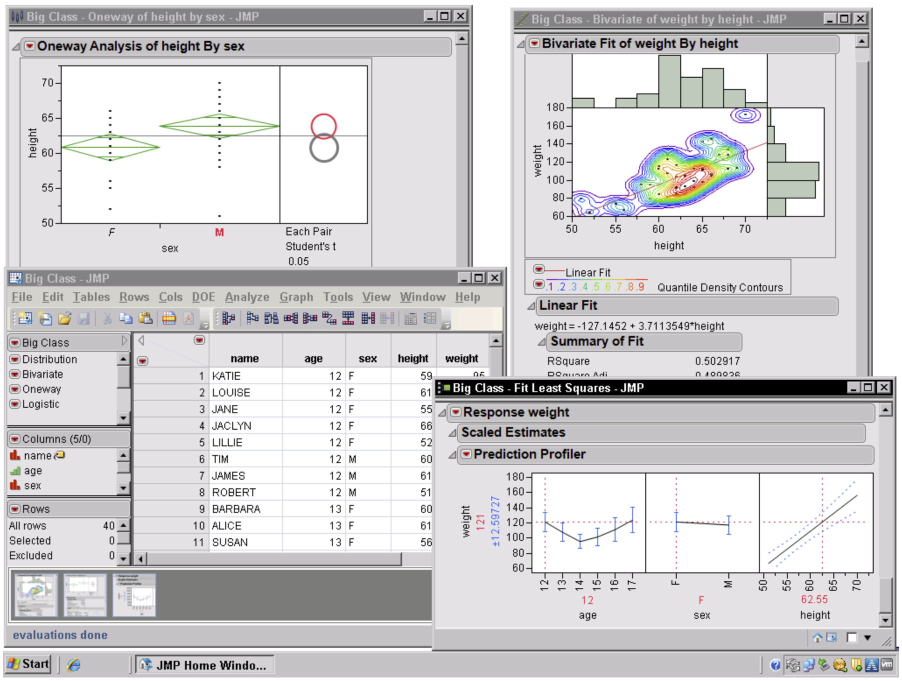


Figure 22-2: A sample JMP statistics display page.

Other stats packages

Dozens more statistical analysis packages are on the market, both for general-purpose usage and for providing special functions for specific types of analysis. Some of the other analysis packages Six Sigma practitioners use are Statistica, Kronos, Statgraphics, Hertzler, and SigmaFlow.

Chapter 23

Managing Six Sigma

In This Chapter

- Understanding Six Sigma project management
- Discovering the different types of Six Sigma Management tools

The only thing more important than practicing Six Sigma is managing Six Sigma. Understanding all the technical practices and analytical tools means nothing if you can't manage resources, schedules, and budgets through the DMAIC process and be accountable for improved processes and the bottom-line results.

Managing Six Sigma projects and programs requires you to understand the methods and tools of DMAIC while applying the methods and tools of management — program leadership, project definition and tracking, business reporting, change management, and information management.

Managing Your Projects Skillfully

A Six Sigma initiative is a continuous series of projects — projects of various sizes and shapes cascading together predictably to create an unending stream of breakthrough improvements in business performance. These improvements occur one project at a time, and each project is an encapsulated world of Six Sigma activity unto itself.

The Six Sigma manager's toolkit is therefore a set of tools for managing projects and helping people perform. These tools are inspired by leadership, enabled by infrastructure, tailored to the Six Sigma methodology, and implemented with the help of technology. Some of these tools are relatively straightforward, such as tools to help you manage project deliverables and tools to help you remember how to follow DMAIC or DFSS (design for Six Sigma, which we discuss in Chapter 4). Others are more involved, such as tools for tracking and communicating critical business indicators and for helping you manage cost and schedule.

Involving all the right people

Everyone is accountable for utilizing resources effectively, removing obstacles, solidifying decisions, and ultimately delivering results. This accountability begins with executive managers, who need the summary information that helps them understand what's on track and where they need to provide help. Likewise, financial executives need to know how projects contribute to the profit and loss (P&L) of business units. Projects can and should have huge financial benefits, so the finance managers and P&L owners want to maintain close touch with their activities and results.

Six Sigma Champions are in the catbird seat and must have a direct line of sight on people and projects; they must constantly know the pulse of all Six Sigma activity. Because Black Belts lead the most-difficult, most-complex projects with the largest impact and return to the business, they must closely track and manage projects, as well as understand all the methods and tools of Six Sigma process improvement.

Functional managers are also important. They must have immediate access to information about people and project staffing and any changes so they can be properly supportive. Six Sigma teams typically involve a variety of participants from functional departments such as engineering, finance, human resources, production, IT, and more, so involving the functional managers closely helps ensure projects are staffed with the right talent. A project can stretch resources, so the functional manager must be actively involved to juggle the tasks of keeping the core functions of the business running while providing support to the Six Sigma team efforts.

And don't forget suppliers and customers; they're part of the value stream and have a direct role to play. Capture the voice of the customer (VOC) and involve the customer in defining value. (Flip to Chapter 2 for more on the VOC.) Similarly, engage suppliers and partners because you must flow requirements to them and you depend on value from them.

Being in charge of your toolkit

Because the constituencies served in a Six Sigma initiative are such a diverse lot, you use a broad set of management tools.

- **Communication and leadership:** Use both formal and informal tools — company intranet sites; Facebook pages and other social media; video messaging; and even letters, memos, and reports — for communication and leadership. And don't forget the most important leadership tool: face-to-face communication, including individuals, workgroups, and large assemblies.

