HEALTHCARE OPERATIONS MANAGEMENT

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To my wife, Sharon, and daughters, Kelly and Katie,
for their love and support throughout my career.

Dan McLaughlin

To my family, Kevin, Jessica, Jake, and Abby,
for their constant understanding and support.

Julie Hays

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During the final stages of the completion of this book, Julie Hays unexpectedly
died. As Dr. Christopher Puto, Dean of the Opus College of Business at the
University of St. Thomas, said, "Julie cared deeply about students and their
learning experience, and she was an accomplished scholar who was
well-respected by her peers." This book is a final tribute to Julie's accomplished
career and is dedicated to her legacy.

ACKNOWLEDGMENTS

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PREFACE

This book is intended to help healthcare professionals meet the challenges and take advantage of the opportunities found in healthcare today. We believe that the answers to many of the dilemmas faced by the healthcare system, such as increasing costs, decreasing profitability, inadequate access, and poor quality, lie within organizational operations—the nuts and bolts of healthcare delivery. The healthcare arena is filled with opportunities for significant operational improvements. We hope that this book will encourage healthcare management students and working professionals to find ways to improve the management and delivery of healthcare to increase the effectiveness and efficiency of tomorrow's healthcare system.

Manufacturing organizations have successfully employed the programs, techniques, and tools of operations improvement for many years. Recently, leading healthcare organizations have begun to employ the same tools. Although many operations management texts are available, few focus on *healthcare* operations, and none take an *integrated* approach. Students interested in healthcare process improvement have difficulty seeing the applicability of the science of operations management when most texts focus on widgets and production lines, while the students' focus is on patients and providers.

This book not only covers the basics of operations improvement, but also provides an overview of the significant environmental trends in the healthcare industry. We focus on the strategic implementation of process improvement programs, techniques, and tools in the healthcare environment with its complex web of reimbursement systems, physician relations, workforce challenges, and strong governmental regulations. This integrated approach will help healthcare professionals gain an understanding of strategic operations management and, more importantly, its applicability to the healthcare industry.

How This Book Is Organized
We have organized this book into five parts:

1. Introduction to healthcare operations;
2. Setting goals and executing strategy;

3. Performance improvement tools, techniques, and programs;
4. Applications to contemporary healthcare operations issues; and
5. Putting it all together for operational excellence.

Although this structure will be helpful for most readers, each chapter stands alone and can be covered or read in any order that makes sense for a particular course or student.

The first part of the book, Introduction to Healthcare Operations, provides an overview of the challenges and opportunities found in today's healthcare environment (Chapter 1). We follow that with a history of the field of management science and operations improvement (Chapter 2). Next, we discuss two of the most influential environmental changes facing healthcare today, evidence-based medicine and pay-for-performance (Chapter 3).

In Part II, Setting Goals and Executing Strategy, Chapter 4 highlights the importance of tying the strategic direction of the organization to operational initiatives. This chapter outlines the use of the balanced scorecard technique to execute and monitor these initiatives to achieve organizational objectives. Typically, strategic initiatives are large in scope, and the tools of project management (Chapter 5) are needed to successfully manage them. Indeed, the use of project management tools can help to ensure the success of any size project. Strategic focus and project management provide the organizational foundation for the remainder of this book.

The next part of the book, Performance Improvement Tools, Techniques, and Programs, provides an introduction to the basic decision-making and problem-solving processes and describes some of the associated tools (Chapter 6). Almost all process improvement initiatives (Six Sigma, Lean, etc.) follow this same process and make use of some or all of the tools in Chapter 6. Good decisions and effective solutions are based on facts, not intuition. Chapter 7 provides an overview of data collection and analysis to enable fact-based decision making.

Six Sigma, Lean, simulation, and supply chain management are more specific philosophies or techniques that can be used to improve processes and systems. The Six Sigma (Chapter 8) methodology is the latest manifestation of the use of quality improvement tools to reduce variation and errors in a process. The Lean (Chapter 9) methodology is focused on eliminating waste in a system or process. Many healthcare decisions and processes can be modeled and optimized or improved by using computer simulation (Chapter 10).

The fourth section of the book, Applications to Contemporary Healthcare Operations Issues, begins with an integrated approach to applying the various tools and techniques for process improvement in the healthcare environment (Chapter 11). We then focus on a special but important case of process improvement, patient scheduling in the ambulatory environ-

ment (Chapter 12). Supply chain management extends the boundaries of the system to include both upstream suppliers and downstream customers, and this is the focus of the final chapter in the section (Chapter 13).

The book's last section, Putting It All Together for Operational Excellence, concludes the book with a discussion, in Chapter 14, of strategies for implementing and maintaining the focus on continuous improvement in healthcare organizations.

We have included many features in this book that we believe will enhance student understanding and learning. Most chapters begin with a vignette, called Operations Management in Action, that offers real-world examples related to the content of the particular chapter. Throughout the book we use a fictitious but realistic organization, Vincent Valley Hospital and Health System, to illustrate the various tools, techniques, and programs discussed. Each chapter concludes with questions for discussion, and Parts II through IV include exercises to be solved.

We have included many examples throughout the text of the use of various contemporary software tools essential for effective operations management. Healthcare leaders and managers must be experts in the application of these tools and stay current with their latest versions. Just as we ask healthcare providers to stay up to date with the latest clinical advances, so too must healthcare managers stay current with these basic tools.

Student Resources

We have developed an extensive companion website with links to a vast amount of supplementary material. This website, ache.org/books/OpsManagement, provides links to material we have developed, as well as other supplemental material. In particular, we have developed, and make available, various Excel templates, Arena models, tutorials, exercises, and PowerPoint presentations for each chapter. Additionally, links to many of the cited articles and books can be found on this website. Finally, the site provides links to a wide variety of information and material related to specific topics, including videos, webcasts, web demonstrations, exercises, and tutorials. Because new and valuable information is constantly being added to the web, we encourage readers to share any relevant sites they find so that we can include them on the companion website. A password is not necessary for access to the website.

Included with this book is the student version of Arena software. This simulation software provides a powerful tool to model and optimize healthcare processes such as patient flow and scheduling. The animation features of Arena provide the healthcare professional with an accessible and easily understood tool to engage colleagues in the intense and complex work of operations improvement.

Instructor Resources

For instructors who choose to use this book in their courses, accompanying resources are available online. For access information, e-mail hap1@ache.org. Contained in these resources are answers or discussion points for the end-of-chapter questions and exercises; teaching tips; and recommended teaching cases, with links to sources as needed.

We hope that this text is helpful to you and your organization on your journey along the path of continuous improvement. We are interested in your progress whether you are a student of healthcare administration, new member of the health administration team, seasoned department head, or physician leader. Please use the e-mail addresses on the companion website to inform us of your successes and let us know what we could do to make this a better text so that we, too, can continuously improve.

—Dan McLaughlin
—Julie Hays

INTRODUCTION TO HEALTHCARE OPERATIONS

1

THE CHALLENGE AND THE OPPORTUNITY

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

Agency for Healthcare Research and
    Quality (AHRQ)
consumer-directed healthcare
evidence-based medicine (EBM)
health savings account
Institute of Medicine (IOM)

knowledge-based management
    (KBM)
patient care microsystem
Vincent Valley Hospital and Health
    System (VVH)

Introduction

The challenges and opportunities in today's complex healthcare delivery systems demand that leaders take charge of their operations. A strong operations focus can reduce costs, increase safety, improve clinical outcomes, and allow an organization to compete effectively in an aggressive marketplace.

In the recent past, the success of many organizations in the American healthcare system has been achieved through executing a few key strategies: First, attract and retain talented clinicians; next, add new technology and specialty care; and finally, find new methods to maximize the organization's reimbursement for these services. In most organizations, new services—not ongoing operations—represented the key to success.

However, that era is ending. Payer resistance to cost increases and a surge in public reporting on the quality of healthcare are strong forces driving a major change in strategy. To succeed in this new environment, a healthcare enterprise must focus on making significant improvements in its core operations.

This book is about how to get things done. It provides an integrated system and set of contemporary operations improvement tools that can be used to make significant gains in any organization. These tools have been successfully deployed in much of the global business community for more than 30 years (Hammer 2005) and now are being used by leading healthcare delivery organizations.

This chapter outlines the purpose of the book, identifies challenges that current healthcare systems are facing, presents a systems view of healthcare, and provides a comprehensive framework for the use of operations tools and methods in healthcare. Finally, Vincent Valley Hospital and Health System (VVH), which is used in examples throughout the book, is described.

Purpose of this Book

Excellence in healthcare derives from three major areas of expertise: clinical care, leadership, and operations. Although clinical expertise and leadership are critical to an organization's success, this book focuses on operations— how to deliver high-quality care in a consistent, efficient manner.

Many books cover operational improvement tools, and some focus on using these tools in healthcare environments. So, why a book devoted to the broad topic of healthcare operations? Because there is a real need for an *integrated* approach to operations improvement that puts all the tools in a logical context and provides a road map for their use. An integrated approach

uses a clinical analogy—first find and diagnose an operations issue, then apply the appropriate treatment tool to solve the problem.

The field of operations research and management science is too deep to cover in one book. In *Healthcare Operations Management*, only tools and techniques that are currently being deployed in leading healthcare organizations are covered in enough detail to enable students and practitioners to "get things done" in their work. Each chapter provides many references for deeper study. The authors have also included additional resources, exercises, and tools on the website that accompanies this book.

This book is organized so that each chapter builds on the next and is cross-referenced. However, each chapter also stands alone, so a reader interested in Six Sigma could start in Chapter 8 and then move back and forth into the other chapters.

This book does not specifically explore "quality" in healthcare as defined by the many agencies that have a mission to ensure healthcare quality, such as the Joint Commission, National Committee for Quality Assurance, National Quality Forum, or federally funded Quality Improvement Organizations. *The Healthcare Quality Book: Vision, Strategy and Tools* (Ransom, Maulik, and Nash 2005) explores this perspective in depth and provides a useful companion to this book. However, the systems, tools, and techniques discussed here are essential to make the operational improvements needed to meet the expectations of these quality-assurance organizations.

The Challenge

The United States spent more than $2 trillion on healthcare in 2007—the most per capita in the world. With health insurance premiums doubling every five years, the annual cost for a family for health insurance is expected to be $22,000 by 2010—*all* of a worker's paycheck at ten dollars an hour. The Centers for Medicare & Medicaid Services predict that within the next decade, one of every five dollars of the U.S. economy will be devoted to healthcare (DoBias and Evans 2006).

Despite its high cost, the value delivered by the system has been questioned by many policymakers. Unexplained variations in healthcare have been estimated to result in 44,000 to 98,000 preventable deaths every year. Preventable healthcare-related injuries cost the economy between $17 billion and $29 billion annually, half of which represents direct healthcare costs (IOM 1999). In 2004, more than half (55 percent) of the American public said that they were dissatisfied with the quality of healthcare in this country, compared to 44 percent in 2000 (Henry J. Kaiser Foundation, Agency for Healthcare Research and Quality, and Harvard School of Public Health 2004).

These problems were studied in the landmark work of the Institute of Medicine (IOM 2001), *Crossing the Quality Chasm—A New Health System for the 21st Century*. The IOM panel concluded that the knowledge to improve patient care is available, but a gap—a chasm—separates that knowledge from everyday practice. The panel summarizes the goals of a new health system in six "aims." (Box 1.1)

BOX 1.1

Six Aims of a New Health System

Patient care should be

1. *Safe*, avoiding injuries to patients from the care that is intended to help them;
2. *Effective*, providing services based on scientific knowledge to all who could benefit, and refraining from providing services to those not likely to benefit (avoiding underuse and overuse, respectively);
3. *Patient-centered*, providing care that is respectful of and responsive to individual patient preferences, needs, and values, and ensuring that patient values guide all clinical decisions;
4. *Timely*, reducing wait times and harmful delays for both those who receive and those who give care;
5. *Efficient*, avoiding waste of equipment, supplies, ideas, and energy; and
6. *Equitable*, providing care that does not vary in quality because of personal characteristics such as gender, ethnicity, geographic location, and socio-economic status.

SOURCE: Reprinted with permission from *Crossing the Quality Chasm—A New Health System for the 21st Century* © 2001 by the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

The IOM panel recommended ten steps to close the gap between care with the above characteristics and current practice (Box 1.2).

BOX 1.2

Ten Steps to Close the Gap

The ten steps to close the gap are:

1. *Care based on continuous healing relationships*. Patients should receive care whenever they need it and in many forms, not just face-to-face visits. This rule implies that the healthcare system should be responsive at all times (24 hours a day, every day), and that access to care should be provided over the Internet, by telephone, and by other means in addition to face-to-face visits.
2. *Customization based on patient needs and values*. The system of care should be designed to meet the most common types of needs, but have the capability to respond to individual patient choices and preferences.

BOX 1.2
Ten Steps to
Close the Gap
(continued)

3. *The patient as the source of control.* Patients should be given all relevant information and the opportunity to exercise whatever degree of control they choose over healthcare decisions that affect them. The health system should be able to accommodate differences in patient preferences and encourage shared decision making.

4. *Shared knowledge and the free flow of information.* Patients should have unfettered access to their own medical information and to clinical knowledge. Clinicians and patients should communicate effectively and share information.

5. *Evidence-based decision making.* Patients should receive care based on the best available scientific knowledge. Care should not vary illogically from clinician to clinician or from place to place.

6. *Safety as a system property.* Patients should be safe from injury caused by the care system. Reducing risk and ensuring safety require greater attention to systems that help prevent and mitigate errors.

7. *The need for transparency.* The healthcare system should make available to patients and their families information that allows them to make informed decisions when selecting a health plan, hospital, or clinical practice, or when choosing among alternative treatments. This should include information describing the system's performance on safety, evidence-based practice, and patient satisfaction.

8. *Anticipation of needs.* The health system should anticipate patient needs rather than simply react to events.

9. *Continuous decrease in waste.* The health system should not waste resources or patient time.

10. *Cooperation among clinicians.* Clinicians and institutions should actively collaborate and communicate to ensure an appropriate exchange of information and coordination of care.

SOURCE: Reprinted with permission from *Crossing the Quality Chasm—A New Health System for the 21st Century* © 2001 by the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

Many healthcare leaders have begun to address these issues and are capitalizing on proven tools employed by other industries to ensure high performance and quality outcomes. For major change to occur in the U.S. health system, however, these strategies must be adopted by a broad spectrum of healthcare providers and implemented consistently throughout the continuum of care—ambulatory, inpatient/acute settings, and long-term care.

The payers for healthcare must engage with the delivery system to find new ways to partner for improvement. In addition, patients have to assume a stronger financial and self-care role in this new system.

Although not all of the IOM goals can be accomplished through operational improvements, this book provides methods and tools to actively change the system to accomplish many aspects of them.

The Opportunity

Although the current American health system presents numerous challenges, opportunities for improvement are emerging as well. Three major trends provide hope that significant change is possible.

Evidence-Based Medicine

The use of evidence-based medicine (EBM) for the delivery of healthcare is the result of 30 years of work by some of the most progressive and thoughtful practitioners in the nation. The movement has produced an array of care guidelines, care patterns, and new shared decision-making tools for both caregivers and patients. The cost of healthcare could be reduced by nearly 29 percent and clinical outcomes improved significantly if EBM guidelines and the most efficient care procedures were used by all practitioners in the United States (Wennberg, Fisher, and Skinner 2004).

Comprehensive resources are available to the healthcare organization that wishes to emphasize EBM. For example, the National Guideline Clearinghouse (NGC 2006) is a comprehensive database of evidence-based clinical practice guidelines and related documents and contains more than 4,000 guidelines. NGC is an initiative of the Agency for Healthcare Research and Quality (AHRQ) of the U.S. Department of Health and Human Services. NGC was originally created by AHRQ in partnership with the American Medical Association and American Association of Health Plans, now America's Health Insurance Plans (AHIP).

Knowledge-Based Management

Knowledge-based management (KBM) employs data and information, rather than feelings or intuition, to support management decisions. Practitioners of KBM use the tools contained in this book for cost reduction, increased safety, and improved clinical outcomes. The evidence for the efficacy of these techniques is contained in the operations research and management science literature. Although these tools have been taught in healthcare graduate programs for many years, they have not migrated widely into practice. Recently, the IOM (Proctor et al. 2005) has recognized the opportunities that the use of KBM presents with its publication *Building a Better Delivery System: A New Engineering/Healthcare Partnership*. In addition, AHRQ and Denver Health provide practical operations improvement tools in *A Toolkit for Redesign in Healthcare* (Gabow et al. 2003).

Healthcare delivery has been slow to adopt information technologies, but many organizations are now beginning to aggressively implement electronic medical record systems and other automated tools. Hillestad et al. (2005) have suggested that broad deployment of these systems could save up to $371 billion annually in the United States.

A More Active Role for the Consumer

Consumers are beginning to assume new roles in their own care through the use of health education and information and more effective partnering with their healthcare providers. Personal maintenance of wellness though a healthy lifestyle is one essential component. Understanding one's disease and treatment options and having an awareness of the cost of care are also important responsibilities of the consumer.

Patients will become good consumers of healthcare by finding and using price information in selecting providers and treatments. Many employers are now offering high-deductible health plans with accompanying health savings accounts (HSAs.) This type of consumer-directed healthcare is likely to grow and increase pressure on providers to deliver cost-effective, customer-sensitive, high-quality care.

The healthcare delivery system of the future will support and empower active, informed consumers.

A Systems Look at Healthcare

The Clinical System

To improve healthcare operations, it is important to understand the systems that influence the delivery of care. Clinical care delivery is embedded in a series of interconnected systems (Figure 1.1).

The *patient care microsystem* is where the healthcare professional provides hands-on care. Elements of the clinical microsystem include:
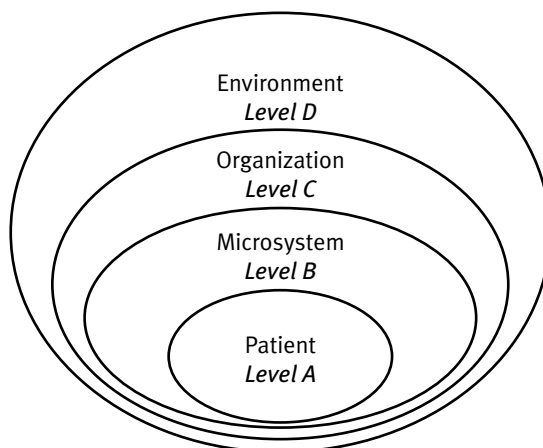
FIGURE 1.1
A Systems View of Healthcare

SOURCE: Ransom, Maulik, and Nash (2005). Based on Ferlie, E., and S. M. Shortell. 2001. "Improving the Quality of Healthcare in the United Kingdom and the United States: A Framework for Change." *The Milbank Quarterly* 79(2): 281–316.