- **Change management:** Change is scary, and people need help. Change management methods and tools enable people to understand the whys and hows of what's different, why they should care, what's in it for them, and how to move forward.
- **Project management:** Six Sigma projects require project management just like other projects do. The Six Sigma project management portfolio includes everything from the capture of ideas to project assignments, staffing, budgets, and performance. More advanced management tools include multi-project and cross-project portfolio management across a shared enterprise environment.
- **Process intelligence (PI):** Process intelligence is having the ability to track process activities and access process information in order to know progress and performance. *Dashboards* and *andons* are examples of PI tools, which also include tables, plots, charts, and other signals of process performance. Combining these tools with budgets, schedules, resources, and business-impact information creates comprehensive pictures of project and program status, progress, and trends.
- **Knowledge management tools:** Six Sigma initiatives generate lots of information, some of it structured (such as information in databases) and much of it unstructured (texts, Tweets, documents, presentations, and so on). *Knowledge management* is the discipline and set of collaboration tools that grant individuals and teams ready information through structured access to various data repositories. By having access to the right knowledge at the right time, managers and practitioners can expedite their returns on improvement investment.
- **Learning tools:** Beyond traditional training, learning tools provide direct, just-in-time, and lower-cost training to individuals, teams, and companies. These tools are critical enablers for the job of training large numbers of people in the concepts, ways, and methods of Six Sigma.

TECHNICAL STUFF

In addition to these program and project management tools, the information technology professionals apply enterprise integration and service management technologies to help tie together and share information. A Service-Oriented Architecture (SOA) implemented across an enterprise service bus (ESB) helps you readily move data and information between and among all these management tools — and also between transaction systems, including customer management, accounting, design, shop-floor, and enterprise resource planning (ERP) systems.

Through the Looking Glass: Communicating Like a Leader

After you've become a Six Sigma practitioner, you're changed forever. You've gone through the looking glass; you have insights and vision that dramatically enhance your abilities. You command new powers and have the ability to foster significant positive change in your world. As a result — regardless of your title or official duties — you become a leader.

Your leadership role compels you to use the single most important tool for any leader: communication. Your Six Sigma knowledge and capabilities give you significant influence, and you apply that influence through all manner of communication. Table 23-1 summarizes the broad set of communication tools such leaders use.

REMEMBER

Whether you're an analyst, an executive, a manager, an engineer, or an administrative assistant, you have the responsibility to communicate. And we don't just mean one-way communications; you have to network, facilitate communications, listen, and help others listen.

Table 23-1 The Tools of Leadership Communication

Communication Tool	***Role***
Face-to-face communication	The most powerful leadership tool is your personal communication. Direct interaction is the best way to listen, learn, and influence.
Formal presentations	A formal presentation, such as a slideshow, a common and effective leadership and communication tool.
Impromptu presentations	Whiteboards and flip charts make ideal platforms for conveying important ideas and information, conducting brainstorming sessions, developing early designs, and troubleshooting.
E-mail	You can communicate messages, directives, requests, and reports by e-mail. Attaching files makes e-mail a powerful communication conduit. ***Note:*** E-mail is a poor and inappropriate choice for resolving issues.
Phone calls	Particularly when an issue or problem arises, nothing is quite as effective as just picking up the phone and calling.
Memos and letters	Formal memoranda and letters are most useful for communicating in an official manner.
Bullhorn	Hey — whatever it takes! Just make sure you get the message out.

Helping Yourself to Project Management Tools

Six Sigma benefits are derived from a series of projects: big projects, little projects, projects within a single department, projects that cross departments, projects inside companies, and projects that even cross company boundaries. Dozens of projects — and, in big companies, hundreds of projects. Dr. Seuss could write a book on all the Six Sigma projects!

We define Six Sigma projects in detail in Chapters 5 and 6. The skills and tools required to manage a Six Sigma project are similar to those required to manage other types of projects; you need to leverage technology for managing the complexity of people, change, and information. Although Six Sigma projects are rigorous, you don't need a certification from the Project Management Institute to manage them. Table 23-2 lists the major categories of project management technology tools Six Sigma practitioners use.

Table 23-2 Categories of Project Management Tools

Category	*Role*
Ideation	Short for "idea-creation" — to foster and capture ideas for potential Six Sigma projects.
Definition	Establish the project scope, write a problem and objective statement, set a schedule, and assign initial team members.
Selection	Establish priorities for projects, manage the queue of projects, and launch projects.
Tracking	Track and manage project progress. Identify and manage variance to plan. Ensure deliverables to the established objectives and schedule.
Reporting	Communicate the status and results of the project — to the project team members, business owners, Six Sigma Champions, executives, and other constituents.

Capturing ideas with ideation tools

Tools for project ideation let you capture the essence of the idea, along with supporting information, in a central database to evaluate and consider. Figure 23-1 shows an example of a web-based project ideation portal.

Defining the project

Project definition is the practice of transforming a practical business problem into a Six Sigma project. The result is a well-defined problem statement and a well-scoped set of objectives, with approvals from those involved in the project or affected by the project. Fifty percent of a project's success is based on how well the project is defined.

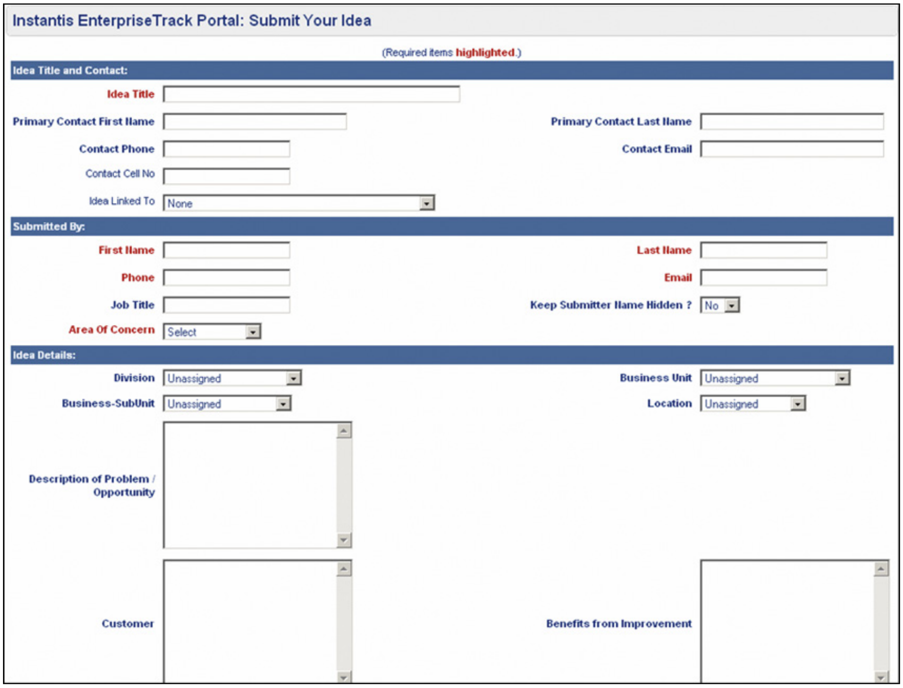


Figure 23-1: Project ideation portal.