- The team of health professionals who provide clinical care to the patient;
- The tools the team has to diagnose and treat the patient (e.g., imaging capabilities, lab tests, drugs); and
- The logic for determining the appropriate treatments and the processes to deliver this care.

Because common conditions (e.g., hypertension) affect a large number of patients, clinical research has determined the most effective way to treat these patients. Therefore, in many cases, the organization and functioning of the microsystem can be optimized.

Process improvements can be made at this level to ensure that the most effective, least costly care is delivered. In addition, the use of EBM guidelines can also help ensure that the patient receives the correct treatment at the correct time.

The *organizational infrastructure* also influences the effective delivery of care to the patient. Ensuring that providers have the correct tools and skills is an important element of infrastructure. The use of KBM provides a mechanism to optimize the use of clinical tools.

The electronic health record is one of the most important advances in the clinical microsystem for both process improvement and the wider use of EBM. Another key component of infrastructure is the leadership displayed by senior staff. Without leadership, effective progress or change will not occur.

Finally, the *environment* strongly influences the delivery of care. Key environmental factors include competition, government regulation, demographics, and payer policies. An organization's strategy is frequently influenced by such factors (e.g., a new regulation from Medicare, a new competitor).

Many of the systems concepts regarding healthcare delivery were initially developed by Avedis Donabedian. These fundamental contributions are discussed in depth in Chapter 2.

System Stability and Change

Elements in each layer of this system interact. Peter Senge (1990) provides a useful theory to understand the interaction of elements in a complex system such as healthcare. In his model, the structure of a system is the primary mechanism for producing an outcome. For example, an organized structure of facilities, trained professionals, supplies, equipment, and EBM care guidelines has a high probability of producing an expected clinical outcome.

No system is ever completely stable. Each system's performance is modified and controlled by feedback (Figure 1.2). Senge (1990, 75) defines feedback as "any reciprocal flow of influence. In systems thinking it is an axiom that every influence is both *cause* and *effect*." As shown in Figure 1.2,
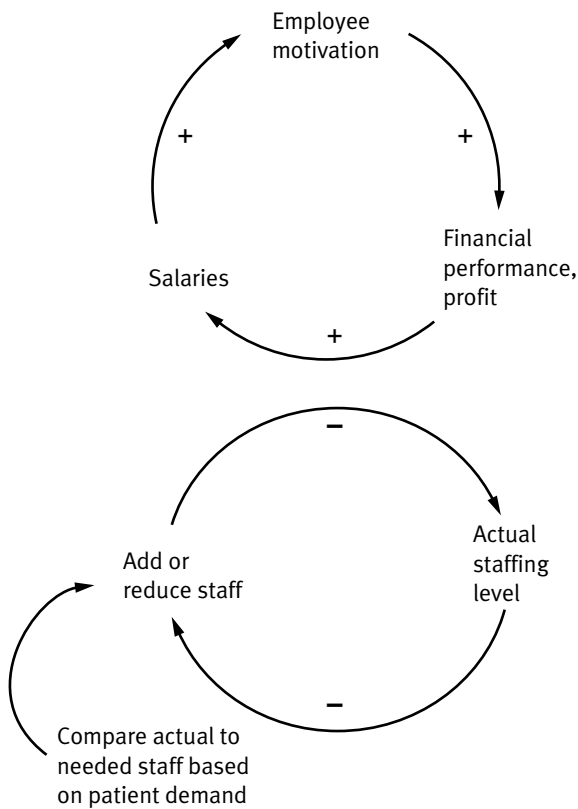
higher salaries provide an incentive for higher performance levels by employ-ees. This, in turn, leads to better financial performance and profitability; increased profits provide additional funds for higher salaries, and the cycle continues. Another frequent example in healthcare delivery is patient lab results that directly influence the medication ordered by a physician. A third example is a financial report that shows an overexpenditure in one category that will prompt a manager to reduce spending to meet budget goals.

A more formal systems definition with feedback includes a process, a sensor that monitors process output, a feedback loop, and a control that modifies how the process operates.

Feedback can be either reinforcing or balancing. *Reinforcing feedback* prompts change that builds on itself and amplifies the outcome of a process, taking the process further and further from its starting point. The effect of reinforcing feedback can be either positive or negative. For example, a rein-forcing change of positive financial results for an organization could lead to higher salaries, which would then lead to even better financial performance because the employees were highly motivated. In contrast, a poor supervisor could lead to employee turnover, short staffing, and even more turnover.

Balancing feedback prompts change that seeks stability. A balancing feedback loop attempts to return the system to its starting point. The human body provides a good example of a complex system that has many balancing feedback mechanisms. For example, an overheated body prompts perspiration until the body is cooled through evaporation. The clinical term for this type of balance is homeostasis. A clinical treatment process that controls drug dosing via real-time monitoring of the patient's physiological responses is an example of balancing feedback. Inpatient unit staffing levels that drive where in a hospital patients are admitted is another. All of these feedback mechanisms are designed to maintain balance in the system.

A confounding problem with feedback is delay. Delays occur when there are interruptions between actions and consequences. When this happens, systems tend to overshoot and perform poorly. For example, an emergency department might experience a surge in patients and call in additional staff. If the surge subsides, the added staff may not be needed and unnecessary expense will have been incurred.

As healthcare leaders focus on improving their operations, it is important to understand the systems in which change resides. Every change will be resisted and reinforced by feedback mechanisms, many of which are not clearly visible. Taking a broad systems view can improve the effectiveness of change.

Many subsystems in the total healthcare system are interconnected. These connections have feedback mechanisms that either reinforce or balance the subsystem's performance. Figure 1.3 shows a simple connection that originates in the environmental segment of the total health system. Each process has both reinforcing and balancing feedback.

An Integrating Framework for Operations Management in Healthcare

This book is divided into five major sections:

- Introduction to healthcare operations;
- Setting goals and executing strategy;

FIGURE 1.3
Linkages
Within the
Healthcare
System:
Chemotherapy

Payers want to reduce costs for chemotherapy	New payment method for chemotherapy is created	Chemotherapy treatment needs to be more efficient to meet payment levels	Changes are made in care processes and support systems to maintain quality while reducing costs
Environment	Organization	Clinical microsystem	Patient
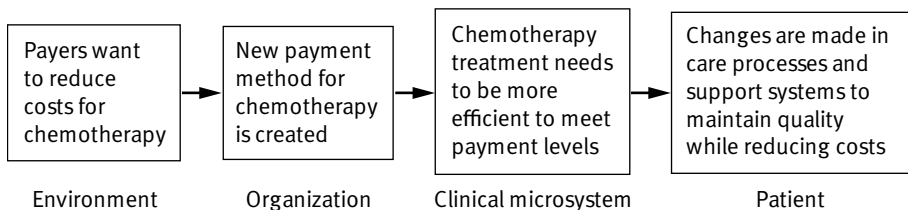
- Performance improvement tools, techniques, and programs;
- Applications to contemporary healthcare operations issues; and
- Putting it all together for operational excellence.

This schema reflects the authors' view that effective operations management in healthcare consists of highly focused strategy execution and organizational change accompanied by the disciplined use of analytical tools, techniques, and programs. The book includes examples of applications of this approach to common healthcare challenges.

Figure 1.4 illustrates this framework. An organization needs to understand the environment, develop a strategy, and implement a system to effectively deploy this strategy. At the same time, the organization must become adept at using all the tools of operations improvement contained in this book. These improvement tools can then be combined to attack the fundamental challenges of operating a complex healthcare delivery organization.

Introduction to Healthcare Operations

The introductory chapters provide an overview of the significant environmental trends healthcare delivery organizations face. Annual updates to industry-wide trends can be found in *Futurescan: Healthcare Trends and Implications 2008–2013* (Society for Healthcare Strategy and Market Development and American College of Healthcare Executives 2008). Progressive organizations will review these publications carefully. Then, using this information, they can respond to external forces by identifying either new strategies or current operating problems that must be addressed.

Business has been aggressively using operations improvement tools for the past 30 years, but the field of operations science actually began many centuries in the past. Chapter 2 provides a brief history.

Healthcare operations are being strongly driven by the effects of EBM and pay-for-performance. Chapter 3 provides an overview of these trends and how organizations can effect change to meet current challenges and opportunities.
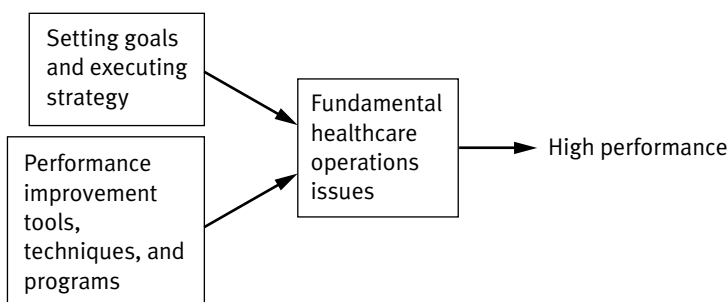
FIGURE 1.4

Framework for Effective Operations Management in Healthcare

Setting Goals and Executing Strategy

A key component of effective operations is the ability to move strategy to action. Chapter 4 shows how the use of the balanced scorecard can accomplish this aim. Change in all organizations is challenging, and formal methods of project management (Chapter 5) can be used to make effective, lasting improvements in an organization's operations.

Performance Improvement Tools, Techniques, and Programs

Once an organization has in place strategy implementation and change management processes, it needs to select the correct tools, techniques, and programs to analyze current operations and implement effective changes.

Chapter 6—Tools for Problem Solving and Decision Making—outlines the basic steps of problem solving, beginning with framing the question or problem and continuing through data collection and analyses to enable effective decision making. Chapter 7—Using Data and Statistical Tools for Operations Improvement—provides a review of the building blocks for many of the more advanced tools used later in the book. (This chapter may serve as a review or reference for readers who already have good statistical skills.)

Some projects will require a focus on process improvement. Six Sigma tools (Chapter 8) can be used to reduce the variability in the outcome of a process. Lean tools (Chapter 9) can be used to eliminate waste and increase speed. Many healthcare processes, such as patient flow, can be modeled and improved by using computer simulation (Chapter 10), which may also be used to evaluate project risks.

Applications to Contemporary Healthcare Operations Issues

This part of the book demonstrates how these concepts can be applied to some of today's fundamental healthcare challenges. Process improvement techniques are widely deployed in many organizations to significantly improve performance; Chapter 11 reviews the tools of process improvement and demonstrates their use in improving patient flow.

Scheduling and capacity management continue to be major concerns for many healthcare delivery organizations, particularly with the advent of advanced access. Chapter 12 demonstrates how simulation can be used to optimize scheduling. Chapter 13—Supply Chain Management—explores the optimal methods of acquiring supplies and maintaining appropriate inventory levels.

In the end, any operations improvement will fail unless steps are taken to maintain the gains; Chapter 14—Putting it All Together for Operational Excellence—contains the necessary tools. The chapter also provides a more detailed algorithm that can help practitioners select the appropriate tools,

methods, and techniques to make significant operational improvements. It includes an example of how Vincent Valley Hospital and Health System (VVH) uses all the tools in the book to achieve operational excellence.

Vincent Valley Hospital and Health System

Woven throughout the sections described below are examples designed to consistently illustrate the tools discussed. A fictitious but realistic health system, VVH, is featured in these examples. (The companion website, ache.org/books/OpsManagement, contains a more expansive description of VVH.)

VVH is located in a Midwestern city of 1.5 million. It has 3,000 employees, operates 350 inpatient beds, and has a medical staff of 450 physicians. In addition, VVH operates nine clinics staffed by physicians who are employees of the system. VVH has two major competitor hospitals, and a number of surgeons from all three hospitals recently joined together to set up an independent ambulatory surgery center.

Three major health plans provide most of the private payment to VVH and, along with the state Medicaid system, have recently begun a pay-for-performance initiative. VVH has a strong balance sheet and a profit margin of approximately 2 percent, but feels financially challenged.

The board of VVH includes many local industry leaders, who have asked the chief executive officer to focus on using the operational techniques that have led them to succeed in their businesses.

Conclusion

This book is an overview of operations management approaches and tools. It is expected that the successful reader will understand all the concepts in the book (and in current use in the field) and should be able to apply at the basic level some of the tools, techniques, and programs presented. It is not expected that the reader will be able to execute at the more advanced level (e.g., Six Sigma black belt, Project Management Professional). However, this book will prepare readers to work effectively with knowledgeable professionals and, most important, enable them to direct their work.

Discussion Questions

1. Review the ten action steps recommended by IOM to close the quality chasm. Rank them from easiest to most difficult to achieve, and give a rationale for your rankings.

2. Give three examples of possibilities for system improvement at the boundaries of the healthcare subsystems (patient, microsystem, organization, and environment).
3. Identify three systems in a healthcare organization (at any level) that have reinforcing feedback.
4. Identify three systems in a healthcare organization (at any level) that have balancing feedback.
5. Identify three systems in a healthcare organization (at any level) where feedback delays affect the performance of the system.

References

DoBias, M., and M. Evans. 2006. "Mixed Signals—The CMS 10-Year Spending Projections Inspire Both Hope and Skepticism, and Leave Plenty of Room for Lobbyists." *Modern Healthcare* 36 (9): 6–8.

Gabow, P., S. Eisert, A. Karkhanis, A. Knight, and P. Dickson. 2003. *A Toolkit for Redesign in Healthcare*. Washington, D.C.: Agency for Healthcare Research and Quality.

Hammer, M. 2005. "Making Operational Innovation Work." *Harvard Management Update* 10 (4): 3–4.

Henry J. Kaiser Foundation, Agency for Healthcare Research and Quality, and Harvard School of Public Health. 2004. *National Survey on Consumers' Experiences with Patient Safety and Quality Information*. Menlo Park, CA: Kaiser Family Foundation. [Online information; retrieved 8/28/06.] www.kff.org/kaiserpolls/upload/National-Survey-on-Consumers-Experiences-With-Patient-Safety-and-Quality-Information-Survey-Summary-and-Chartpack.pdf.

Hillestad, R., J. Bigelow, A. Bower, F. Girosi, R. Meili, R. Scoville, and R. Taylor. 2005. "Can Electronic Medical Record Systems Transform Health Care? Potential Health Benefits, Savings, and Costs." *Health Affairs* 24 (5): 1103–17.

Institute of Medicine. 2001. *Crossing the Quality Chasm—A New Health System for the 21st Century*. Washington, D.C.: National Academies Press.

———. 1999. *To Err Is Human: Building a Safer Health System*. Washington, D.C.: National Academies Press.

National Guideline Clearinghouse (NGC). 2006. [Online information; retrieved 8/28/06.] www.guideline.gov/.

Proctor, P., W. Reid, D. Compton, J. H. Grossman, and G. Fanjiang. 2005. *Building a Better Delivery System: A New Engineering/Health Care Partnership*. Washington, D.C.: Institute of Medicine.

Ransom, S. B., J. S. Maulik, and D. B. Nash, (eds.), 2005. *The Healthcare Quality Book: Vision, Strategy, and Tools*. Chicago: Health Administration Press.

Senge, P. M. 1990. *The Fifth Discipline—The Art and Practice of the Learning Organization*. New York: Doubleday.

Society for Healthcare Strategy and Market Development and American College of
    Healthcare Executives. 2008. *Futurescan: Healthcare Trends and Implications
    2008–2013.* Chicago: Health Administration Press.

Wennberg, J. E., E. S. Fisher, and J. S. Skinner. 2004. "Geography and the Debate
    over Medicare Reform." *Health Affairs* 23 (Sept. 2004 Variations Supple-
    ment): W96–W114.

2

HISTORY OF PERFORMANCE IMPROVEMENT

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

agile

Agency for Healthcare Research and Quality (AHRQ)

Centers for Medicare & Medicaid Services (CMS)

continuous quality improvement (CQI)

critical path method (CPM)

Deming's 14 points for healthcare

enterprise resource planning (ERP)

Institute for Healthcare Improvement (IHI)

ISO 9000

Juran's quality trilogy

just-in-time (JIT)

knowledge-based management (KBM)

knowledge hierarchy

Lean

Malcolm Baldrige National Quality Award

materials requirements planning (MRP)

plan-do-check-act (PDCA)

plan-do-study-act, a variation of plan-do-check-act

program evaluation and review technique (PERT)

service process matrix

service typologies

single-minute exchange of die (SMED)

Six Sigma

statistical process control (SPC)

supply chain management (SCM)

systems thinking

total quality management (TQM)

Toyota Production System (TPS)

Operations Management in Action

During the Crimean War, reports of terrible conditions in military hospitals alarmed British citizens. In response to the outcry, Florence Nightingale was commissioned to oversee the introduction of nurses to military hospitals and to improve conditions in the hospitals. When Nightingale arrived in Scutari, Turkey, she found the hospital overcrowded and filthy. Nightingale instituted many changes to improve the sanitary conditions in the hospital, and many lives were saved as a result of these reforms.

Nightingale was one of the first people in healthcare to collect, tabulate, interpret, and graphically display data related to the effect of process changes on care outcomes. Today, this is called "evidence-based medicine." To quantify the overcrowding problem, she compared the amount of space per patient in London hospitals, 1,600 square feet, to the space in Scutari, about 400 square feet. She developed a standard Model Hospital Statistical Form to enable the collection of consistent data for analysis and comparison. In February 1855, the mortality rate of patients in Scutari was 42 percent. As a result of Nightingale's changes, the mortality rate decreased to 2.2 percent by June 1855. To present these data in a persuasive manner, she developed a new type of graphic display, the polar area diagram.

After the war, Nightingale used the data she had collected to demonstrate that the mortality rate in Scutari, after her reforms, was significantly lower than in other British military hospitals. Although the British military hierarchy was resistant to her changes, the data were convincing and resulted in reforms to military hospitals and the establishment of the Royal Commission on the Health of the Army.

Florence Nightingale would recognize many of the philosophies, tools, and techniques outlined in this text as being essentially the same as those she effectively employed to achieve lasting reform in hospitals throughout the world.

SOURCES: Cohen 1984; Neuhauser 2003; and Nightingale 1858, 1999.