Behind the magic trio — problem statement, objective statement, and approvals — are several supporting elements that make up a sound project definition. Every project definition should contain a concise and accurate description for each of the elements in Table 23-3.

Table 23-3 Basic Elements of Project Definition

Element	*Definition*
Purpose	The reason and motivation for doing the project. The purpose includes a precise statement of the problem and its impacts.
Objectives	The core set of objectives that must be met if the project is to be judged a success; they may be milestone-based. Be specific in identifying the anticipated levels of improvement.

Element	*Definition*
Benefits	The anticipated gain from successfully meeting the project objectives. For Six Sigma projects, this item specifically includes the bottom-line benefits.
Team members	The group of individuals needed to help complete the project. The team must be small to remain agile, yet have the right expertise and representation. Generally speaking, a team of 6 to 8 people is required, with extra help on a part-time basis.
Schedule	The total duration of the project, as well as the individual duration of each project phase.
Risk and controls	Scope, schedule, and objectives hang in a delicate balance. A change in any one affects at least one of the other two. You must reasonably estimate the risk and impact of such changes and identify the controls you'll apply to both prevent them from occurring and respond if they do.

REMEMBER

Managers are responsible for defining projects. They must decide what is to be worked on in order to meet business and customer requirements. But that doesn't mean that managers make such decisions without the help of the Six Sigma practitioners. The best projects are defined when joint effort occurs between the managers and the Six Sigma practitioners.

To define a project, use a project definition worksheet to break down the many elements of a project into easy-to-handle pieces. At the highest level, this is all there is to the essence of project definition. Although it may sound easy, you have to put a lot of information and work into defining projects — and then you have a lot to track and manage.

You have difficult objectives in front of you; your resources are limited — in terms of budget, available people, and equipment with which to work — and the schedule is always tight. You must account for the constraints and risk factors, too. Done properly, a well-defined project will enable your planning process and put you on the road to success.

Pick a winner! Selecting the project

Project selection is a delicate act of evaluation, alignment, and prioritization. Your Six Sigma projects must be of proper value and contribution in their own right, but they must also be set in the context of the improvement of the business. Rogue Six Sigma projects can solve the wrong problems.

As part of the selection process, first define the project in rough terms (but sufficiently quantify it in scope, schedule, and difficulty); we cover project definition in the preceding section. Then you can use the following sections to determine whether the project is worth doing.

Evaluation

Evaluate any proposed project for its direct contribution to its specific area of business. These contributions should include quantifiable metrics, such as significant percentage of defect reduction or measured customer satisfaction improvements, as well as the financial contributions to profitability. Here are some examples:

- **Quantifiable Improvements:** > 70 percent over baseline performance on key metrics
- **Quantifiable Returns:** Return on Investment < 1 year

Alignment

After assessing a proposed project's contribution, evaluate the project in terms of its alignment to the goals and strategies of the business and for its context relative to core or enabling business processes. The Six Sigma Champion should evaluate for you how the project will contribute to the overall business needs. Here are some considerations:

- **Consider the project in terms of hard dollar value or soft contribution.** No more than 25 percent of projects should be soft savings projects.
- **Fit the project profile to the overall business to ensure its efforts and contributions are placed strategically.**
- **Consider the learning value and the contributions to generating momentum toward the total Six Sigma improvement initiative.**

In many cases, the project represents a part of a larger opportunity, or it should be realigned to better fit the business strategy. In such cases, recast the project within the new context. In this way, you ensure an effective alignment of Six Sigma with the needs of the business.

Priority

As a result of your evaluation and alignment, you're in position to assign a level of priority to the project from zero (project disapproved) to ten (top resources and budget). Because a Six Sigma initiative is a project incubator, defining and applying a prioritization scheme is important.

Your ultimate goal is to first work on projects that have the largest impact on the organization, either strategically or financially, with the highest probability of success and with the lowest amount of resources needed. Use a simple matrix to compare these parameters and help prioritize projects.

Tracking the project

Project plans are really great — until the day the project begins and everything changes. You can track and manage the project relative to the plans with project management tools. These tools help you follow progress and report on status; make changes to resources, budgets, and schedules; and redefine work and deliverables. In many cases, the tools also manage changes to the plan and compare the real results, called *actuals,* to the original baseline to produce variance-to-plan information.

Project tracking tools include text documents, supporting spreadsheets for financials, a Gantt or similar type of project schedule with milestones, and resource information and reporting mechanisms:

- **Word processor:** A tool like Microsoft Word captures all textual information and stores it in files. You can build templates to help ensure information is complete and consistent across projects.
- **Spreadsheet:** A general-purpose tool like Microsoft Excel can help you track project costs and returns.
- **Scheduler:** Dozens and dozens — hundreds — of project scheduling tools are on the market. The most commonly used basic project planning and tracking tool is Microsoft Project. See Figure 23-2 for an example of a project schedule. Integrated enterprise-class tools like Instantis are more powerful and can perform project scheduling for Six Sigma–specific projects from an Internet-based architecture.
- **Reporting:** Most project planning and scheduling tools typically generate project status reports directly.

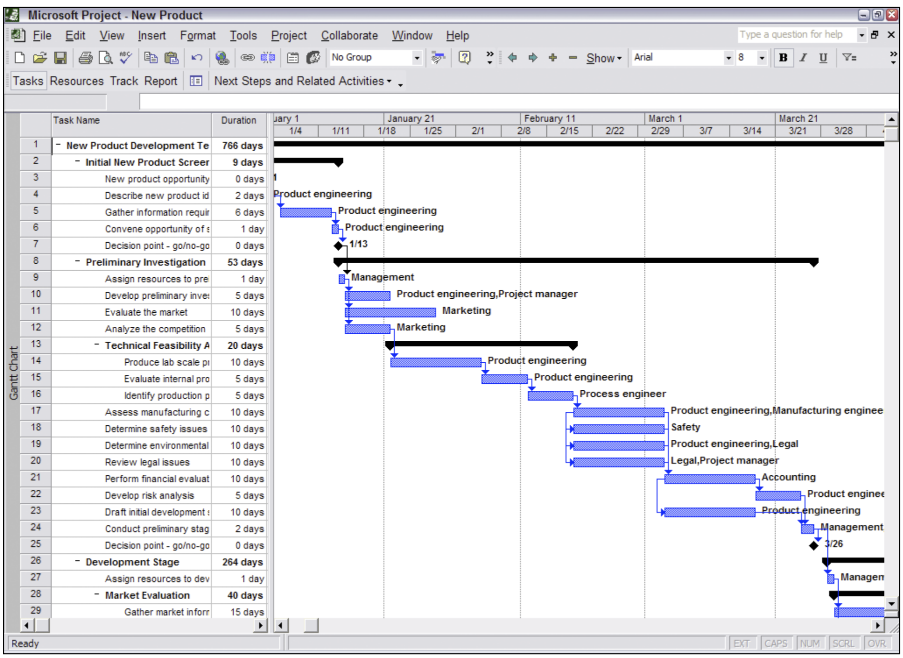


Figure 23-2: A project schedule in Gantt format.

- **Document management:** Often overlooked, but still critically important, are the tools for managing the plethora of project documentation. *Document management* is the practice of securing a set of data files in a repository with strict access and revision controls. These systems are invaluable for controlling updates to official or reference documentation.

First review this information, and, when approved, set down the *baseline plan* against which everyone works. Review any subsequent changes to the plan with the Champion and other stakeholders to determine whether the project should continue with or without the changes, be placed on hold, or eliminated.

Just the Facts, Ma'am: Intelligence Tools

Process intelligence tools give you all the information you need to understand what's happening with process behavior and performance. These tools are vitally important because they provide visibility into the bottom-line results of your projects and programs.

Gaining process intelligence

Enterprise-class integrated technology packages include a suite of tools that capture process information in real time, providing effective management information and control tools as shown in Figure 23-3.

Dealing with dashboards

Query and reporting tools help you cull information from databases and create nicely formatted reports — often called *dashboards.* This class of tools isn't specific to Six Sigma, but because they're generic, they're adaptable to the application. Figure 23-4 gives an example of an executive dashboard.

Keeping a balanced scorecard

The *balanced scorecard* is an applicable management tool for Six Sigma managers. With its balanced focus on customer, process, team capability, and financial metrics, the balanced scorecard is an ideal executive tool, generally speaking.

Many balanced scorecards are generated manually by using generic collection and reporting tools such as spreadsheets. More sophisticated tools sample, collect, and display balanced scorecard information in real time. You can see a sample balanced scorecard in Figure 23-5.

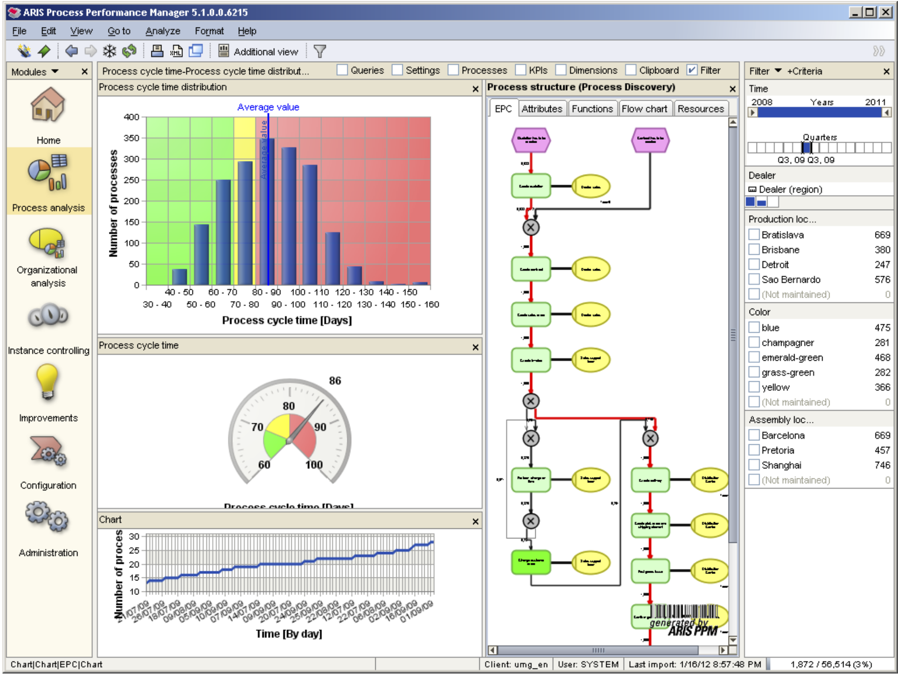


Figure 23-3: Process intelligence.

Figure 23-4: An executive dashboard.

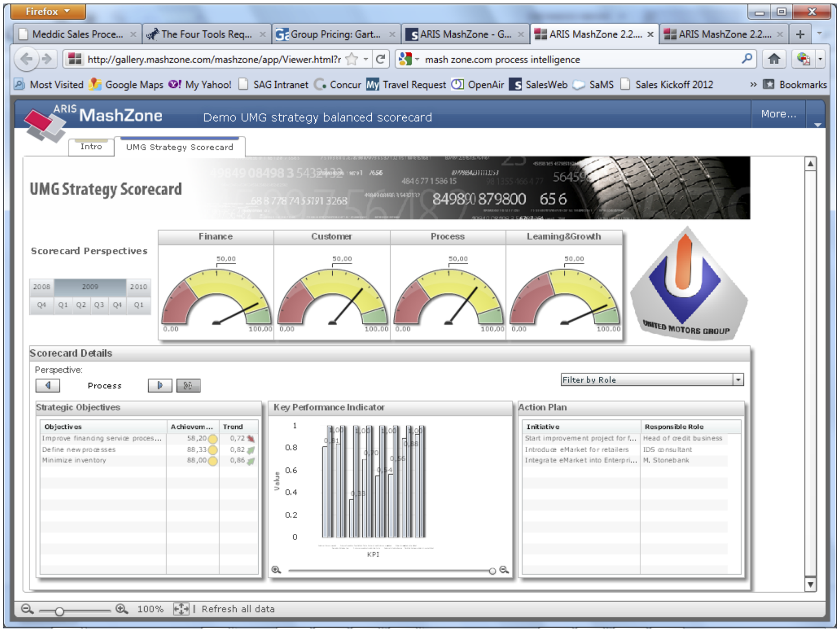


Figure 23-5: Balanced scorecard.