Overview

This chapter provides the background and historical context of performance improvement, which is not a new concept—many of the tools, techniques, and philosophies outlined in this text are based in the past. Although the terminology has changed, many of the core concepts remain the same.

The major topics in this chapter include:

- Systems thinking and knowledge-based management;
- Scientific management and project management;

- Quality experts;
- Service typologies; and
- Philosophies of performance improvement, including Six Sigma, Lean, and supply chain management.

Background

Operations management is the design, operation, and improvement of the processes and systems that create and deliver the organization's products and services. Operations managers plan and control delivery processes and systems within the organization. The goal of operations management is to more effectively and efficiently produce and deliver the organization's products and services. Healthcare professionals have realized that the theories, tools, and techniques of operations management, if properly applied, can enable their own organizations to become more efficient and effective. The operations management information presented in this book should enable healthcare professionals to design systems, processes, products, and services that meet the needs of their organizations' stakeholders. It should also enable the continuous improvement of these systems and services to meet the needs of a quickly changing environment. The healthcare industry is facing many challenges. The costs of care and level of services delivered are increasing; more and more we are able to prolong lives as technology advances and the population ages. In 2004, 15 percent of the U.S. economy was devoted to medical care, up from 11 percent in 1987 (CMS 2005). The need for quality care with zero defects, or failures in care, is being driven by government and other stakeholders. The need to produce more of a higher quality product or service at a reduced cost can only be met through better utilization of resources.

The healthcare environment has recognized the need to control costs while increasing both the level and quality of service. These seemingly contradictory goals can only be reached if healthcare providers can offer their services more effectively and efficiently, better utilizing limited resources that include financial assets, employees and staff, machines and facilities, and time. Healthcare providers have the need and opportunity to adopt many of the tools and techniques that have enabled other service industries and manufacturing to become both more efficient and effective. Six Sigma and Lean are two of the philosophies that have been successfully implemented in the manufacturing sector to decrease costs, increase product quality, and improve timeliness of delivery. As Donald Berwick, M.D., president and chief executive officer (CEO) of the Institute for Healthcare Improvement (IHI), says, "We have to bring the science of management back into healthcare in a way that we haven't in a very long time" (Allen 2004).

To improve systems and processes, one must first know the system or process and its desired inputs and outputs. This book takes a systems view of service provision and delivery, as illustrated in Figure 2.1.

Knowledge-Based Management

To design effective and efficient systems and processes or improve existing processes, knowledge of the systems and processes is needed. This book focuses on knowledge-based management (KBM)—using data and information to base management decisions on facts rather than feelings or intuition.

The "knowledge hierarchy," as it is sometimes called in the literature, is generally attributed to Harlan Cleveland (1982) or Russell Ackoff (1989), an operations researcher and leading systems theorist. The knowledge hierarchy relates to the learning that ultimately underpins KBM and consists of five categories, summarized below (Zeleny 1987) and illustrated in Figure 2.2.

- *Data:* symbols or raw numbers that simply exist; they have no structure or organization. Organizations collect data with their computer systems; individuals collect data through their experiences. In short, "know *nothing.*"
- *Information:* data that are organized or processed to have meaning. Information can be useful, but it is not *necessarily* useful. It can answer such questions as who, what, where, and when. Know *what.*
- *Knowledge:* information that is deliberately useful. Knowledge enables decision making. Know *how.*
- *Understanding:* allows use of what is known and enables the development of new knowledge. Understanding represents the difference between learning and memorizing. Know *why.*
- *Wisdom:* adds moral and ethical views to understanding. Wisdom answers questions to which there is no known correct answer and, in some cases, where there will never be a known correct answer. Know *right.*

FIGURE 2.1
Systems View

INPUT → Transformation process → OUTPUT

Feedback

Labor
Material
Machines
Management
Capital

Goods or services
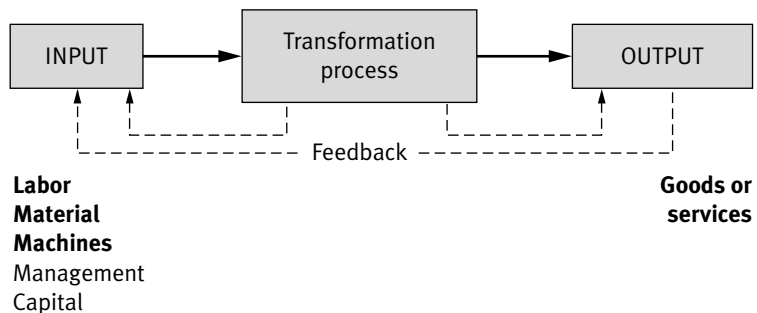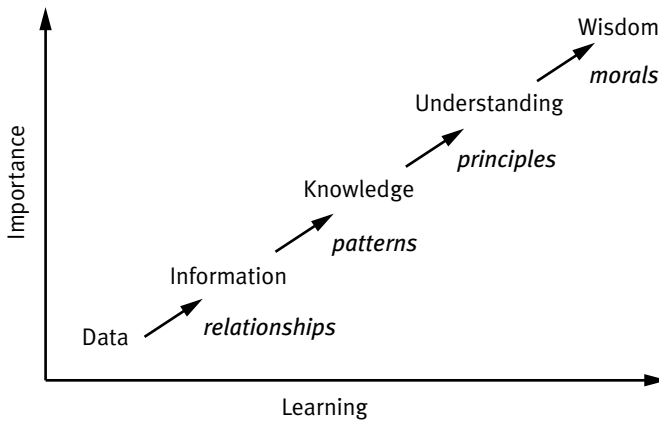
FIGURE 2.2
Knowledge
Hierarchy

A simple example may help to explain this hierarchy. Your height is 67 inches, and your weight is 175 pounds (data). You have a body mass index (BMI) of 26.7 (information). A healthy BMI is 18.5 to 25.5 (knowledge). Your BMI is high, and to be healthy you should lower it (understanding). You begin a diet and exercise program and lower your BMI (wisdom).

Finnie (1997, 24) summarizes the relationships within the hierarchy, and our focus on its less important levels:

> There is another aspect to learning that relates to the five types of the content in the mind. We talk about the accumulation of information, but we fail to distinguish between data, information, knowledge, understanding, and wisdom. An ounce of information is worth a pound of data, an ounce of knowledge is worth a pound of information, an ounce of understanding is worth a pound of knowledge, an ounce of wisdom is worth a pound of understanding. In the past, our focus has been inversely related to importance. We have focused mainly on data and information, a little bit on knowledge, nothing on understanding, and virtually less than nothing on wisdom.

The roots of the knowledge hierarchy can be traced even further back to eighteenth century philosopher Immanuel Kant, much of whose work attempted to address the questions of what and how we can know.

The two major philosophical movements that significantly influenced Kant were empiricism and rationalism (McCormick 2006). The empiricists, most notably John Locke, argued that human knowledge originates in one's experiences. According to Locke, the mind is a blank slate that fills with ideas through its interaction with the world; experience is where all knowledge

originates. The rationalists, including Descartes and Galileo, on the other hand, argued that the world is knowable through an analysis of ideas and logical reasoning. Both the empiricists and rationalists viewed the mind as passive, either because it received ideas onto a blank slate or because it possessed innate ideas that could be logically analyzed.

Kant joined these philosophical ideologies and argued that experience leads to knowing only if the mind provides a structure for those experiences. Although the idea that the rational mind plays a role in defining reality is now common, in Kant's time this was a major insight into what and how we know. Knowledge does not flow from our experiences alone, nor from only our ability to reason; rather, knowledge flows from our ability to apply reasoning to our experiences. Relating Kant to the knowledge hierarchy, data are our experiences, information is obtained through logical reasoning, and knowledge is obtained when we take data and apply structured reasoning to that data to acquire knowledge (Ressler and Ahrens 2006).

The intent of this text is to enable readers to gain knowledge. We discuss tools and techniques that enable the application of logical reasoning to data in order to obtain knowledge and use it to make better decisions. This knowledge and understanding should enable the reader to provide healthcare in a more efficient and effective manner.

History of Scientific Management

Frederick Taylor originated the term "scientific management" in *The Principles of Scientific Management* (Taylor 1911). Scientific management methods called for eliminating the old rule-of-thumb, individual way of performing work and, through study and optimization of the work, replacing the varied methods with the one "best" way of performing the work to improve productivity and efficiency. Today, the term **scientific management** has been replaced with **operations management**, but the intent is similar: study the process or system and determine ways to optimize it in order to make it more efficient and effective.

Mass Production

The Industrial Revolution and mass production set the stage for much of Taylor's work. Prior to the Industrial Revolution, individual craftsmen performed all tasks necessary to produce a good using their own tools and procedures. In the eighteenth century, Adam Smith advocated the division of labor—making work more efficient through specialization. To support a division of labor, a large number of workers are brought together, and each performs a specific task related to the production of a good. Thus, the factory system of mass production was born, and Henry Ford's assem-

bly line eventually came into being, setting the stage for Taylor's scientific management.

Mass production allows for significant economies of scale, as predicted by Smith. Before Ford set up his moving assembly line, each car chassis was assembled by a single worker and took about 12½ hours to produce. After the introduction of the assembly line, this time was reduced to 93 minutes (Bellis 2006). The standardization of products and work allowed for a reduction in the time needed to produce cars and significantly reduced the costs of production. The selling price of the Model T fell from $1,000 to $360 between 1908 and 1916 (Simkin 2005), allowing Ford to capture a large portion of the market.

Although Ford is commonly credited with introducing the moving assembly line and mass production in modern times, they existed several hundred years earlier. The Venetian Arsenal of the 1500s produced nearly one ship every day and employed 16,000 people (NationMaster.com 2004). Ships were mass produced using premanufactured, standardized parts on a floating assembly line (Schmenner 2001).

One of the first examples of mass production in the healthcare industry is Shouldice Hospital (Heskett 2003). Much like Ford, who said people could have the Model T in any color, "so long as it's black," Shouldice performs just one type of surgery. The hospital performs only routine hernia operations, not more complicated hernia surgery or any other types of surgery.

There exists in healthcare growing evidence that experience in treating specific illnesses and conditions affects the outcome of that care. Higher volumes of cases often result in better outcomes (Halm, Lee, and Chassin 2002). Although higher volume alone does not produce better outcomes, the additional practice associated with higher volume results in better outcomes. The idea of "practice makes perfect," or learning curve effects, has led organizations such as the Leapfrog Group (made up of organizations that provide healthcare benefits) to make patient volume one of its criteria for quality. The Agency for Healthcare Research and Quality (AHRQ) report "Making Health Care Safer: A Critical Analysis of Patient Safety Practices" (Auerbach 2001) devotes an entire chapter to this issue and its effect on practice.

Frederick Taylor

Taylor began his work when mass production and the factory system were in their infancy. He believed that U.S. industry was "wasting" human effort and that, as a result, national efficiency (now called productivity) was significantly lower than it could be. The introduction to *The Principles of Scientific Management* (Taylor 1911) illustrates his intent:

But our larger wastes of human effort, which go on every day through such of our acts as are blundering, ill-directed, or inefficient, and which Mr. Roosevelt

refers to as a lack of "national efficiency," are less visible, less tangible, and are but vaguely appreciated. . . . This paper has been written:

First. To point out, through a series of simple illustrations, the great loss which the whole country is suffering through inefficiency in almost all of our daily acts.

Second. To try to convince the reader that the remedy for this inefficiency lies in systematic management, rather than in searching for some unusual or extraordinary man.

Third. To prove that the best management is a true science, resting upon clearly defined laws, rules, and principles, as a foundation. And further to show that the fundamental principles of scientific management are applicable to all kinds of human activities, from our simplest individual acts to the work of our great corporations, which call for the most elaborate cooperation. And, briefly, through a series of illustrations, to convince the reader that whenever these principles are correctly applied, results must follow which are truly astounding.

Note that Taylor specifically mentions systems management as opposed to the individual; this is a common theme that we revisit throughout this book. Rather than focusing on individuals as the cause of problems and the source of solutions, the focus is on systems and their optimization.

Taylor believed that much waste was the result of what he called "soldiering," which today might be called "slacking." He believed that the underlying causes of soldiering were as follows (Taylor 1911):

First. The fallacy, which has from time immemorial been almost universal among workmen, that a material increase in the output of each man or each machine in the trade would result in the end in throwing a large number of men out of work.

Second. The defective systems of management which are in common use, and which make it necessary for each workman to soldier, or work slowly, in order that he may protect his own best interests.

Third. The inefficient rule-of-thumb methods, which are still almost universal in all trades, and in practicing which our workmen waste a large part of their effort.

To eliminate soldiering, Taylor proposed instituting incentive schemes. While at Midvale Steel Company, he used time studies to set daily production quotas. Incentives were paid to those workers reaching their daily goals, and those not reaching their goals were paid significantly less. Productivity at Midvale doubled. Not surprisingly, Taylor's ideas produced considerable backlash. The backlash against increasingly popular pay-for-performance programs in healthcare today is analogous to that experienced by Taylor.

Taylor believed there was "one best way" to perform a task and that careful study and analysis would lead to the discovery of that way. While at Bethlehem Steel Corporation, he studied the shoveling of coal. Using time studies and a careful analysis of how the work was done, he determined that the optimal amount per load was 21 pounds. Taylor then developed shovels that would hold exactly 21 pounds for each type of coal (workers had previously supplied their own shovels; NetMBA.com 2005). He also determined the "ideal" work rate and rest periods to ensure that workers could shovel all day without fatigue. As a result of Taylor's improved methods, Bethlehem Steel was able to reduce the number of workers shoveling coal from 500 to 140 (Nelson 1980).

Taylor's four principles of scientific management are to:

1. Develop and standardize work methods based on scientific study and use these to replace individual rule-of-thumb methods;
2. Select, train, and develop workers rather than allowing them to choose their own tasks and train themselves;
3. Develop a spirit of cooperation between management and workers to ensure that the scientifically developed work methods are both sustainable and implemented on a continuing basis; and
4. Divide work between management and workers so that each does an equal share, where management plans the work and workers actually do the work.

Although some of Taylor's ideas would be problematic today—particularly the notion that workers are "machinelike" and motivated solely by money—many of his ideas can be seen in the foundations of "new" initiatives such as Six Sigma and Lean.

Frank and Lillian Gilbreth

The Gilbreths were contemporaries of Frederick Taylor. Frank, who worked in the construction industry, noticed that no two bricklayers performed their tasks the same way. He believed that bricklaying could be standardized and the one best way determined. He studied the work of bricklaying and analyzed the workers' motions, finding much unnecessary stooping, walking, and reaching. He eliminated these motions by developing an adjustable scaffold designed to hold both bricks and mortar (Taylor 1911). As a result of this and other improvements, Frank Gilbreth reduced the number of motions in bricklaying from 18 to 5 (International Work Simplification Institute 1968) and raised output from 1,000 to 2,700 bricks a day (Perkins 1997). He applied what he had learned from his bricklaying experiments to other industries and work.

In his study of surgical operations, Frank Gilbreth found that doctors spent more time searching for instruments than performing the surgery. In response, he developed a technique still seen in operating rooms today: When

the doctor needs an instrument, he extends his hand, palm up, and asks for the instrument, which is then placed in his hand. Not only does this eliminate searching for the instrument, but it allows the doctor to stay focused on the surgical area and therefore reduces surgical time (Perkins 1997).

Frank and Lillian Gilbreth may be more familiarly known as the parents in the book (Gilbreth and Carey 1948), movie (Lang 1950), and remake of the movie (Levy 2003) *Cheaper by the Dozen*. The Gilbreths incorporated many of their time-saving ideas in the family arena. For example, they only bought one type of sock for all 12 of their children, thus eliminating time-consuming sorting.

Scientific Management Today

Scientific management fell out of favor during the Depression, partly because of the belief that it dehumanized employees, but mainly because it was believed that productivity improvements resulted in downsizing and greater unemployment. Not until World War II was there a resurgence of interest in scientific management, or "operations research," as it came to be called. Despite this period of disfavor, modern operations management has its roots in the theories of scientific management.

In healthcare today, standardized methods and procedures are used to reduce costs and increase the quality of outcomes. Specialized equipment has been developed to speed procedures and reduce labor costs. In some sense, we are still searching for the "one best way." However, care must be taken to heed the lessons of the past. If the "new" tools of operations management are perceived to be dehumanizing or to result in downsizing by healthcare organizations, their implementation will meet significant resistance.

Project Management

The discipline of project management began with the development of the Gantt chart in the early twentieth century. Henry Gantt worked closely with Frederick Taylor at Midvale Steel and in Navy ship construction during World War I. From this work, he developed Gantt charts—bar graphs that illustrate the duration of project tasks and visually display scheduled and actual progress. Gantt charts were used to help manage such large projects as the construction of the Hoover Dam and proved to be such a powerful tool that they are still commonly used today.

Although Gantt charts were used in large projects, they are not ideal for large, complicated projects because they do not explicitly show precedence relationships, that is, what tasks need to be completed before other tasks can start. In the 1950s, two mathematic project scheduling techniques were developed: the program evaluation and review technique (PERT) and the critical path method (CPM). Both techniques begin by developing a project network showing the precedence relationships among tasks and task duration.

PERT was developed by the U.S. Navy in response to the desire to accelerate the Polaris missile program. This "need for speed" was precipitated by the Soviet launch of Sputnik, the first space satellite. PERT uses a probability distribution (the Beta distribution), rather than a point estimate, for the duration of each project task. The probability of completing the entire project in a given amount of time can then be determined. This technique is most useful for estimating project completion time when task times are uncertain and for evaluating risks to project completion prior to the start of a project.

The CPM technique was developed at the same time as PERT by the DuPont and Remington Rand corporations to manage plant maintenance projects. CPM uses the project network and point estimates of task duration times to determine the critical path through the network, or the sequence of activities that will take the longest to complete. If any one of the activities on the critical path is delayed, the entire project will be delayed. This technique is most useful when task times can be estimated with certainty and is typically used in project management and control.

Although both of these techniques are powerful analytical tools for planning, implementing, controlling, and evaluating a project plan, performing the required calculations by hand is quite tedious, and their use was not widespread. With the advent of commercially available project management software for personal computers in the late 1960s, use of these techniques increased considerably. Today, numerous project management software packages are commercially available, and these techniques are used extensively in industry. Microsoft Project, for instance, can perform network analysis based on either PERT or CPM; however, the default is CPM, making this the more commonly used technique.