Collaborating in Style: Knowledge Management

Knowledge management (KM) tools are extensive collaboration vehicles that help you transfer and share knowledge and information across your organization. The savvy Six Sigma manager employs these tools to ensure a widespread effect of the behaviors and results of a Six Sigma initiative.

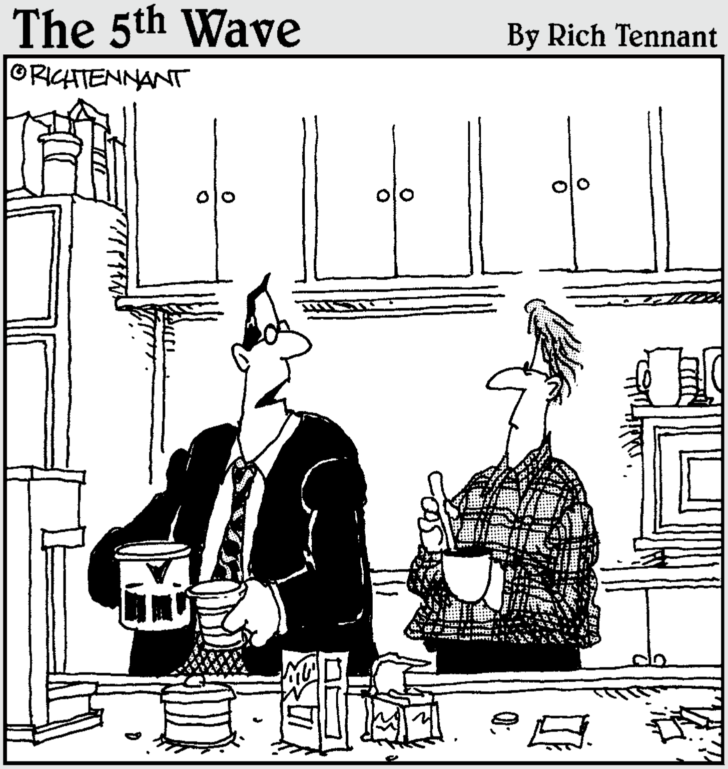
KM tools are almost exclusively enterprise-class applications that operate across networks. They work together with learning tools to provide effective and efficient mechanisms for sharing intellectual capital and creating an environment of responsiveness and furthering innovation. KM tools are an informal, bottom-up way to bring together and share information.

The marketplace for KM tools is broad, and in the broadest sense, it includes all information, reporting, and content management technologies. More specifically, KM tools enable people to collect, access, manage, and share all relevant information on a variety of topics.

REMEMBER

Knowledge management isn't an esoteric field of academic ballyhoo about life in the electronically-enabled information age. Six Sigma initiatives produce a wealth of vital information that contributes significantly to the intellectual capital of your business. KM is the technology that releases this capital into your organization to generate sustained growth and performance improvement.

Part VI
The Part of Tens



"I'm one of the Six Sigma Black Belts in the company, but several of us still wear suspenders."

In this part . . .

These chapters offer extra information in easily digestible tidbits. We give you short lists of best practices, common mistakes, and where to go for help.

Chapter 24

Ten Top Do's and Don'ts of Six Sigma

In This Chapter

- Keeping important goals in mind
- Approaching Six Sigma with the right mindset and plan
- Avoiding common Six Sigma pitfalls

Successful Six Sigma efforts have several practices and characteristics in common, and they also avoid common pitfalls. This chapter gives you ten do's and don'ts for successfully applying Six Sigma. As you launch into your own Six Sigma journey, use these guidelines as landmarks to set your course and bearing. Even after you've been doing Six Sigma for a while, periodically comparing what you do with what others have found to be most effective is a good idea, so revisit this chapter from time to time.

Do Target Tangible Results

Typically, Six Sigma leads organizations to reduce their costs by as much as 20 to 30 percent of revenue. At the same time, these organizations increase their revenues by 10 percent or more.

To realize these returns, however, each Six Sigma DMAIC project must be tied to a tangible financial measure of return — dollars saved, new revenue gained, specific costs avoided, and so on (see Chapter 5 for details). You must formally measure, track, and roll up these financial gains if you want to achieve the startling financial returns that are the hallmark of Six Sigma. Without tying projects to tangible financial measures and tracking their financial impact, Six Sigma efforts naturally drift away from their financial potential.

REMEMBER

In isolated cases, a Six Sigma project isn't directly focused on cost reduction or revenue enhancement but rather on some other objective of the organization. If you complete a project with an object of increasing brand awareness, for example, you may have difficulty quantifying how much that project improves the company's bottom line. But if the project enables the company's key business strategies, it's still worth the effort.

Do Think Before You Act

Too often, people jump into action and do something — anything — to solve a problem. They confuse action with effectiveness. This approach showcases activity, but it usually ends in a continuation of the problem or, at best, a less-than-optimal solution.

Businesses and organizations have a vested interest in getting optimal results quickly and consistently. Six Sigma's DMAIC methodology (which we cover in Chapter 4) forces you to shift the bulk of the activity of solving a problem into defining, measuring, and planning a solution. Each project starts with a detailed, in-depth definition of what the problem really is and what the objectives of the solution are. Next, you take extensive measurements to verify the current performance of the process or system and then follow it with in-depth analysis of inputs, outputs, conditions, and causes and effects. Only after you complete all these steps do you attempt an improvement solution. The result of this upfront rigor is almost always an optimal solution that you can quickly and efficiently put in place. In the long run, the front-loaded DMAIC approach solves the problem more quickly and with better, more consistent results than other approaches do.

Do Put Your Faith in Data

An admonition among Six Sigma practitioners says, "In God we trust; all others must have data." Without data, decisions are based on supposition, estimation, opinion, and sometimes wishful thinking. Data allow you to objectively identify and select the truly best ideas and solutions from among the many alternatives. If you listen, the data tell you what you need to do to improve by leaps and bounds. Common sense, opinion, and "trying harder" aren't guaranteed to get you there.

Making decisions based on data, however, isn't easy. Data require you to suspend judgment and personal bias and to confront sometimes brutal and undesirable facts. In the long run, though, trusting data consistently leads you to better and more-rapid solutions.

Do Align Projects with Key Goals

One of the most important Six Sigma success factors is selecting projects that line up with the key goals of your organization (see Chapter 5 for details).

Successful and lasting Six Sigma efforts are always made up of projects that are each specifically focused on moving an organization toward its stated goals.

Do Unleash Everyone's Potential

The best Six Sigma efforts extend beyond full-time Black Belts. When an organization broadens its Six Sigma knowledge and participation to Green Belts, Yellow Belts, and even those with basic Six Sigma awareness, it unleashes the vast potential of a greater number of its employees. What an advantage! Instead of relying on a handful of isolated, specialized experts to drive organization-wide improvement, an entire army is enlisted to contribute to the effort.

Do Leverage Technology

Technology and software are inseparable from Six Sigma. Yet many people try to segment technology into its own, isolated corner. Others dismiss its contribution outright because they don't understand how to leverage its potential.

The right technology can help anyone in Six Sigma do his or her work better and faster — and that's a goal everyone wants to achieve. Anymore, you need technology to get to the problem — especially as more and more processes are defined and managed within IT.

Don't Deploy Six Sigma without a Leader

Some organizations deploy Six Sigma without a designated, empowered deployment leader. Sure, these companies train Belts, assign projects, provide tools, and track results. They believe breakthrough change will occur by the sum of the individual, independent efforts. But a Six Sigma deployment without a leader is like a ship without a captain: Individual crew members may know what to do in their own areas, but the project has no direction or overall progress. Make sure you have a leader on board.

Don't Take Too Big a Bite

Almost invariably, the failure of any Six Sigma project can be traced to a scope that was too broad. Trying to minimize variation in an entire product, for example, is so defocused that little improvement can happen on any part of the product. Concentrating on minimizing the variation in a single critical characteristic of a product, however, allows you to dig deep enough to discover the real source of improvement.

Always err on the side of scoping your projects too small. Improvement is continuous; you can always come back later and do more.

Don't Think, "But We're Different"

Considering yourself or your organization to be unique — so unique that what's worked for others can't possibly work for you — is natural. It's also one of the most common myths people have about Six Sigma.

Six Sigma is a general methodology. It has proven itself in every arena where it's been applied — manufacturing, operations, logistics, design, supply chains, services, transactions, processing, legal, human resources, software, sales, marketing, management, healthcare, the public sector, defense contracting — the list goes on and on! Don't fall into the trap of thinking you're the lone exception to the rule.

Don't Overtrain

Not every officer of the peace needs to be trained as an elite Special Forces commando. Likewise, not everyone doing Six Sigma needs to know the details of every advanced statistical tool and method.

The amount of information in Six Sigma courses has ratcheted up as consultants and trainers have competed against each other in their marketing efforts. But the fact that you can learn it doesn't mean you need to. Only a handful of Six Sigma tools are actually used regularly. (We include only these essential tools in this book.) The majority of available tools are really brought out only occasionally for rare Sunday drives.

Don't get fooled into thinking that more and more knowledge is always better. And don't think you have to use every tool on every project. Expediency in learning and in application is the key! The best system gets the right knowledge to the right person at the right time.

Chapter 25

Ten Ways to Gain Synergies with Lean and Six Sigma

In This Chapter

- Bringing Lean philosophy and practices to Six Sigma initiatives
- Expanding Six Sigma with Lean tools

Six Sigma and Lean are different but closely related improvement methodologies. Throughout this book, you see how Six Sigma is a rigorous project-driven approach to reducing variance and eliminating defects in processes. *Lean*, meanwhile, is fundamentally about helping people do more with less — delivering more customer value with less waste. These practices are complimentary, and in today's world, you'll find that the methods and toolsets of Lean and Six Sigma are often combined. As a Six Sigma practitioner, you can bolster your approach by taking advantage of Lean methods and tools.

This chapter introduces ten ways you can utilize Lean to improve your Six Sigma practices. And to go even deeper with Lean, check out the latest edition of *Lean For Dummies* by Natalie Sayer and Bruce Williams (Wiley).

Add Customer Value

Creating value for the customer is a foundational principle of Lean. Chapter 11 addresses how you ascertain whether a process or activity is adding value. This same definition is a core tenet of Lean practice. An activity or process is considered to be value add only if it meets all three of the following conditions; otherwise, it's non-value add, or waste:

- It must transform the product or service.
- The customer must be willing to pay for it.
- It must be done correctly the first time.

Map the Value Stream

One of the Lean tools we cover in this book is value stream mapping (VSM). VSM helps you get the big-picture view of your processes. Use this approach to effectively see a process end-to-end — from suppliers through to customers and end-consumers. This strategy helps you prevent optimizing one subprocess at the expense of another one in the value stream. Learn how to create and leverage value stream maps and be ready to infuse this method appropriately into your DMAIC projects. You can read more about value stream mapping in Chapter 7.

Strive for Flow

One of the basic Lean principles for effective production is flow. A stream of single items progressing through a process turns out to be more optimal and ideal than any alternatives — especially batch. Within your Six Sigma projects, identify and enact process changes that promote this ideal: the concept of single piece flow.