Projects are an integral part of many of the process improvement initiatives found in the healthcare industry. Project management and its tools are needed to ensure that projects related to quality (Six Sigma), Lean, and supply chain management are completed in the most effective and timely manner possible.

Quality

Walter Shewhart

Although W. Edwards Deming and Joseph Juran are sometimes referred to as the fathers of the quality movement, Walter Shewhart is its grandfather. Both Deming and Juran studied under Shewhart, and much of their work was influenced by his ideas.

Shewhart believed that managers needed certain information to enable them to make scientific, efficient, and economical decisions. He developed statistical process control (SPC) charts to supply that information (Shewhart 1931). He also believed that management and production practices need to

be continuously evaluated and adopted or rejected based on this evaluation if an organization hopes to evolve and survive. The Deming cycle of improvement, or Deming wheel (plan-do-check-act [PDCA] or plan-do-study-act), was adapted from Shewhart's work (Shewhart and Deming 1939).

W. Edwards Deming

Deming was an employee of the U.S. Government Services in the 1930s and 1940s, working with statistical sampling techniques. He became a supporter and student of Shewhart, believing that his techniques could be useful in non-manufacturing environments. Deming applied SPC methods to his work at the National Bureau of the Census to improve clerical operations in preparation for the 1940 population census. In some cases, productivity improved by a factor of six. Deming taught seminars to bring his and Shewhart's work to U.S. and Canadian organizations, where major reductions in scrap and rework resulted. However, after the war Deming's ideas lost popularity in the United States, mainly because demand for all products was so great that quality became unimportant; any product was snapped up by hungry consumers.

After the war Deming went to Japan as an adviser for that country's census. While he was there, the Union of Japanese Scientists and Engineers invited him to lecture on quality control techniques, and Deming brought his message to Japanese executives: Improving quality will reduce expenses while increasing productivity and market share. During the 1950s and 1960s, Deming's ideas were widely known and implemented in Japan, but not in the United States.

The energy crisis of the 1970s and resulting increase in popularity of Japanese automobiles and decline of the U.S. auto industry set the stage for the return of Deming's ideas. The lower prices and higher quality of Japanese automobiles and electronic goods threatened U.S. industries and the economy. The 1980 television documentary *If Japan Can, Why Can't We* (Mason 1980), investigating the increasing competition U.S. industry was facing from Japan, made Deming and his quality ideas known to an even broader audience. Much like the Institute of Medicine report *To Err Is Human* (1999) increased awareness of the need for quality in healthcare, this documentary increased awareness of the need for quality in manufacturing.

Deming's quality ideas reflected his statistical background, but experience in their implementation caused him to broaden his approach. He believed that managers must understand the two types of variation. The first type, variation from special causes, is a result of a change in the system and can be identified or assigned and the problem fixed. The second type, variation from common causes, is a result of the natural differences in the system and cannot be eliminated without changing the system. Although it might be possible to identify the common causes of variation, they cannot be "fixed" without the authority and ability to improve the system for which management is typically responsible.

Deming's quality ideas went far beyond SPC to include a systematic approach to problem solving and continuous process improvement with his PDCA cycle. He also believed that management is ultimately responsible for quality and must actively support and encourage quality "transformations" within organizations. In the preface to *Out of the Crisis*, Deming (1986) writes:

> Drastic changes are required. The first step in the transformation is to learn how to change. . . . Long term commitment to new learning and new philosophy is required of any management that seeks transformation. The timid and the faint-hearted, and people that expect quick results are doomed to disappointment. Whilst the introduction of statistical problem solving and quality techniques and computerization and robotization have a part to play, this is not the solution: Solving problems, big problems and little problems, will not halt the decline of American industry, nor will expansion in use of computers, gadgets, and robotic machinery.
>
> Benefits from massive expansion of new machinery also constitute a vain hope. Massive immediate expansion in the teaching of statistical methods to production workers is not the answer either, nor wholesale flashes of quality control circles. All these activities make their contribution, but they only prolong the life of the patient, they cannot halt the decline. Only transformation of management and of Government's relations with industry can halt the decline.

Out of the Crisis contains Deming's famous 14 points for management (Deming 1986). Although not as well known, he also published an adaptation of the 14 points for medical service (Box 2.1), which he attributed to Drs. Paul B. Batalden and Loren Vorlicky of the Health Services Research Center, Minneapolis.

BOX 2.1
Deming's Adaptation of the 14 Points for Medical Service

1. Establish constancy of purpose toward service.
   a. Define in operational terms what you mean by "service to patients."
   b. Specify standards of service for a year hence and for five years hence.
   c. Define the patients whom you are seeking to serve.
   d. Constancy of purpose brings innovation.
   e. Innovate for better service.
   f. Put resources into maintenance and new aids to production.
   g. Decide whom the administrators are responsible to and the means by which they will be held responsible.
   h. Translate this constancy of purpose to service to patients and the community.
   i. The board of directors must hold onto the purpose.

2. Adopt the new philosophy. We are in a new economic age. We can no longer live with commonly accepted levels of mistakes, materials not

BOX 2.1

Deming's
Adaptation of
the 14 Points
for Medical
Service
(continued)

suited to the job, people on the job who do not know what the job is and are afraid to ask, failure of management to understand their job, antiquated methods of training on the job, and inadequate and ineffective supervision. The board must put resources into this new philosophy, with commitment to in-service training.

3. a. Require statistical evidence of quality of incoming materials, such as pharmaceuticals. Inspection is not the answer. Inspection is too late and is unreliable. Inspection does not produce quality. The quality is already built in and paid for. Require corrective action, where needed, for all tasks that are performed in the hospital.
    b. Institute a rigid program of feedback from patients in regard to their satisfaction with services.
    c. Look for evidence of rework or defects and the cost that may accrue.

4. Deal with vendors that can furnish statistical evidence of control. We must take a clear stand that price of services has no meaning without adequate measure of quality. Without such a stand for rigorous measures of quality, business drifts to the lowest bidder, low quality and high cost being the inevitable result.

    Requirement of suitable measures of quality will, in all likelihood, require us to reduce the number of vendors. We must work with vendors so that we understand the procedures that they use to achieve reduced numbers of defects.

5. Improve constantly and forever the system of production and service.

6. Restructure training.
    a. Develop the concept of tutors.
    b. Develop increased in-service education.
    c. Teach employees methods of statistical control on the job.
    d. Provide operational definitions of all jobs.
    e. Provide training until the learner's work reaches the state of statistical control.

7. Improve supervision. Supervision is the responsibility of the management.
    a. Supervisors need time to help people on the job.
    b. Supervisors need to find ways to translate the constancy of purpose to the individual employee.
    c. Supervisors must be trained in simple statistical methods with the aim to detect and eliminate special causes of mistakes and rework.
    d. Focus supervisory time on people who are out of statistical control and not those who are low performers. If the members of a group are in fact in statistical control, there will be some low performers and some high performers.

e. Teach supervisors how to use the results of surveys of patients.

8. Drive out fear. We must break down the class distinctions between types of workers within the organization—physicians, nonphysicians, clinical providers versus nonclinical providers, physician to physician. Discontinue gossip. Cease to blame employees for problems of the system. Management should be held responsible for faults of the system. People need to feel secure to make suggestions. Management must follow through on suggestions. People on the job cannot work effectively if they dare not offer suggestions for simplification and improvement of the system.

9. Break down barriers between departments. One way would be to encourage switches of personnel in related departments.

10. Eliminate numerical goals, slogans, and posters imploring people to do better. Instead, display accomplishments of the management in respect to helping employees improve their performance.

11. Eliminate work standards that set quotas. Work standards must produce quality, not mere quantity. It is better to take aim at rework, error, and defects.

12. Institute a massive training program in statistical techniques. Bring statistical techniques down to the level of the individual employee's job, and help him to gather information about the nature of his job in a systematic way.

13. Institute a vigorous program for retraining people in new skills. People must be secure about their jobs in the future and must know that acquiring new skills will facilitate security.

14. Create a structure in top management that will push every day on the previous 13 points. Top management may organize a task force with the authority and obligation to act. This task force will require guidance from an experienced consultant, but the consultant cannot take on obligations that only the management can carry out.

The New Economics for Industry, Government, Education (Deming 1994) outlines the Deming System of Profound Knowledge. Deming believed that to transform organizations, the individuals in those organizations need to understand the four parts of his system of profound knowledge:

1. *Appreciation for a system:* everything is related to everything else, and those inside the system need to understand the relationships within it.
2. *Knowledge about variation:* this refers to what can and cannot be done to decrease either of the two types of variation.

3. *Theory of knowledge:* this refers to the need for understanding and knowledge rather than information.
4. *Knowledge of psychology:* people are intrinsically motivated and different from one another, and attempts to use extrinsic motivators can result in unwanted outcomes.

Deming's 14 points and system of profound knowledge still provide a roadmap for organizational transformation.

Joseph M. Juran

Joseph Juran was a contemporary of Deming and a student of Shewhart. He began his career at the famous Western Electric Hawthorne Plant, site of the Hawthorne studies (Mayo 1933) related to worker motivation. Western Electric had close ties to Bell Telephone, Shewhart's employer, because the company was the sole supplier of telephone equipment to Bell.

During World War II, Juran served as assistant administrator for the Lend-Lease Administration. Juran's quality improvement techniques made him instrumental in improving the efficiency of processes by eliminating unnecessary paperwork and ensuring the timely arrival of supplies to U.S. allies.

Juran's Quality Handbook (Juran and Godfrey 1998) was first published in 1951 and remains a standard reference for quality. Juran was one of the first to define quality from the customer perspective as "fitness for use." He compared this definition with the alternative, and somewhat confusing, definition of quality as the number or type of features (Michael Porter's differentiation).

Juran's contributions to quality include the adaptation of the Pareto principle to the quality arena. According to this principle, 80 percent of defects are caused by 20 percent of problems, and quality improvement should therefore focus on the "vital few" to gain the most benefit. The roots of Six Sigma programs can be seen in Juran's (1986) quality trilogy, shown in Table 2.1.

Avedis Donabedian

Avedis Donabedian was born in 1919 in Beirut, Lebanon, and received a medical degree from the American University of Beirut. In 1955, he earned a master's degree in public health from Harvard University. While a student at Harvard, Donabedian wrote a paper on quality assessment that brought his work to the attention of various experts in the field of public health. He taught for a short period at New York Medical College before becoming a faculty member at the School of Public Health of the University of Michigan, where he stayed for the remainder of his career.

Shortly after Donabedian joined the University of Michigan faculty, the U.S. Public Health Service began a project looking at the entire field of health services research. Donabedian was asked to review and evaluate the literature on quality assessment for this project. This work culminated in his

TABLE 2.1
Juran's Quality
Trilogy

	Basic Quality Processes
Quality Planning	Identify the customers, both external and internal. Determine customer needs. Develop product features that respond to customer needs. (Products include both goods and services.) Establish quality goals that meet the needs of customers and suppliers alike, and do so at a minimum combined cost. Develop a process that can produce the needed product features. Prove the process capability—prove that the process can meet quality goals under operating conditions.
Control	Choose control subjects—what to control. Choose units of measurement. Establish measurement. Establish standards of performance. Measure actual performance. Interpret the difference (actual versus standard). Take action on the difference.
Improvement	Prove the need for improvement. Identify specific projects for improvement. Organize to guide the projects. Organize for diagnosis—for discovery of causes. Diagnose to find the causes. Provide remedies. Prove that the remedies are effective under operating conditions. Provide for control to hold the gains.

SOURCE: Juran, J. M. 1986. "The Quality Trilogy." *Quality Progress* 19 (8): 19–24. Reprinted with permission from Juran Institute, Inc.

famous article, "Evaluating the Quality of Medical Care" (Donabedian 1966). This was followed by a three-volume book set, *Exploration in Quality Assessment and Monitoring* (Donabedian 1980, 1982, 1985). Over the course of his career, Donabedian authored 16 books and more than 100 articles focused on quality assessment and improvement in the healthcare sector on such topics as the definition of quality in healthcare, relationship between outcomes and process, effect of clinical decisions on quality, effectiveness of quality programs, and relationship between quality and cost (Sunol 2000).

Donabedian (1980) defined healthcare quality in terms of efficacy, efficiency, optimality, adaptability, legitimacy, equality, and cost. Donabedian (1966) was one of the first to view healthcare as a system composed of structure, process, and outcome, providing a framework for health services

research still used today. He also highlighted many of the issues still faced in attempting to measure structures, processes, and outcomes.

Donabedian defined outcomes as recovery, restoration of function, and survival, but he also included less easily measured outcomes such as patient satisfaction. Process of care consists of the methods by which care is delivered, including gathering appropriate and necessary information, developing competence in diagnosis and therapy, and providing preventive care. Finally, structure is related to the environment in which care takes place, including facilities and equipment, medical staff qualifications, administrative structure, and programs. Donabedian (1966, 188) believed that quality of care is not only related to each of these elements individually, but also to the relationships among them:

> Clearly, the relationships between process and outcome, and between structure and both process and outcome, are not fully understood. With regard to this, the requirements of validation are best expressed by the concept, already referred to, of a chain of events in which each event is an end to the one that comes before it and a necessary condition to the one that follows.

Similar to Deming and Juran, Donabedian advocated the continuous improvement of healthcare quality through structure and process changes supported by outcome assessment.

The influence of Donabedian's seminal work in healthcare can still be seen. Pay-for-performance programs (structure) reward providers for delivering care that meets evidence-based goals assessed in terms of process or outcomes. The 5 Million Lives Campaign (and its predecessor, the 100,000 Lives Campaign; IHI 2006) is a program (structure) designed to decrease mortality (outcome) through the use of evidence-based practices and procedures (process). Not only are assessments of process, structure, and outcome being developed, implemented, and reported, but the focus is shifting toward the more systematic view of healthcare advocated by Donabedian.

TQM and CQI, Leading to Six Sigma

The U.S. Navy is credited with coining the term "total quality management" (TQM) in the 1980s to describe its approach, informed by Japanese models, to quality management and improvement (Hefkin 1993). TQM has come to mean a management philosophy or program aimed at ensuring quality (defined as customer satisfaction) by focusing on quality throughout the organization and product/service life cycle. All stakeholders in the organization participate in a continuous improvement cycle.

TQM (or continuous quality improvement [CQI], as it is referred to in healthcare) is not defined by any one organization or individual and has come to encompass the theory and ideas of such quality experts as W. Edwards Deming, Joseph M. Juran, Philip B. Crosby, Armand V. Feigen-

baum, Kaoru Ishikawa, and Avedis Donabedian. TQM may therefore mean different things to different people, and implementation and vocabulary vary from one organization to the next. Possibly as a result, TQM programs have become less popular in the United States and have been replaced with more codified programs such as Six Sigma, Lean, and the Baldrige criteria.

Six Sigma and TQM are both based on the teachings of Shewhart, Deming, Juran, and other quality experts. Both TQM and Six Sigma emphasize the importance of top management support and leadership, and both focus on continuous improvement as a means to ensure the long-term viability of an organization. The define-measure-analyze-improve-control cycle of Six Sigma has its roots in the PDCA cycle (see Chapter 8) of TQM. Six Sigma and TQM have been described as both philosophies and methodologies. Six Sigma can also be defined as a metric, or goal, of 3.4 defects per million opportunities, whereas TQM never had that specific goal. TQM was never as clearly defined as Six Sigma, nor are certification programs specifically associated with TQM.

TQM was defined mainly by academics and is more abstract and general, whereas Six Sigma has its base in industry—Motorola and GE were early developers—and is more specific, providing a clear framework for organizations to follow. Early TQM efforts focused on quality as the primary goal; improved business performance was thought to be a natural outcome of this goal. Quality departments were mainly responsible for TQM throughout the organization. While Six Sigma makes quality as defined by the customer a primary goal and focuses on tangible results, it also takes into account the effects on business performance. No longer is the focus on quality for quality's sake, but rather a quality focus is seen as a means to improve organizational performance. Six Sigma training in the use of specific tools and techniques provides common understanding and common vocabulary both throughout and across organizations; this method makes quality the goal of the entire organization, not just the quality department.

Basically, Six Sigma took the theory and tools of TQM and codified their implementation, providing a well-defined approach to quality so that organizations could more quickly and easily adopt Six Sigma.

ISO 9000

The ISO 9000 series of standards are primarily concerned with quality management, or how the organization ensures that its products and services satisfy the customer's quality requirements and comply with applicable regulations. The five international ISO 9000 standards were first published in 1987 by the International Organization for Standardization (ISO). In 2002, the ISO 9000 standard was renamed ISO 9000:2000; the ISO 9001, 9002, and 9003 standards were consolidated into ISO 9001:2000; and the ISO 9004 standard was renamed ISO 9004:2000. The standards are concerned with the processes of

ensuring quality rather than the products or services themselves. These standards give organizations guidelines to develop and maintain effective quality systems.

Many organizations require that their vendors be ISO certified. For an organization to be registered as an ISO 9000 supplier, it must demonstrate to an accredited registrar (third-party organizations who are themselves certified as registrars) compliance with the requirements specified in the standard(s). Organizations that are not required by their vendors to be certified can use the standards to ensure quality systems without attempting to be certified.

In the interest of improving the quality of healthcare and reducing or maintaining costs, many automotive manufacturers have begun to require that their healthcare providers be ISO 9000 certified. Driven by this, ISO developed guidelines for implementing ISO 9000 quality management systems in the healthcare sector, "IWA 1, Quality Management Systems—Guidelines for Process Improvements in Health Service Organizations" (ISO 2005). These guidelines were developed through an International Workshop Agreement (IWA) and based on an earlier draft jointly developed by the American Society for Quality and Automotive Industry Action Group, a worldwide industry association representing automotive organizations including Ford, Daimler-Chrysler, and General Motors. The guidelines are based on ISO 9004:2000, supplemented with specific information to aid healthcare organizations in the attainment of ISO certification and the improvement of quality systems.

Baldrige Award

Japanese automobiles and electronics gained market share in the United States during the 1970s because of their higher quality and lower costs. In the early 1980s, both U.S. government and industry believed that the only way for the country to stay competitive was to increase industry focus on quality. The Malcolm Baldrige National Quality Award was established by Congress in 1987 to recognize U.S. organizations for their achievements in quality. It was hoped that the award would raise awareness about the importance of quality as a competitive priority and help to disseminate best practices by providing examples of how to achieve quality and performance excellence. The award was originally given annually to a maximum of three organizations in each of three categories: manufacturing, service, and small business. In 1999 the categories of education and healthcare were added, and in 2002 the first Baldrige Award in healthcare was given. The healthcare category includes hospitals, health maintenance organizations, long-term care facilities, healthcare practitioner offices, home health agencies, health insurance companies, and medical/dental laboratories. By 2005, 83 applications had been submitted in the healthcare category. Two additional categories, nonprofit and government, were added in 2006.