3-Gen: Go to Gemba

Six Sigma is often highly analytical, which sometimes leads to a tendency to perform Six Sigma analysis and project work in a location removed from where the process or defects are actually occurring. Lean has an approach called 3-Gen. Derived from three Japanese words — *genchi, genbutsu,* and *genjitsu* — 3-Gen is the practice of *going to gemba,* or physically going to where the action is, where value is being created, or where waste is occurring so you can observe firsthand what is happening and get real data and facts to solve problems and improve processes. Working from second-hand knowledge never results in the kind of deep understanding required to make breakthrough improvements. Make sure you cultivate the attitude of "go and see" in order to fully understand the problems you are trying to solve.

Muda-Mura-Muri: Expand Your Definition of Waste

In Six Sigma, your focus is primarily on variance and defects. Lean has a broader definition of *muda* (Japanese for waste) that officially includes seven forms of waste: transportation, waiting, overproduction, inventory, movement, extra processing, and of course defects. In addition, *mura* is waste due to unevenness or variation, and *muri* is waste caused by overstressing people, equipment, or systems. By broadening your view of waste to include muda, mura, and muri, you can better attack the sources of challenges to your processes.

5S the Workplace

As described in Chapter 19, the Lean practice of *5S* is important as a fundamental behavior to reduce waste through workplace organization. Sort, straighten, scrub, standardize — these simple and practical steps lead to an improved work environment. (***Note:*** Some people add a sixth *S* for "safety.")

Keep Simple Things Simple

Not all improvement efforts need the analytical rigor and depth of what a Black Belt does within a DMAIC project road map. Some efforts are better suited to the Lean *kaizen* approach of everyday improvement. Instead of tackling a three-month Six Sigma project, Lean teams make incremental improvements in a matter of routine. The Deming cycle of Plan-Do-Check-Act (PDCA) fills in this way, alongside the Six Sigma improvement process of DMAIC.

Teach *kaizen* — the acts of everyday improvement — and help people think this way. *Kaizen* is a strongly principled underpinning that naturally addresses a broad swath of your needs and enables your Six Sigma projects to run better.

Remember that Everyone Plays a Part

In Six Sigma, the specialists — the Black Belts, Master Black Belts, Champions, and even Green Belts — perform the bulk of the DMAIC improvement process. They lead, manage, and perform most of the Six Sigma project work. Lean is different. In Lean, improvement projects involve everyone — not just the specialists. Everyone who is involved in the process in any way is included.

Because not everyone is trained in the advanced methods and tools of Six Sigma, Lean team project members don't address the issues with the same level of statistical depth and rigor. But many process challenges don't require that; instead, they require changes in behaviors, attitudes, and activities. For that, it's more about involvement and inclusion than about deep statistical analysis. If the process challenge you're facing is more about people, Lean provides a complimentary approach.

View Improvement as a Mindset

Most Six Sigma training is geared toward Black Belts and Green Belts. But remember the Yellow Belts — that is, everyone else (see Chapter 4). In your Six Sigma deployment, you should provide training to everyone in your organization because you want everyone thinking in a data-driven, cause-and-effect process manner.

Lean really emphasizes this improvement mindset. In Lean, everyone feels compelled and is organizationally empowered and encouraged to make improvements every day and all the time. This thinking is the essence of *kaizen.* By incorporating this fundamental Lean principle in your Six Sigma practice, you expand your initiative's reach, effectiveness, and sustainability.

Make Sure Managers Improve, Too

Process improvement isn't just for the so-called worker bees; managers and executives must be actively engaged. Sometimes in Six Sigma, the managers believe their jobs are done after they've endorsed and encouraged process improvement practices. But as important as this support may be, that's not the whole story.

In Lean companies, all the top managers are involved to the extent that they conduct their own daily improvement work. No one in these types of successful organizations is exempt from joining the effort. This leadership philosophy from Lean is invaluable to companies doing Six Sigma: Managers develop the mindset, learn the tools, involve themselves directly in their application, and directly lead their staffs by example. In many Six Sigma initiatives, companies require all managers to complete Green Belt training.

Chapter 26

Ten Places to Go for Help

In This Chapter

- Using the power of the Internet
- Going to the professionals

Six Sigma is big, and it can seem almost daunting at times. Although you may be blazing new trails through your own life and organization, thousands of people have forged similar trails before you. You have many, many resources for all kinds of help on every Six Sigma subject imaginable. Practitioners, corporations, societies, associations, academics, consultants, and authors — they're all out there and available to assist you with knowledge, education, training, advice, tools, technologies, and publications. And they're easy to find. This chapter helps guide you to these resources.

Court Your Colleagues

Chances are you know someone who has been directly involved in Six Sigma. If you're working in a company that's deployed Six Sigma, you have Champions, Master Black Belts, and Black Belts all around you. Also, thousands of certified practitioners from early-adopter Six Sigma companies such as GE have spread across the globe.

Even if you don't know of anyone personally, you may be surprised by just how few degrees of separation lie between your interest and a Six Sigma expert. Ask your friends and associates in your social groups, at your church, or even at the ballgame. They're out there; you just have to ask around.

Web Searches and Social Networks

Web portals aggregate vast sums of information and whisk you directly to the source with the click of your computer mouse. We recommend the web as the starting point for outside help.

Social media sites such as LinkedIn and Facebook have forums and communities dedicated to topics around Six Sigma. Check out the specialty forum iSixSigma at `www.isixsigma.com`.

Contact Six Sigma Corporations

Hundreds of corporations have deployed Six Sigma in every industry and every corner of the world. Many of them will openly meet with you to discuss their experiences and offer advice. Several, such as pioneers Motorola and GE, have consulting groups that offer this advice as a service. Don't hesitate to call on a company that's been through the process.