The program is a cooperative effort of government and the private sector. Annual government funding is $5 million, and the actual evaluations are performed by a board of examiners that includes experts from industry, aca-

demia, government, and nonprofits. The examiners volunteer their time to review applications, conduct site visits, and provide applicants with feedback on their strengths and opportunities for improvement in each of seven categories. Additionally, board members give presentations on quality management, performance improvement, and the Baldrige Award.

One of the main purposes of the award is the dissemination of best practices and strategies. Recipients are asked to participate in conferences, provide basic materials on their organizations' performance strategies and methods to interested parties, and answer inquiries from the media. Baldrige Award recipients have gone above and beyond these expectations to give thousands of presentations aimed at educating other organizations on the benefits of using the Baldrige framework and disseminating best practices.

JIT, Leading to Lean and Agile

Just-in-time (JIT) is an inventory management strategy aimed at reducing or eliminating inventory. It is one part of Lean manufacturing, or the Toyota Production System (TPS). The goal of Lean production is to eliminate waste, of which inventory is one form. JIT was the term originally used for Lean production in the United States, where industry leaders noted the success of the Japanese auto manufacturers and attempted to copy it by adopting Japanese practices. As academics and organizations realized that Lean production was more than JIT, inventory management terms like big JIT and little JIT were employed, and JIT production became somewhat synonymous with Lean production. For clarity, the term JIT indicates the inventory management strategy in this text.

After World War II, Japanese industry needed to rebuild and grow, and its leaders wanted to copy the assembly line and mass production systems found in the United States. However, they had limited resources and limited storage space. At the Toyota Motor Corporation, Taiichi Ohno and Shigeo Shingo began to develop what has become known as the Toyota Production System, or TPS. They began by realizing that large amounts of capital dollars are tied up in inventory in the mass production system that was at that time typical.

Ohno and Shingo sought to reduce inventory by various means, most importantly by increasing the flow rate of product. Standardization reduced the number of parts in inventory and the number of tools and machines needed. Processes like single-minute exchange of die (SMED) allowed for quick changeovers of tooling, increasing the amount of time that could be used for production by reducing setup time. As in-process inventory was reduced, large amounts of capital were freed. Customer lead time and uncertainty about orders were reduced as the speed of product flow increased throughout the plant. Because inventory provides a buffer for poor quality, reducing inventory forced Toyota to pay extremely close attention to not only its own quality but suppliers' quality as well. To discover the best ways to fix the system to reduce inventory, management and line workers needed to cooperate, and teams became an integral part of Lean.

When the U.S. auto industry began to be threatened by Japanese automobiles, management and scholars from the United States began to study this "Japanese" system. However, what they brought back were usually the most visible techniques of the program—JIT, kanbans, quality circles—rather than the underlying principles of Lean. Not surprisingly, many of the first U.S. firms that attempted to copy this system failed; however, some were successful. *The Machine that Changed the World* (Womack, Jones, and Roos 1990), a study of Japanese, European, and American automobile manufacturing practices, first introduced the term "Lean manufacturing" and brought the theory, principles, and techniques of Lean to a broad audience.

Lean is both a management philosophy and a strategy. Its goal is to eliminate all waste in the system. Although Lean production originated in manufacturing, the goal of eliminating waste is easily applied to the service sector. Many healthcare organizations are using the tools and techniques associated with Lean to improve efficiency and effectiveness.

Lean is sometimes seen as being more all encompassing than TQM or Six Sigma. In order to be a truly Lean organization, it must have quality. In order to be a quality organization, it does not necessarily need to be Lean. On the other hand, if customers value speed of delivery and low cost, and quality is defined as customer satisfaction, a quality focus would cause an organization to strive to be Lean. Either program would result in the same outcome.

Baldrige, Six Sigma, Lean, and ISO 9000

All of the above are systems or frameworks for performance improvement, and each has a slightly different focus, tools, and techniques associated with it. However, all of these programs emphasize customer focus, process or system analysis, teamwork, and quality, and they are all compatible. As Patrice L. Spath, of Brown-Spath & Associates, says, "They are tools, techniques, methodologies. Jack Welch [former GE CEO who helped make Six Sigma a household word] had a vision—he probably could have used any tools or techniques," she adds. "It's not the graphics you use; it's the vision of the leaders and how you align and excite organizations about achieving that vision" (Homa-Lowry, Bertin-Epp, and Spath 2002).

The importance of the culture of the organization and management's ability to shape that culture cannot be overestimated. The successful implementation of any program or deployment of any technique requires a culture that supports those changes. The leading cause of failure of new initiatives is lack of top management support or lack of buy-in on the part of employees. Management must truly believe that a particular initiative will make the organization better and must demonstrate their support in that belief, both ideologically and financially, to ensure the success of the initiative. Employee buy-in and support will only happen when top management commitment is evident. Communication and training can aid this process, but only true management commitment will ensure success.

Service Typologies

Service typologies, or classification schemes, are primarily used to segment different types of services to gain strategic insight into the management and positioning of a particular service (Cook, Goh, and Chung 1999). The focus of these service typologies varies. A few are based on ownership type (e.g., nonprofit). A large number are based in a customer/marketing perspective with dimensions such as product tangibility or type of customer. Finally, some service typologies are more operational in nature. Here, the focus is on the more operational typologies, where typical dimensions include customer contact, capital intensity, customer involvement, and the service process.

Prior to the 1970s few typologies existed. During the 1980s, a large number of service typologies were put forth by experts in the field. However, this trend tapered off in the 1990s. Beginning with Chase (1978), many of these typologies have level or extent of customer contact as a distinguishing dimension of services. High customer contact services are more difficult to manage and control because they are more variable in nature. Schmenner (1986) extended this idea and developed a service typology similar to the product-process manufacturing typology of Hayes and Wheelwright (1979).

The Schmenner typology distinguishes services based on the degree of labor intensity and the degree of customer interaction and service customization. Labor intensity is the relative proportion of labor as opposed to capital (facility and equipment) found in a process. Customer interaction is the degree to which a customer is involved in the service process, and service customization is the degree to which a particular service offering can be tailored for a particular customer. The resulting matrix was divided into four quadrants, each with a different combination of the distinguishing characteristics: professional service, mass service, service shop, and service factory.

Professional services have high labor intensity and a high degree of customer interaction and service customization. Typically, physicians and lawyers fall into this quadrant of the matrix. Mass services have a high degree of labor intensity and a low degree of interaction and customization. Services found in this quadrant include schools and retail firms. Service shops have a low degree of labor intensity and a high degree of interaction and customization. Hospitals are classified in this quadrant. Finally, service factories have a low degree of labor intensity and a low degree of interaction and customization. Fast-food restaurants such as McDonald's are found in this quadrant.

From a managerial perspective, as labor intensity increases there is a greater need to focus on workforce issues and less on facility, equipment, and technological advances. Firms with low customer interaction and customization may have a more difficult time differentiating themselves in the market. However, costs can be decreased because these organizations benefit from economies of scale and procedures and processes can be highly standardized.

Schmenner argued that many of the successful strategic moves within service industries had been toward the diagonal, as shown in Figure 2.3, and up the diagonal toward a service-factory type of operation. Reducing labor intensity and reducing interaction and customization enabled service firms to become more profitable. Control in service operations is more difficult than in manufacturing operations, and Schmenner saw the trend toward the diagonal as a manifestation of the desire of many service organizations to gain more control of their operations.

More recently, Schmenner (2004) redefined the axes of his matrix (Figure 2.3) based on the theory of swift, even flow (Schmenner 2001; Schmenner and Swink 1998), which asserts that a process is more productive as the stream of materials (customers or information) flows more swiftly and evenly. Productivity rises as the speed of flow through the process increases and falls as the variability associated with that process increases.

In the new service process matrix, the interaction and customization axis is defined as variation. When viewed from an operations standpoint, interaction and customization are sources of variability in a service process. Schmenner was careful to note that the variation is associated with the service process rather than variety in the service output. The interaction and customization axis was redefined as relative throughput time. Throughput time is the period that starts when the customer begins or enters the service process and ends after the service is delivered to the customer and she exits the system. The primary concern here is not the level of labor intensity, but rather how quickly relative to competitors the service can be delivered to the customer.

Rather than being concerned with profitability, this matrix is related to productivity. Examining this new matrix provides insight into service organizations. Profitable service firms can be found anywhere in the matrix. In fact, service organ-

FIGURE 2.3
Service Process Matrix
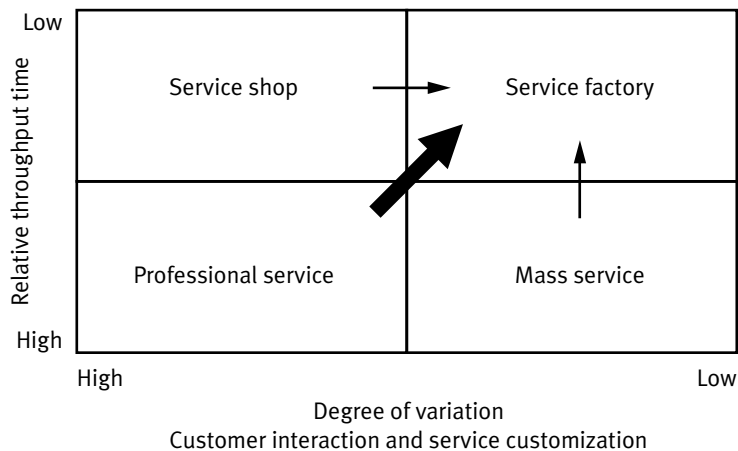
izations may be able to gain competitive advantage by positioning themselves where others are not present. However, service organizations focused on increasing productivity need to move toward and up the diagonal. Reducing variation or decreasing throughput time increases the productivity of the organization.

In the healthcare arena, minute clinics and surgical centers provide examples of how healthcare organizations have reduced variation or increased throughput to move toward and up the diagonal and increase productivity. Other trends in healthcare also support the ideas behind the service process matrix. For example, advanced access scheduling is aimed at increasing patient throughput, and evidence-based medicine is aimed at reducing process variation.

The service process matrix can help to explain the increasing popularity of such initiatives as Lean, Six Sigma, and supply chain management. Lean initiatives are typically aimed at increasing throughput, whereas quality/Six Sigma initiatives are aimed at reducing variation and eliminating errors. The rising popularity of these initiatives can be explained by organizations' desire to move toward and up the diagonal of the service process matrix to increase productivity. Finally, supply chain management can be viewed as an organizaiton's desire to increase throughput and decrease variability in the total supply chain system.

Supply Chain Management

The term "supply chain management" (SCM) was first used in the early 1980s. In 2005, the Council of Supply Chain Management Professionals agreed on the following definition of SCM (Council of Supply Chain Management Professionals 2006):

> Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all Logistics Management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, Supply Chain Management integrates supply and demand management within and across companies.

This definition makes it apparent that SCM is a broad discipline, encompassing activities outside as well as inside an organization.

SCM has its roots in systems thinking. Systems thinking is based on the idea that "everything affects everything else." The need for systems thinking is predicated on the fact that it is possible, and even likely, to optimize one part of a system while the whole system is suboptimal. A current example of a suboptimal system in healthcare can be seen in prescription drugs. In the United States, the customer can optimize his drug purchases (minimize cost) by purchasing drugs from pharmacies located in foreign countries (e.g., Canada, Mexico). Often, these drugs are manufactured in the United States. While the customer has minimized *his* costs, the total supply chain has

additional costs from the extra transportation incurred by shipping drugs to Canada or another foreign country and then back to the United States.

SCM became increasingly important to manufacturing organizations in the late 1990s, driven by the need to decrease costs in response to competitive pressures and enabled by technological advances. As manufacturing became more automated, labor costs as a percentage of total costs decreased, and the percentage of material and supply costs increased. Currently, 70 to 80 percent of the cost of a manufactured good is in purchased materials and services and less than 25 percent is in labor (Bureau of Economic Analysis 2006). Consequently, there are fewer opportunities for reducing the cost of goods through decreasing labor and more opportunities associated with managing the supply chain. Additionally, advances in information technology allowed firms to collect and analyze the information needed to more efficiently manage their supply chains. Beginning with the inventory management systems of the 1970s, including materials requirements planning, followed by the enterprise resource planning systems of the 1990s, SCM was enabled by technology. As industry moved to more sophisticated technological systems for managing the flow of information and goods, the ability to collect and respond to information about the entire supply chain increased, and firms were able to actively manage their supply chains.

In the healthcare industry, interest in SCM has lagged behind that in the manufacturing sector partly because deployment of information technology has been slower, but mainly because of the labor intensity found in most healthcare organizations. Labor still accounts for 50 percent of the cost of healthcare (Bureau of Economic Analysis 2006). There is still opportunity to reduce labor costs. However, SCM is becoming increasingly important with the increasing focus on reducing the costs of healthcare and the need to reduce those costs through the development of more efficient and effective supply chains.

Conclusion

Service organizations in general and healthcare organizations in particular have lagged in their adoption of process improvement philosophies, techniques, and tools of operations management, but they no longer have this option. Healthcare organizations are facing increasing pressures from consumers, industry, and governments to deliver their services in a more efficient and effective manner and need to adopt these "new" philosophies to remain competitive. In healthcare today, organizations such as IHI and AHRQ are leading the way in the development and dissemination of tools, techniques, and programs aimed at improving the quality, safety, efficiency, and effectiveness of the healthcare system. Although these tools and techniques have been adapted for contemporary healthcare, their roots are in the past, and an understanding of this history (Figure 2.4) can enable organizations to move successfully into the future.

FIGURE 2.4 Important Events in Performance Improvement
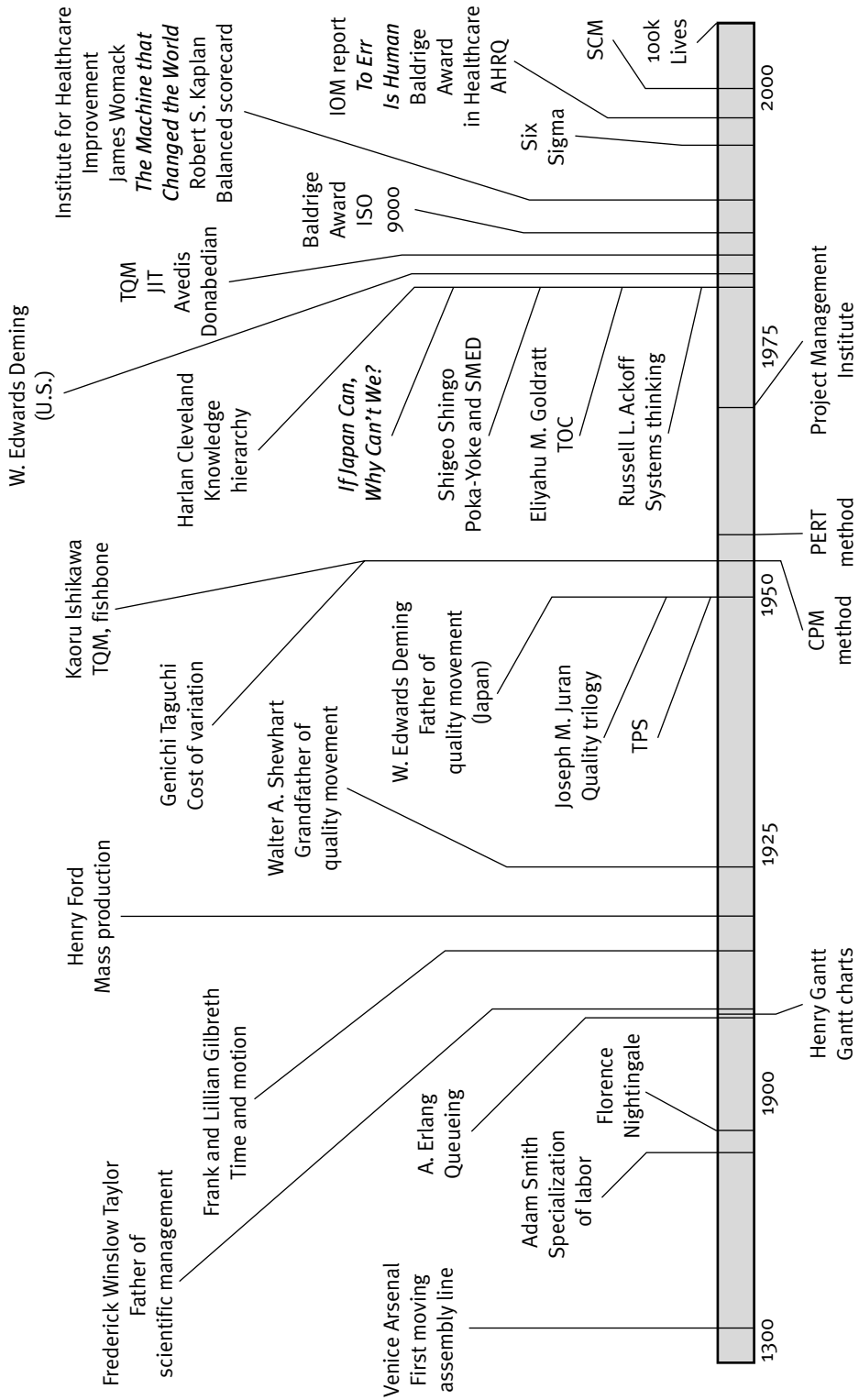
Discussion Questions

1. What is the difference between data, information, knowledge, and wisdom? Give specific examples of each in your own organization.
2. How has operations management changed since its early days as scientific management?
3. What are the major factors leading to increased interest in the use of operations management tools and techniques in the healthcare sector?
4. Why has ISO 9000 certification become important to healthcare organizations?
5. Research firms that have won the Baldrige Award in the healthcare sector. What factors led to their success in winning the award?
6. What are some of the reasons for the success of Six Sigma?
7. What are some of the reasons for the success of Lean?
8. How are Lean initiatives similar to TQM and/or Six Sigma initiatives? How are they different?
9. Why is SCM becoming increasingly important to healthcare organizations?

References

Ackoff, R. L. 1989. "From Data to Wisdom." *Journal of Applied Systems Analysis* 16: 3–9.

Allen, S. 2004. "Emergency Room Recovery." *The Boston Globe* July 18: A1.

Auerbach, A. D. 2001. "Making Health Care Safer: A Critical Analysis of Patient Safety Practices," In *Localizing Care to High-Volume Centers*. Evidence Report/Technology Assessment: No. 43, AHRQ Publication No. 01-E058. Rockville, MD: Agency for Healthcare Research and Quality.

Bellis, M. 2006. "Henry Ford (1863–1947)." [Online information; retrieved 6/8/06.] http://inventors.about.com/library/inventors/blford.htm.

Bureau of Economic Analysis, U.S. Department of Commerce. 2006. "Benchmark Input-Output Accounts." [Online information; retrieved 12/20/06.] http://bea.gov/bea/dn2/home/benchmark.htm.

Centers for Medicare & Medicaid Services (CMS), Office of the Actuary. 2005. *Data from the National Health Statistics Group: NHE Summary Including Share of GDP, CY 1960–2004*. Baltimore: CMS [Online information; retrieved 6/8/06.] www.cms.hhs.gov/NationalHealthExpendData/downloads/nhegdp04.zip.

Chase, R. B. 1978. "Where Does the Customer Fit in a Service Operation?" *Harvard Business Review* 56 (6): 137–42.

Cleveland, H. 1982. "Information as a Resource." *The Futurist* 16 (Dec.): 34–39.

Cohen, I. B. 1984. "Florence Nightingale." *Scientific American* 250 (3): 128–37.

Cook, D. P., C. Goh, and C. H. Chung. 1999. "Service Typologies: A State of the Art Survey." *Production and Operations Management* 8 (3): 318–38.

Council of Supply Chain Management Professionals. 2006. "Supply Chain Management/ Logistics Management Definitions." [Online information; retrieved 12/20/06.] www.cscmp.org/Website/AboutCSCMP/Definitions/Definitions.asp.

Deming, W. E. 1998. "The Deming Philosophy." [Online information; retrieved 6/9/06.] http://deming.ces.clemson.edu/pub/den/deming_philosophy.htm.

———. 1994. *The New Economics for Industry, Government, Education*, 2nd ed. Cambridge, MA: MIT Press.

_____. 1986. *Out of the Crisis.* Cambridge, MA: Cambridge University Press.

Donabedian, A. 1985. *Exploration in Quality Assessment and Monitoring, Volume 3. The Methods and Findings of Quality Assessment and Monitoring: An Illustrated Analysis.* Ann Arbor, MI: Health Administration Press.

———. 1982. *Exploration in Quality Assessment and Monitoring, Volume 2. The Criteria and Standards of Quality.* Ann Arbor, MI: Health Administration Press.

———. 1980. *Exploration in Quality Assessment and Monitoring, Volume 1. Definition of Quality and Approaches to its Assessment.* Ann Arbor, MI: Health Administration Press.

———. 1966. "Evaluating the Quality of Medical Care." *Milbank Memorial Fund Quarterly* 44 (3): 166–206.

Finnie, W. 1997. "Strategies, Systems, and Organizations: An Interview with Russell L. Ackoff." *Strategy and Leadership* 25 (2): 22–28.

Gilbreth, F. B., and E. G. Carey. 1948. *Cheaper by the Dozen.* New York: T.Y. Crowell Co.

Halm, E. A., C. Lee, and M. R. Chassin. 2002. "Is Volume Related to Outcome in Health Care? A Systematic Review and Methodologic Critique of the Literature." *Annals of Internal Medicine* 137 (6): 511–20.

Hayes, R. H., and S. C. Wheelwright. 1979. "Link Manufacturing Process and Product Life Cycles." *Harvard Business Review* 57 (1): 133–40.

Hefkin, D. C. 1993. *The Navy's Quality Journey: Operational Implementation of TQL.* Executive Research Project CS5. Washington, D.C.: Industrial College of the Armed Forces.

Heskett, J. L. 2003. *Shouldice Hospital Ltd.* Harvard Business School Case 9-683-068. Boston: Harvard Business School Publishing.

Homa-Lowry, J., D. Bertin-Epp, and P. L. Spath. 2002. "Enhance Pursuit of Excellence by Integrating ISO 9000, Baldrige: National Baldrige Winners Often Use ISO as Platform." *HealthCare Benchmarks and Quality Improvement* 9 (9): 25–29.

Institute for Healthcare Improvement (IHI). 2006. "Protecting 5 Million Lives from Harm." [Online information; retrieved 6/20/07.] www.ihi.org/IHI/Programs/ Campaign/Campaign.htm.

Institute of Medicine. 1999. *To Err Is Human: Building a Safer Health System.* Washington, D.C.: National Academies Press.

International Organization for Standardization (ISO). 2005. "IWA 1, Quality Management Systems—Guidelines for Process Improvements in Health Service Organizations." [Online white paper; retrieved 10/29/07.] www.iso.org.

International Work Simplification Institute. 1968. "Pioneers in Improvement and Our Modern Standard of Living." *IW/SI News* Sept. 18. [Online information; retrieved 6/8/06.] http://gilbrethnetwork.tripod.com/bio.html.

Juran, J. M. 1986. "The Quality Trilogy." *Quality Progress* 19 (8): 19–24.

Juran, J. M., and A. B. Godfrey. 1998. *Juran's Quality Handbook*, 5th ed. New York: McGraw-Hill.

Lang, W. 1950. *Cheaper by the Dozen*. Beverly Hills, CA: Twentieth Century Fox Film Corporation.

Levy, S. 2003. *Cheaper by the Dozen*. Beverly Hills, CA: 20th Century Fox.

Mason, C. C. 1980. *If Japan Can, Why Can't We?* New York: NBC.

Mayo, E. 1933. *The Human Problems of an Industrial Civilization*. New York: MacMillan.

McCormick, M. 2006. "Immanuel Kant (1724–1804) Metaphysics." [Online information; retrieved 6/8/06.] www.iep.utm.edu/k/kantmeta.htm.

NationMaster.com. 2004. "Venetian Arsenal." [Online information; retrieved 6/8/06.] www.nationmaster.com/encyclopedia/Venetian-Arsenal.

Nelson, D. 1980. *Frederick Taylor and the Rise of Scientific Management*. Madison: University of Wisconsin Press.

NetMBA.com. 2005. "Frederick Taylor and Scientific Management." [Online information; retrieved 6/8/06.] www.netmba.com/mgmt/scientific/.

Neuhauser, D. 2003. "Florence Nightingale Gets No Respect: As a Statistician That Is." *Quality & Safety in Health Care* 12 (4): 317.

Nightingale, F. 1999. *Florence Nightingale: Measuring Hospital Care Outcomes*. Oakbrook Terrace, IL: Joint Commission on Accreditation of Healthcare Organizations.

———. 1858. *Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army*. Presented by request to the Secretary of State for War. Privately printed for Miss Nightingale by Harrison and Sons.

Perkins, J. S. 1997. "Frank B. Gilbreth's Research: The Quest of the One Best Way." *THE QUEST, Newsletter of the Gilbreth Network* 1 (2). [Online information; retrieved 10/29/07.] http://gilbrethnetwork.tripod.com/qv1n2.html.

Ressler, T., and M. Ahrens. 2006. *The Decision Making Book*. Minneapolis, MN: University of St. Thomas.

Schmenner, R. W. 2004. "Service Businesses and Productivity." *Decision Sciences* 35 (3): 333–47.

———. 2001. "Looking Ahead by Looking Back: Swift, Even Flow in the History of Manufacturing." *Production and Operations Management* 10 (1): 87–96.

———. 1986. "How Can Service Businesses Survive and Prosper?" *Sloan Management Review* 27 (3): 21–32.

Schmenner, R. W., and M. L. Swink. 1998. "On Theory in Operations Management." *Journal of Operations Management* 17 (1): 97–113.

Shewhart, W. A. 1931. *Economic Control of Quality of Manufactured Product*. New York: D. Van Nostrand Company, Inc.

Shewhart, W. A., and W. E. Deming. 1939. *Statistical Method from the Viewpoint of Quality Control*. Washington, D.C.: The Graduate School, U.S. Department of Agriculture.

Simkin, J. 2005. "Henry Ford." [Online information; retrieved 6/8/06.] www.spartacus.schoolnet.co.uk/USAford.htm.

Sunol, R. 2000. "Avedis Donabedian." *International Journal for Quality in Health Care* 12 (6): 451–54.

Taylor, F. W. 1911. *The Principles of Scientific Management*. New York: Harper and Row.

Womack, J. P., D. T. Jones, and D. Roos. 1990. *The Machine that Changed the World: Based on the Massachusetts Institute of Technology 5-Million Dollar 5-Year Study on the Future of the Automobile*. New York: Rawson Associates.

Zeleny, M. 1987. "Management Support Systems: Towards Integrated Knowledge Management." *Human Systems Management* 7 (1): 59–70.

3

EVIDENCE-BASED MEDICINE AND PAY-FOR-PERFORMANCE

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

ambulatory care sensitive condition (ACSC)

Bridges to Excellence (BTE)

care management process

certificate of need (CON)

clinical guideline

clinical protocol

custom patient care

evidence-based medicine (EBM)

Integrated Healthcare Association (IHA)

Medicare Payment Advisory Commission (MedPAC)

Minnesota Advantage

Patient Choice

prevention quality indicator (PQI)

pay-for-performance (P4P)

Premier Hospital Demonstration

public reporting

risk adjustment

standard patient care

tiering

Operations Management in Action

In December 2004, the Institute for Healthcare Improvement (IHI) began the 100,000 Lives Campaign, the first-ever national campaign to promote saving a specified number of lives in hospitals by a certain date (June 14, 2006) through the implementation of proven, evidence-based practices and procedures. IHI determined that evidence in the medical literature indicated that by implementing six proven interventions hospitals could prevent 100,000 deaths in the United States. The targeted interventions (IHI 2006) were:

1. Deploy rapid-response teams *by allowing any staff member, regardless of position in the chain of command, to call upon a specialty team to examine a patient at the first sign of decline;*
2. Deliver reliable evidence-based care for acute myocardial infarction *by consistently delivering key measures, including early administration of aspirin and beta-blockers, that prevent patient deaths from heart attack;*
3. Prevent adverse drug events *by implementing medication reconciliation, which requires that a list of all of a patient's medications (even for unrelated illnesses) be compiled and reconciled to ensure that the patient is given (or prescribed) the right medications at the correct dosages—at admission, discharge, and before transfer to another care unit;*
4. Prevent central line infections *by consistently delivering five interdependent, scientifically grounded steps collectively called the "central line bundle";*
5. Prevent surgical-site infections *by reliably delivering the correct perioperative antibiotics, maintaining glucose levels, and avoiding shaving hair at the surgical site; and*
6. Prevent ventilator-associated pneumonia *by implementing five interdependent, scientifically grounded steps collectively called the "ventilator bundle," for example, elevating the head of the hospital bed to between 30 and 45 degrees, thereby dramatically reducing mortality and length of stay in the intensive care unit.*

One of the key interventions was the implementation of rapid-response teams. Julia Herzenberg of Kaiser's San Francisco hospital led its 100,000 Lives Campaign. She helped assemble her hospital's rapid-response team and says (Kertesz 2005):

Several studies have shown that patients show some instability for a period prior to cardiac arrest. Now, often nothing is done. With a rapid response team, if a nurse or even a receptionist is concerned about a patient, they

can call up the rapid response team, which does an assessment as to whether an intervention is needed. The hope is that it will decrease deaths and the number of people going to ICUs.

More than 2,800 hospitals in the United States participated in the 100,000 Lives Campaign, and in June 2006 IHI reported that it had exceeded its target, estimating that 123,000 needless deaths had been averted. IHI has built on this success and has now embarked on a 5 Million Lives Campaign.

Overview

The science of medicine advanced rapidly through the latter half of the twentieth century with advances in pharmaceuticals, surgical techniques, and laboratory and imaging technology and the rapid subspecialization of medicine itself. This "age of miracles" improved health and lengthened life spans. In the mid 1960s, the federal government began the Medicare and Medicaid programs, and this new source of funding fueled the growth and expansion of the healthcare delivery system.

Unfortunately, because this growth was so explosive, many new tools and clinical approaches were initiated that had little scientific merit. As these clinical approaches were used broadly, they became "community standards." In addition, many highly effective, simple clinical tools and techniques were not being used consistently.

In response to these problems, a number of courageous clinicians began the movement that has resulted in what is known today as evidence-based medicine (EBM). According to the Centre for Evidence-Based Medicine (2006), "Evidence-based medicine is the conscientious, explicit and judicious use of current best evidence in making decisions about the care of individual patients." In almost all cases, the broad application of EBM not only improves clinical outcomes for patients but reduces costs in the system as well.

This chapter reviews:

- The history and current status of EBM;
- Standard and custom care;
- Public reporting, pay-for-performance (P4P), and tiering; and
- Issues in the use of P4P and EBM for changing clinician behavior.

EBM is explored in depth, followed by an examination of how payers are using these principles to encourage the use of EBM by clinicians. The operations tools included in other chapters of this book are linked to achieving EBM goals. The chapter concludes with an example of how a relatively simple government

policy based on EBM could be implemented to drive significant cost reductions and quality improvements in the U.S. healthcare system.

The companion web site at ache.org/books/OpsManagement contains many additional references and, because these topics are changing rapidly, will be updated frequently.

Evidence-Based Medicine

The expansion of clinical knowledge has three major phases. First, basic research is done in the lab and with animal models. Second, carefully controlled clinical trials are conducted to demonstrate the efficacy of a new diagnostic or treatment methodology. Third, the clinical trial results are translated into clinical practice.

This final phase of translation is where the system breaks down. As Claude Lenfant (2003, 869), director of the National Heart, Lung, and Blood Institute, has stated:

> Regardless of the reasons for this phenomenon—structural, economic or motivational—the result is the same: we are not reaping the full public health benefits of our investment in research. . . And it is not just recent research results that are not finding their way into clinical practices and public health behaviors, there is plenty of evidence that "old" research outcomes have been lost in translation as well.

Lenfant cites the poor application of beta-blockers for heart attack patients as an example. Only 62.5 percent of patients were getting this treatment 15 years after its high level of effectiveness had been demonstrated. He cites another simple and inexpensive treatment—aspirin for a variety of cardiovascular diseases—that was being given to just 33 percent of appropriate patients as of 2000. Many other studies have documented this same barrier to the translation of clinical trials to extensive adoption by practitioners.

The cure to this wide variation in practice is the consistent application of EBM. The major tool is the clinical guideline (also known as a protocol), which the Institute of Medicine defines as "systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances" (Timmermans and Mauck 2005, 18). One source for such information is the National Guideline Clearinghouse (2006), a comprehensive database of evidence-based clinical practice guidelines and related documents that contains more than 4,000 guidelines.

What are the barriers to the wider application of EBM? Timmermans and Mauck (2005) postulate that critics of EBM question the science and trials that were used to develop clinical guidelines. Another perceived barrier is the challenge to professional autonomy—the concern that guideline use will

override the patient's specific and unique needs. Another frequently cited criticism is that EBM will decrease variation so much that "natural" discoveries and new clinical approaches will not occur. However, even in the face of these criticisms, many leading clinicians have moved to embrace EBM and consider the current challenge to be discovering the optimal methods to expand its use.

Most guidelines are developed by committees of physicians within professional associations or medical groups based on a review of the salient EBM literature. Once guidelines have been developed, Timmermans and Mauck (2005) advocate for multidisciplinary project teams to customize the guideline and its application to specific organizations. One author of this book (McLaughlin) used this approach at Hennepin County Medical Center in Minneapolis, which now uses clinical guidelines for more than 50 percent of its inpatient care.

Standard and Custom Patient Care

One continuing criticism of EBM is that all patients are unique, and EBM is "cookbook" medicine that only applies to a few patients. EBM proponents counter this argument with simple examples of well-accepted and effective clinical practices that are inconsistently followed. A more productive view of the mix of the art and science in medicine is provided by Bohmer (2005), who suggests that all healthcare is a blend of custom and standard care. Figure 3.1 shows the four currently used models that blend these two approaches.
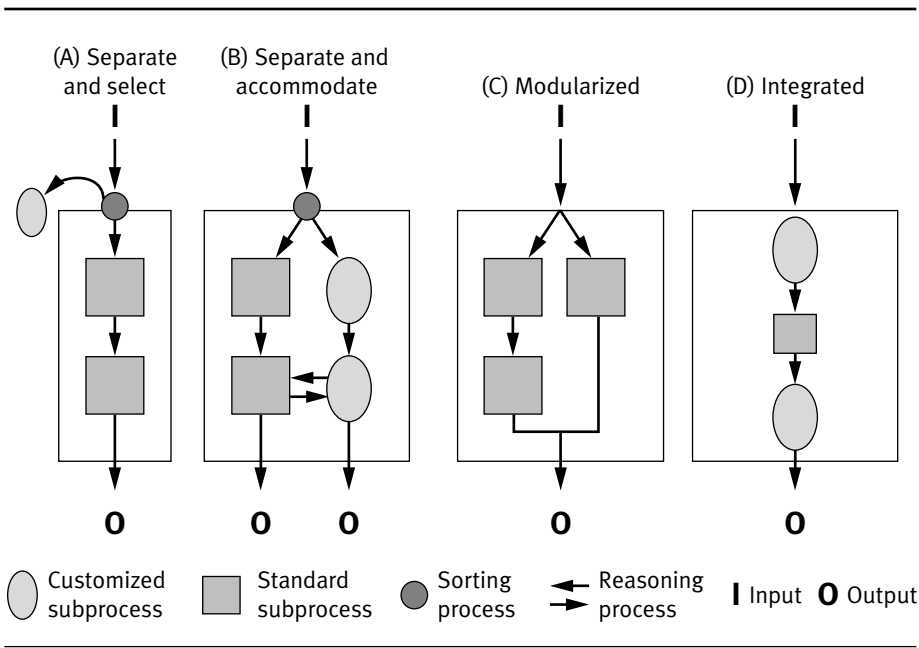
FIGURE 3.1

Four Approaches to Blending Custom and Standard Processes

SOURCE: Bohmer, R. M. J. 2005. "Medicine's Service Challenge: Blending Custom and Standard Care." *Health Care Management Review* 30 (4): 322–30. Used with permission.