Join Associations and Societies

Associations and professional societies offer a variety of services to members, including access to knowledge, special events, contacts, and discounts on materials and services. If you're entering the Six Sigma world, we recommend joining one of these organizations:

- **The Shingo Prize for Operational Excellence:** This award and accreditation body combines the best of Six Sigma and Lean principles into guidelines and a model for operational excellence.
- **American Society for Quality (ASQ):** ASQ is the largest quality association in the United States, with over 100,000 members.
- **Six Sigma Benchmarking Association:** This association conducts benchmarking studies, shares best practices, and facilitates process improvement and total quality.
- **American Statistical Association (ASA):** ASA is a scientific and educational society that promotes statistical practice, applications, and research; publishes statistical journals; and improves statistical education.
- **The International Society of Six Sigma Professionals (ISSSP):** ISSSP is the industry organization that caters to the professional.
- **The Royal Statistical Society (RSS):** RSS, based in the United Kingdom, is the world's oldest quality association. RSS publishes a journal, organizes meetings, sets and maintains professional standards, accredits university courses, and administers examinations.

Attend Conferences

Numerous organizations regularly sponsor conferences and symposia across the United States and around the world on topics in Six Sigma, quality, and business process improvement. These conferences are outstanding forums for meeting with peers, surveying product and service providers, and attending seminars on current topics. Look at ASQ, IQPC, ISSSP, and the Shingo Prize in the preceding section. In addition, Worldwide Conventions and Business Forums (WCBF) hosts Six Sigma conferences, including market-specific events focused on healthcare.

In addition to these major industry events, many events of specialty topical interest hosted by associations, consultancies, and tool vendors occur regularly. For example, check out the International Conference on Axiomatic Design, or the TRIZ Futures Conference.

Read The Books

At last count, we place the number of books on Six Sigma at nearly 1,000 titles! You can find them easily online through Amazon. The authors of these tomes are usually consultants and practitioners who have published these works based directly on industry experience. The works are generally grouped by topic; choose the ones that suit you.

Talk to Technology Vendors

An increasing number of powerful software and technology products to enable your Six Sigma initiatives are on the market (see Part V). These vendors sell the software, provide product training, and assist with implementation and integration in your environment.

Chat with Consultants

Numerous consultancies cater to supporting Six Sigma initiatives and can help you with every aspect of your interest — from “Should I consider a Six Sigma initiative?” to “How do I run a process simulation?” and everything in between. The consultancies fall primarily into three categories:

- **Large scale consultancies from Big-6-type firms:** These firms have Six Sigma expertise but also tend to provide enterprise-class coverage of topics in business process management and information technology systems integration.
- **Six Sigma consultancies:** These firms cater specifically to Six Sigma implementation and support.
- **Boutiques:** Numerous highly focused one-person firms dot the landscape; these consultants provide specialized assistance in specific topics and areas.

Consulting is expensive. Don't be surprised to pay $3,000 or more per day for experienced senior consulting. It's worth it if you can afford it.

Survey the Six Sigma Trainers

Training in the principles and practices of Six Sigma is a commodity industry with many providers. Training is available in every conceivable topic and format, including traditional classroom, computer-based training, and asynchronous learning networks. Several firms license training materials and train a company's trainers. Training providers come in three main flavors:

- **Academics:** More and more colleges and universities offer Six Sigma training, usually through the engineering department or the business school, as either part of the undergraduate/graduate curriculum or as an outreach through a professional development center. Contact your local institution for more information.
- **Training consultancies:** Most of the Six Sigma consulting firms also offer training. Unlike many academic sources, consultancies train on both technical and nontechnical topics. In addition, they often tailor the training curriculum to the needs of a particular business. The preceding section has info on consultancies.
- **Online training:** Online training is increasingly available on topics in Six Sigma. Online courses are available through universities, and several of the training consultancies are also offered by firms that specialize in online curriculum.

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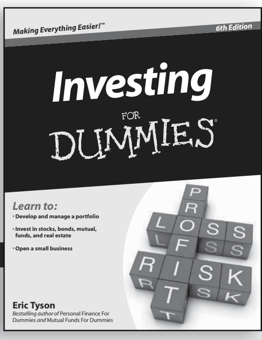

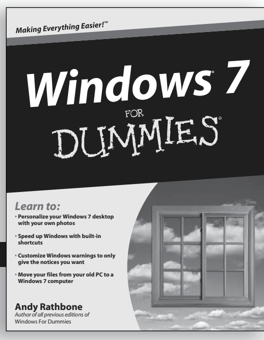

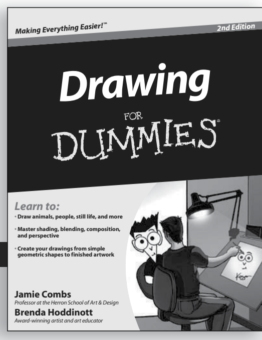

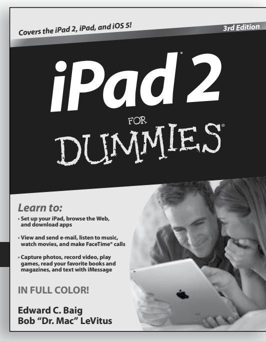

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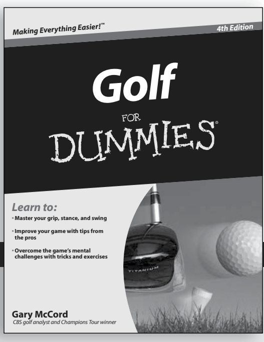

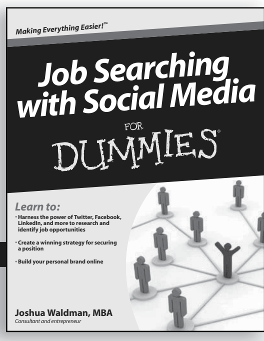

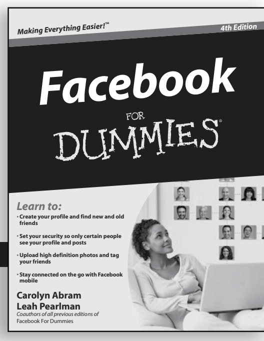

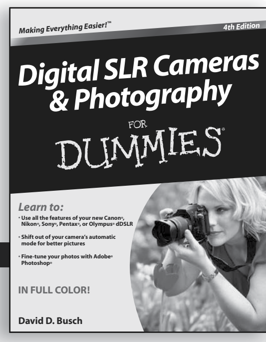

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