Model A (separate and select) provides an initial sorting by patients themselves. Those with standard problems are treated with standard care using EBM guidelines. Examples of this type of system are specialty hospitals for laser eye surgery or walk-in clinics operating in pharmacies and retail outlets. Patients who do not fit the provider's homogenous clinical conditions are referred to other providers who can deliver customized care.

Model B (separate and accommodate) combines the two methods inside one provider organization. The Duke University Health System has developed standard protocols for its cardiac patients. Patients are initially sorted, and those who can be treated with the standard protocols are cared for by nurse practitioners using a standard care model. Cardiologists care for the remainder using custom care. However, on every fourth visit to the nurse practitioner, the cardiologist and nurse practitioner review the patient's case together to ensure that standard care is still the best treatment approach.

Model C (modularized) is used when the clinician moves from the role of care provider to that of architect of care design for the patient. In this case, a number of standard processes are assembled to treat the patient. The Andrews Air Force Base clinic uses this system to treat hypertension patients. "After an initial evaluation, treatment may include weight control, diet modification, drug therapy, stress control, and ongoing surveillance. Each component may be provided by a separate professional and sometimes a separate organization. What makes the care uniquely suited to each patient is the combination of components" (Bohmer 2005, 326).

Model D (integrated) combines both standard care and custom care in a single organization. In contrast to Model B, each patient receives a mix of both custom and standard care based on his or her condition. Intermountain Healthcare System employs this model through the use of 62 standard care processes available as protocols in its electronic health record. These processes cover "the care of over 90% of patients admitted in IHC hospitals" (Bohmer 2005, 326). Clinicians are encouraged to override elements in these protocols when it is in the best interest of the patient. All of these overrides are collected and analyzed, and changes are made to the protocol, which is an effective method to continuously improve clinical care. All of the tools and techniques of operations improvement included in the remainder of this book can be used to make standard care processes operate effectively and efficiently.

Financial Gains from EBM

EBM has the potential to not only improve clinical outcomes but also to decrease total cost in the healthcare system. The Agency for Healthcare Research and Quality (2006) has identified 14 prevention quality indicators (PQIs) (Table 3.1). This set of measures can be used with hospital inpatient dis-

TABLE 3.1
Prevention
Quality
Indicators

Number	Prevention Quality Indicator
1	Diabetes short-term complication admission rate
2	Perforated appendix admission rate
3	Diabetes long-term complication admission rate
4	Chronic obstructive pulmonary disease admission rate
5	Hypertension admission rate
6	Congestive heart failure admission rate
7	Low birth weight
8	Dehydration admission rate
9	Bacterial pneumonia admission rate
10	Urinary tract infection admission rate
11	Angina admission without procedure
12	Uncontrolled diabetes admission rate
13	Adult asthma admission rate
14	Rate of lower-extremity amputation among patients with diabetes

SOURCE: Agency for Healthcare Research and Quality (2006).

charge data to identify ambulatory care sensitive conditions (ACSCs). ACSCs are conditions for which good ambulatory care can potentially prevent the need for hospitalization, or for which early intervention can prevent complications or more severe disease. Each PQI can be targeted for improvement by healthcare providers through the use of guidelines and a mix of standard and custom care.

A study undertaken by the Minnesota Department of Health on inpatient admissions in 2003 showed that $371 million could be saved each year if hospital admissions for ACSCs (9 percent of all inpatient admissions) were eliminated (Gildemeister 2006).

Chronic Care

Casalino et al. (2003) studied how medical groups choose to implement EBM guidelines. They found four major strategies, which they named care management processes (CMPs):

1. case management;
2. guidelines adopted by the group and available in the chart;
3. feedback to physicians on the care they deliver compared with guideline-recommended care; and
4. disease registries to track patients with chronic conditions.

Casalino et al. (2003) surveyed 1,587 physician organizations throughout the United States in 2002 and reviewed the care of patients for four chronic conditions: diabetes, asthma, congestive heart failure, and depression. Of

the 16 possible uses (4 diseases $\times$ 4 CMPs) of CMPs, they found the national average to be 5.1. This low rate of usage (1.27 per disease) has led health plans, private buyers, and government agencies to devise strategies to more rapidly increase the use of EBM and related clinical management strategies.

Tools to Expand the Use of EBM

Organizations that are outside the healthcare delivery system itself have used the increased acceptance of EBM as the basis for new programs focused on encouraging increased implementation of EBM. These programs, sometimes called "value purchasing," include public reporting of clinical results, P4P, and tiered systems of care.

Public Reporting
Although strongly resisted by clinicians for many years, public reporting has come of age. The Centers for Medicare & Medicaid Services (CMS) now report the performance of hospitals, long-term care facilities, and medical groups online (e.g., www.hospitalcompare.hhs.gov). Many health plans also report performance and the prices of providers in their networks to assist their plan members, particularly those with consumer-directed health insurance products.

In addition, community-based public reporting has arisen nationally with medical group reporting in a number of states. Leading examples include:

- California Cooperative Healthcare Reporting Initiative, San Francisco
- Massachusetts Health Quality Partners, Watertown
- Minnesota Community Measurement, St. Paul
- Wisconsin Collaborative for Healthcare Quality, Madison

Although it is a growing field, a number of issues surround public reporting. The first and most prominent is risk adjustment. Most clinicians feel their patients are "sicker" than average and that contemporary risk adjustment systems do not adequately account for this. Patient compliance is another challenging aspect of public reporting. If a doctor follows EBM guidelines for diagnosis and treatment but the patient does not take her medication, should the doctor be given a poor grade?

One of the anticipated effects of public reporting is that patients will use the Internet to shop for quality healthcare products as they might for an automobile or television. Currently, few patients use these public systems to guide their buying decisions. However, clinical leaders do review the public reports and target improvement efforts to areas where they have poor performance compared with their peers.

Hibbard, Stockard, and Tusler (2003) studied public reporting of quality in hospitals in Wisconsin. One group of hospitals had its quality metrics publicly reported, another group received a private report, and a third group received no data. The researchers found a significant difference in the quality improvement activities by those hospitals that had their quality reports made public. For example, in the area of obstetric care the public-report hospitals initiated an average of 3.4 projects, the private-report hospitals had 2.5 projects, and the no-report hospitals had 2.0 projects.

Shaller et al. (2003) recommend five strategies that will be necessary to make public reporting effective and widely used. First, consumers need to be convinced that quality problems are real and can be improved; the mindset of "My doctor provides high-quality care—don't they all?" must be overcome. Second, purchasers and policymakers must ensure that quality reporting is standardized and universal. Third, consumers must be given quality information that is relevant and easy to understand and use. Fourth, dissemination methods need to be optimized. Fifth, quality improvement efforts undertaken by providers need to be rewarded with systems such as P4P and tiering, as described in the following sections.

Pay-for-Performance

Another logical tool to expand the use of EBM is the financing system. Many buyers of healthcare are now installing P4P systems to encourage providers to deliver EBM care.

P4P methods

Rosenthal et al. (2004) identified more than 31 P4P projects covering more than 20 million individuals under way in the United States. In general, P4P systems add payments to the amount that would otherwise be paid to a provider. To obtain these additional payments, the provider must demonstrate that he is delivering care that meets clinical EBM goals. These clinical measures can be either process or outcome measures.

Although many providers would prefer to be measured on outcomes, this approach is difficult to use as some outcomes need to be measured over many years. In addition, some providers have a small number of patients in a particular clinical group so outcome results can vary dramatically. Therefore, process measures are used for many conditions; these measures are backed by extensive EBM literature. For example, a patient with diabetes whose blood pressure is maintained in a normal range will experience fewer complications than one whose blood pressure is uncontrolled. Blood pressure can be measured and reported at every visit, whereas complications will occur infrequently.

Rosenthal et al. (2004) also found that most of the P4P programs in place reward high-performing medical groups and hospitals. This, of course, rewards these organizations for past investments in EBM and systems. However,

if the intent of P4P is to encourage broader use of EBM, payment systems will also need to be developed to provide incentives for providers who improve as well as those who are the highest performers.

The Medicare Payment Advisory Commission (MedPAC) advises Congress on improvements in the Medicare system. As P4P use has grown in commercial markets, MedPAC has made recommendations to improve Medicare's payment systems by adding P4P (Milgate and Cheng 2006). MedPAC determined a number of criteria that should be employed in this policy change. The commission recommends that in a Medicare P4P system evidence-based measures should be readily available and data collection should not be burdensome. In addition, appropriate risk-adjustment tools need to be available and quality goals attainable through operations improvements such as implementing the CMPs of Casalino et al. (2003).

Using these criteria, MedPAC suggested a number of design principles. Providers should be rewarded for both high performance and improvement. Although MedPAC quotes some studies asserting that effective P4P must provide payments of 5 percent to 20 percent in additional funds for physicians and 1 percent to 4 percent for hospitals, MedPAC recommends a P4P payment increase of only 1 to 2 percent for Medicare because of its large presence in the market. Finally, MedPAC recommends that an initial measurement set should be determined but also suggests that this set should be evaluated and updated frequently.

Issues in P4P

P4P is a system that has breached the wall of professional autonomy to influence the day-to-day care of many patients. However, significant system changes frequently result in unintended consequences no matter how well they have been designed. Gosfield (2004) enumerates a number of challenges in current versions of P4P. Once P4P programs change behavior in providers, will payers cease to reward providers? How will P4P incentives be allocated from one disease to another? For example, will the P4P payments for patients with diabetes be higher than for patients with low back pain, and by what rationale if so? Finally, where does the P4P funding come from—is it just another version of a discount or withhold?

Another interesting issue is the intersection of existing payment systems and P4P. For example, if a physician orders additional tests to meet P4P guidelines, will she be penalized by a health plan for excessive testing in aggregate? Another common concern of providers is the trade-off of new revenue versus the additional cost of the administrative resources needed to provide the data. Finally, risk adjustment and patient compliance also complicate the administration of P4P methods.

Roland (2004) has examined the effects of P4P in the United Kingdom and believes early signs in this system point to a number of positive and

negative effects. Positive changes in the system include the expansion of clinical computing systems, the expansion of the role of nurses, increases in clinics that specialize in one disease, and improved health outcomes. Possible challenges in the new P4P system include fragmentation of care for patients with multiple illnesses, loss of a holistic approach, reductions in quality for those conditions not included in the system, and increased administrative costs. Galvin (2006) reports on interesting initial results:

> Physicians were scored on 146 indicators of quality, with clinical quality accounting for more than 50 percent of the total. Each point earned had a financial bonus associated with it, and general practitioners stood to achieve compensation amounting to 30 percent of their salary. This represented $1.8 billion in new money, a 20 percent increase in the National Health Service budget. First-year results are in: [General practitioners] greatly exceeded projections of their performance and achieved an eye-popping mean of more than 91 percent compliance with clinical guidelines. This resulted in payments estimated at $700 million more than expected.

Examples of P4P

P4P is a relatively new and growing phenomenon, so a number of examples now exist but many new organizations are implementing P4P programs every year. Three representative examples are discussed below. Updated examples will be continuously added to this book's companion web site.

Bridges to Excellence

Bridges to Excellence (BTE) is a multistate, multiemployer coalition developed by employers, physicians, healthcare services researchers, and other industry experts (BTE 2006). The BTE program is a grantee of the Robert Wood Johnson Foundation and has a mission of rewarding quality across the healthcare system.

The Physician Office Link BTE program enables physician office sites to qualify for bonuses based on implementation of specific processes to reduce errors and increase quality. Sites can earn up to $50 per year for each patient covered by a participating employer and plan.

Diabetes Care Link enables physicians to achieve one- or three-year recognition for high performance in diabetes care. Qualifying physicians receive up to $80 for each patient with diabetes covered by a participating employer and plan. This program has shown significant quality gains. For participants from 1997 to 2003:

- The average rate of patients with diabetes who had hemoglobin A1c (HbA1c) levels of less than 7 percent increased from 25 percent to 46 percent, an indication that more adults with diabetes are maintaining

proper control of HbA1c (a measure of average blood glucose over the previous three months).

- The rate of patients with diabetes who had controlled low-density lipoprotein (LDL) cholesterol below 100 mg/dL rose from 17 percent to 45 percent.
- The rate of patients with diabetes who were monitored for kidney disease rose from 60 percent to 85 percent.

Cardiac Care Link enables physicians to achieve three-year recognition for high performance in cardiac care. Qualifying physicians are eligible to receive up to $160 for each cardiac patient covered by a participating employer and plan.

Both Diabetes Care Link and Cardiac Care Link offer a suite of products and tools to engage cardiac patients in their care, achieve better outcomes, and identify local physicians who meet high performance standards.

Integrated Healthcare Association

The Integrated Healthcare Association (IHA) is a statewide leadership group of California health plans, physician groups, and healthcare systems, plus academic, consumer, purchaser, and pharmaceutical representatives (IHA 2006). Six participating health plans (representing more than 8 million enrollees) have agreed to participate: Aetna, Blue Cross of California, Blue Shield of California, CIGNA HealthCare of California, Health Net, and PacifiCare. Each plan will use results on common performance measures while still designing its own physician group bonus program.

IHA estimates that $100 million or more could be paid out to physician groups in the first year, based on performance results. A single scorecard incorporating patient satisfaction and clinical measures will be developed for each physician group and made public. Future plans include expanded measures and increased funding.

Premier Hospital Demonstration

A good example of hospital P4P is the Premier Hospital Demonstration. This CMS-sponsored demonstration includes 268 hospitals that are part of the Premier alliance of nonprofit hospitals (Kahn et al. 2006). This P4P project is unique in that hospitals that participate can both gain *and* lose compensation based on their performance in the areas of care for heart attacks, heart failure, pneumonia, coronary artery bypass, and hip and knee replacements. This demonstration may help inform any changes in Medicare's payment system.

Tiering

Tiering is another method being used to encourage the spread of EBM. Tiered systems present health plan members with a number of network or

medical clinic options that have variable premiums or copays. The health plan creates the tiers based on quality and cost. In some cases, tiering is solely based on cost, and health plan members are directed to other public sources for quality information. (See the discussion of public reporting earlier in this chapter.)

Patient Choice

A relatively mature example of tiering is Medica's Patient Choice (Lee 2002). This program was developed in Minnesota and has been replicated in other areas of the United States. In 1997, the Buyers Healthcare Action Group, an organization of Minnesota business leaders, was frustrated by escalating healthcare prices and the lack of focus on quality and launched Choice Plus. This first tiered healthcare delivery network in the country became Medica Health Plan's Patient Choice program and is the longest-running, most well-established plan of its kind.

Patient Choice first divides the total universe of primary care physicians into care systems, the rule being that each primary care physician must be in only one care system. The care system then contracts with specialists, hospitals, and other caregivers and submits a price bid to Patient Choice. Patient Choice combines the price bid and the care system quality scores into an aggregate value score. The care systems with the highest scores are assigned a value ranging from "$" to "$$$." If a health plan member chooses to receive care in the "$" system, she will pay the lowest premium. She will pay the highest premium if she chooses a "$$$" system. Patient Choice believes this system achieves three goals (Medica 2006):

1. Allow providers to be accountable to their patients for their care delivery results and recognize and reward those who deliver quality care;
2. Give employers the ability to use their purchasing dollars to obtain greater value without limiting consumer choice; and
3. Educate consumers to be better managers of their care and empower them to make value-based choices.

Minnesota Advantage

The Minnesota Advantage Health Plan (2006) for state of Minnesota employees builds on the success of Patient Choice. Its cost-sharing features are expected to help the state better control healthcare costs while maintaining flexibility in access to doctors and clinics. Under Minnesota Advantage, state employees share in the cost of specific medical services they obtain by paying varying levels of out-of-pocket costs (deductibles, office visit copayments, and coinsurance).

The state has placed providers into one of four cost levels depending on the care system in which the provider participates and that care system's total

cost of delivering healthcare. A care system includes primary care providers, specialty providers, and hospitals. Although the specialty providers and hospitals may be in a number of care systems, the primary care clinics must be unique, as in Patient Choice. The tiering system is based on the primary care clinic's care system. The amount of cost sharing paid when using healthcare services varies depending on the cost level of the provider chosen by the employee.

The most important aspect of this tiering system is its annual first-dollar deductible (Table 3.2). Minnesota employees have responded to this annual first-dollar deductible incentive by moving their choice of providers to those in the lower-cost tiers. Figure 3.2 shows the distribution of clinic tiers in 2004 and 2006. Providers have responded to this market pressure by increasing their use of generic drugs, extending office hours to minimize emergency department visits, and working with their primary hospitals to reduce hospitalization costs. These operations improvements have moved many clinics into the lower-cost tiers.

Tiering is a powerful motivator for providers, as it shifts market share. This is in contrast to the weaker effects of public reporting and additional P4P revenue. A provider who finds herself in a low-quality, high-cost tier can use the tools contained in this book to identify the causes and charter projects to make the needed improvements in cost and quality.

Vincent Valley Hospital and Health System and P4P

The leadership of Vincent Valley Hospital and Health System (VVH) was encouraged by its board to participate in BTE (2006), an employer-sponsored program that provides participating medical groups with up to $80 a year per patient with diabetes if they are top performers in diabetes care. The specific goals VVH chose to target are those identified by the Institute for Clinical Systems Improvement (2005):

- HbA1c of less than 7 percent
- LDL lower than 100 mg/dL

TABLE 3.2
Minnesota Advantage Health Plan Annual First-Dollar Deductible, 2006

Tier	Individual	Family
1	$30	$60
2	$100	$200
3	$280	$560
4	$500	$1,000

SOURCE: Minnesota Advantage Health Plan (2006).
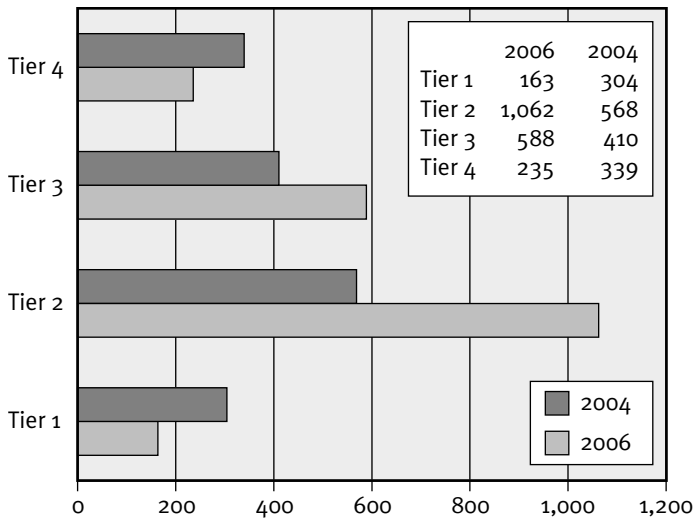
FIGURE 3.2
Number of Primary Care Clinics in Each Payment Tier for Minnesota Advantage, 2004 and 2006

	2006	2004
Tier 1	163	304
Tier 2	1,062	568
Tier 3	588	410
Tier 4	235	339

NOTE: A chi-square test indicates significant differences in tier membership from 2004 to 2006. Membership in Tier 1 decreased significantly, while membership in Tier 2 increased significantly. Although membership in Tier 3 increased significantly, the difference is not of practical significance. Membership in Tier 4 decreased significantly. In summary, very low cost and very high cost providers moved to the middle, or Tier 2, level.

SOURCE: Minnesota Advantage Health Plan (2006).

- Blood pressure lower than 130/80
- Nonsmoking status
- Aspirin for patients over age 40

VVH also chose to use the Institute for Clinical Systems Improvement care guidelines as the basis for implementation (see companion web site).

The operations management tools and approaches detailed in the remainder of this book were used to achieve these goals. Chapter 14 describes how VVH acccomplished this.

Using EBM and Public Reporting to Advance Health Policy: A Proposal

Public policymakers face the urgent challenge of restraining healthcare costs and meeting the Institute of Medicine's six quality aims. Yet there has been strong public support for the policy direction of letting the marketplace drive U.S. health policy aims. This implies that top-down, centralized, government-run healthcare is unlikely in the United States. However, the new policy tools discussed in this chapter could be combined into a solution that involves minimal governmental intrusion into the delivery of healthcare.

The government, at the state level, has a powerful tool that could be used in combination with the growing tools of EBM and public reporting of quality—the certificate of need (CON). In many states, agencies review and grant providers a CON for major capital expenditures for buildings or equipment. The provider would violate state law if it made the expenditure without a CON. However, because the rules governing the granting of CONs are complex and ineffective, CONs are not considered an adequate policy tool today.

CONs could become a powerful tool to control costs and increase quality if they were used in the following manner. First, all providers would be divided into groups (e.g., primary care doctors, specialty doctors, hospitals). Next, each provider would be ranked on costs using Medicare data as aggregated in the various Medicare classification systems (e.g., diagnosis-related groups, ambulatory care groups). Each would also be ranked by aggregate quality measures as publicly reported by CMS and other reporting agencies. The providers would then receive an aggregate ranking based 50 percent on quality and 50 percent on cost.

A major goal of health policy reformers has been to reduce the inflation rate of healthcare services to match the general inflation rate. Therefore, the state could model each provider based on the cost increases and potential savings achieved from their quality performance. States would then separate providers into those that met their policy goal of low inflation and those that did not. When providers wished to expand, only those meeting the policy goals would be granted a CON.

This fairly simple system would face resistance by providers, particularly those with poor performance. It could also harm underserved communities if their sole providers scored poorly in this system. However, this system would have a number of advantages. By using publicly available data, it would be transparent and readily understood by providers, patients, and policymakers. By denying low-performing organizations a CON, it would provide powerful incentives for organizations to improve or lose market share. It would also align rewards in the system with provider values, as all providers want to deliver high-quality, cost-effective care. Finally, it would require a minimal bureaucratic role for government, making it the simple scorekeeper and granter or denier of CONs.

Conclusion

It is unclear how strongly the broad spread of EBM and the new policy tools will influence the delivery of healthcare in the United States. However, it is clear that providers with high-performing, cost-effective operations will be most likely to succeed.

Discussion Questions

1. What are other examples of a care delivery setting with a mix of standard and custom care?
2. Select three PQIs from Table 3.1 and go the National Guideline Clearinghouse to find guidelines that would minimize hospital admissions for these conditions. What would be the challenges in implementing each of these guidelines?
3. Review the four public reporting systems listed earlier in the chapter. How well do they meet the five goals of Shaller et al. for public reporting?
4. What are three strategies to maximize P4P revenue?
5. What projects would you initiate if you were in a primary care clinic that was classified as Tier 4 in the Minnesota Advantage program?
6. Assume you are a lobbyist for the CON policy proposal outlined at the end of the chapter. What would be your arguments to a skeptical state legislature worried about "government-run healthcare?"

References

Agency for Healthcare Research and Quality, U.S. Department of Health and Human Services. 2006. *Guide to Prevention Quality Indicators: Hospital Admission for Ambulatory Care Sensitive Conditions.* [Online information; retrieved 8/30/06.] www.qualityindicators.ahrq.gov/downloads/pqi/pqi_guide_v30a.pdf.

Bohmer, R. M. J. 2005. "Medicine's Service Challenge: Blending Custom and Standard Care." *Health Care Management Review* 30 (4): 322–30.

Bridges to Excellence. 2006. [Online information; retrieved 8/29/06.] www.bridgestoexcellence.org.

Casalino, L., R. Gillies, S. Shortell, J. A. Schmittdiel, T. Bodenheimer, J. C. Robinson, T. Rundall, N. Oswald, H. Schauffler, and M. C. Wang. 2003. "External Incentives, Information Technology, and Organized Processes to Improve Health Care Quality for Patients with Chronic Diseases." *Journal of the American Medical Association* 289 (4): 434–41.

Centre for Evidence-Based Medicine. 2006. [Online information; retrieved 8/30/06.] www.cebm.net.

Galvin, R. 2006. "Pay-for-Performance: Too Much of a Good Thing? A Conversation with Martin Roland." *Health Affairs* Web Exclusives 25: pw412–19.

Gildemeister, S. 2006. "Hospitalizations for Ambulatory Care Sensitive Conditions—Indicator of Opportunities to Improve the Quality of Outpatient Care?" Presented at the Minnesota Health Services Research Conference, Minneapolis, MN, March 7.

Gosfield, A. G. 2004. "P4P Contracting: Bold Leaps or Baby Steps?" *Patient Safety and Quality* Oct./Dec. [Online information; retrieved 8/29/06.] www.psqh.com/octdec04/gosfield.html.

Hibbard, J. H., J. Stockard, and M. Tusler. 2003. "Does Publicizing Hospital Performance Stimulate Quality Improvement Efforts?" *Health Affairs* 22 (2): 84–94.

Institute for Clinical Systems Improvement. 2005. "Diabetes Mellitus, Type 2; Management of." [Online information; retrieved 9/1/06.] hwww.icsi.org/knowledge/detail.asp?catID=29&itemID=182.

Institute for Healthcare Improvement. 2006. "100,000 Lives Campaign." [Online information; retrieved 9/1/06.] www.ihi.org/IHI/Programs/Campaign/.

Integrated Healthcare Association. 2006. [Online information; retrieved 8/30/06.] www.iha.org.

Kahn, C. N., T. Ault, H. Isenstein, L. Potetz, and S. Van Gelder. 2006. "Snapshot of Hospital Quality Reporting and Pay-for-Performance Under Medicare." *Health Affairs* 25 (1): 148–62.

Kertesz, L. 2005. "Bringing Evidence-Based Medicine into the Physician's Office." *Coverage* Nov./Dec. [Online information; retrieved 9/1/06.] www.ahip.org/content/default.aspx?bc=31|130|136|13958|13962.

Lee, K. 2002. "Tiered Provider Networks Bring Promise of Higher Quality Care." *Employee Benefit News* 16 (11): 41–42.

Lenfant, C. 2003. "Clinical Research to Clinical Practice—Lost in Translation?" *New England Journal of Medicine* 349 (9): 868–74.

Medica. 2006. "Patient Choice." [Online information; retrieved 8/30/06.] www.pchealthcare.com/.

Milgate, K., and S. B. Cheng. 2006. "Pay-for-Performance: The MedPAC Perspective." *Health Affairs* 25 (2): 413–19.

Minnesota Advantage Health Plan. 2006. [Online information; retrieved 8/30/06.] www.doer.state.mn.us/ei-segip/health.htm.

National Guideline Clearinghouse. 2006. [Online information; retrieved 8/28/06.] www.guideline.gov/.

Roland, M. 2004. "Linking Physicians' Pay for Quality of Care—A Major Experiment in the United Kingdom." *New England Journal of Medicine* 351 (14): 1448–54.

Rosenthal, M. B., R. Fernandopulle, H. R. Song, and B. Landon. 2004. "Paying for Quality: Providers' Incentives for Quality Improvement." *Health Affairs* 23 (2): 127–41.

Shaller, D., S. Sofaer, S. D. Findlay, J. H. Hibbard, D. Lansky, and S. Delbanco. 2003. "Consumers and Quality-Driven Health Care: A Call to Action." *Health Affairs* 22 (2): 95–101.

Timmermans, S., and A. Mauck. 2005. "The Promises and Pitfalls of Evidence-Based Medicine." *Health Affairs* 24 (1): 18–28.

II

SETTING GOALS AND EXECUTING STRATEGY

4

STRATEGY AND THE BALANCED SCORECARD

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

Balanced Scorecard Collaborative

cause-and-effect statement

diagnosis-related group (DRG)

full-time equivalent (FTE) employee

if-then statement

lagging indicator

leading indicator

performance driver

perspectives

quality function deployment (QFD)

relative value unit (RVU)

strategy map

value proposition

Operations Management in Action

Falls Memorial Hospital in International Falls was down to five days of cash on hand when Mary Klimp became chief executive officer (CEO) in late 1998. On the Canadian border in northern Minnesota, the hospital is 100 miles from any secondary center and 165 miles from a tertiary care center in Duluth. The average daily census was 3.5, and the profit margin was –3 percent.

The leadership created a strategic plan in 1999 and began using the balanced scorecard in 2000. Without outside consulting assistance, they put their balanced scorecard into a spreadsheet and used it with the board, administration, medical staff, department managers, and all staff. The scorecard was also part of the orientation of every new employee and was posted throughout the hospital. The implementation process took nine months, but the CEO estimates that ongoing maintenance takes no more than seven hours a month.

Currently, Falls Memorial measures 16 different performance indicators on its scorecard and has made a remarkable turnaround. As of late 2003, the hospital had nearly 100 days of cash on hand, had a profit margin of 15 percent, and had undertaken extensive capital expansion. The inpatient census had more than tripled to 11. Leadership attributed the improvement primarily to the balanced scorecard.

Mary Klimp says, "My proudest balanced scorecard moment was when I met a housekeeper in the hall who remarked that the balanced scorecard indicated that the hospital was doing great and that she was proud to work here." Klimp believes that this widespread staff understanding of strategy has been an important marketing tool for the hospital.

SOURCE: Mountain States Group 2003.

Overview

Most healthcare organizations have good strategic plans; what frequently fails is their execution. This chapter demonstrates how the balanced scorecard can be used as an effective tool to consistently move strategy to execution. First, traditional management systems are examined and their failures explored. Next, the theory of the balanced scorecard and strategy mapping is reviewed and its application to healthcare organizations explained. Practical steps to implement and maintain a balanced scorecard system are provided. Detailed examples from Vincent Valley Hospital and Health System (VVH) will demonstrate the application of these tools. The companion web site contains templates and explanatory videos that can be used for student exercises or to implement a balanced scorecard in an existing healthcare organization.

This chapter gives readers a basic understanding of balanced scorecards to enable them to:

- Explain how a balanced scorecard can be used to move strategy to action.
- Explain how to monitor strategy from the four perspectives.
- Identify key initiatives to achieve a strategic objective.
- Develop a strategy map linking initiatives.
- Identify and measure leading and lagging indicators for each initiative.
- Use Microsoft PowerPoint and Excel to create strategy maps and scorecards.

Moving Strategy to Execution

The Challenge of Execution

Environmental causes commonly cited for the failure of execution in healthcare organizations include intense financial pressures, complex operating structures, and cultures with multistakeholder leadership that resists change. New and redefined relationships of healthcare providers, particularly physicians, are being accompanied by a rapid growth of medical treatment knowledge and technology. Increased public scrutiny of how healthcare is delivered is leading to the associated rise of consumer-directed healthcare.

No matter how significant these external factors, most organizations flounder on internal factors. Mankins and Steele (2005) studied strategy execution failures in all types of enterprises and identified nine key factors that contribute to poor performance:

1. Inadequate or unavailable resources;
2. Poorly communicated strategy;
3. Poorly defined actions required to execute the strategy;
4. Unclear accountability for execution;
5. Organizational silos;
6. A culture that blocks execution;
7. Inadequate performance monitoring;
8. Inadequate consequences for failure or success; and
9. Poor, uncommitted senior leadership.

These factors also plague healthcare organizations. To gain competitive advantage from its operations, an organization needs an effective system to move its strategies forward. The management systems of the past are poor tools for today's challenging environment.

The day-to-day world of a current healthcare leader is intense (Figure 4.1). Because of ever-present communications technologies (beepers, cell phones,

FIGURE 4.1

The Complex
World of
Today's
Healthcare
Leader

	Urgent operating problems	
Last year's initiative		This year's new initiative

What's on your desk today?

Employee turnover—recruiting		Financial performance pressure
	40 e-mails 10 voice mails	
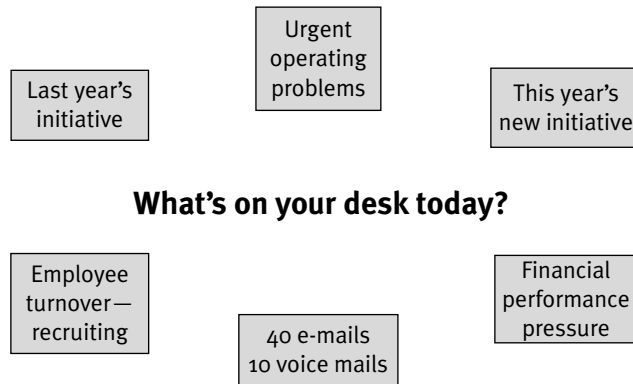
personal digital assistants, Internet, wi-fi), managers float in a sea of inputs and daily challenges.

Healthcare delivery environments are susceptible to focusing on urgent issues rather than addressing important challenges of strategy execution. And although organizations can develop effective project managers (as discussed in Chapter 5), they will fail to compete successfully if they do not place these projects in a broader system of strategy implementation. Fortunately, the balanced scorecard provides a framework and sophisticated mechanisms to move from strategy to execution.

Why Do Today's Management Tools Fail?

Historically, most organizations have been managed with three primary tools: strategic plans, financial reports, and operational reports. Figure 4.2 shows the relationships among these tools. In this traditional system, the first step is to create a strategic plan, which is usually updated annually. Next, a budget and operations or project plan is created. The operational plan is sometimes referred to as the tactical plan; it provides a more detailed level of task descriptions with timelines and expected outcomes. The organization's performance is monitored by senior management through the financial and operational reports. Finally, if deviations from expected performance are encountered, managers take corrective action.

Although theoretically easy to grasp, this management system frequently fails for a number of common reasons. Organizations are awash in operating data, and there is no effort to identify key metrics. The strategic plans, financial reports, and operational reports are all created by different departments, and each report is reviewed in different time frames, often by different managers. Finally, none of the reports connect with one another.

These are the root causes of poor execution. If strategies are not linked to "actionable" items, operations will not change, nor will the financial
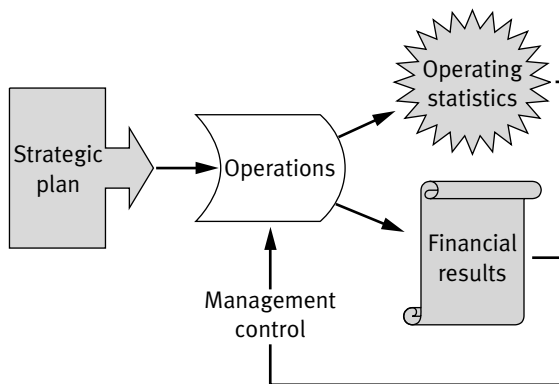
results. In addition, strategic plans are frequently not linked to departmental or individual goals and, therefore, reside only on the shelf in the executive suite.

Many strategic plans contain a logic hole, meaning they lack an explanation of how accomplishing a strategic objective will provide a specific financial or operational outcome. For example:

- Strategic objective: increase the use of evidence-based medicine (EBM)
- Expected outcome: increased patient satisfaction

Although this proposition may seem correct on the surface, the logic to connect the use of EBM to patient satisfaction is unclear. In fact, patient satisfaction may decrease if providers consistently meet EBM guidelines by counseling patients on personal lifestyle issues (e.g., "Will you stop smoking?"or "You need to lose weight").

Frequently, the time frame of strategy execution is also problematic. Financial reports tend to be timely and accurate but only reflect the current reporting period. Unfortunately, the review of these reports does not encourage the long-term strategic allocation of resources (e.g., a major capital expenditure) that may require multiple-year investments. A good current-month financial outcome is probably due to an action that occurred many months in the past. The cumulative result of these problems is poor execution, leading to poor outcomes.

Robert Kaplan and David Norton
In the early 1990s, Kaplan and Norton undertook a study to examine how companies measure their performance. The growing sophistication of company-wide information systems was beginning to provide senior management with executive information systems, which could provide sophisticated displays and "dashboards" of company performance. The original purpose of Kaplan and Norton's study was to understand and document this trend.

However, their study uncovered a number of reporting practices that many leading companies were using to measure their performance. These firms looked at their operations from a number of perspectives that, in total, provided a "balanced scorecard." The essential elements of this work were first reported in *The Balanced Scorecard: Translating Strategy into Action* (Kaplan and Norton 1996) and *The Strategy-Focused Organization* (Kaplan and Norton 2001).

The key element of the balanced scorecard is, of course, balance. An organization can be viewed from many perspectives, but Kaplan and Norton identified four common perspectives from which an organization must examine its operations (Figure 4.3):

1. Financial;
2. Customer;
3. Internal process and innovation; and
4. Employee learning and growth.

As an organization is viewed from each perspective, different measures of performance are important. Every perspective in a complete balanced scorecard contains a set of objectives, measures, targets, and actions. Each measure in each perspective must be linked to the organization's overall strategy.

The indicators of performance in each of the four perspectives must be both leading (predicting the future) and lagging (reporting on performance today). Indicators must also be obtained from inside the organization and from the external environment.

Although many think of the balanced scorecard as a reporting technique, its true power comes from its ability to link strategy to action. Balanced scorecard practitioners develop strategy maps that link projects and actions to outcomes in a series of maps. These maps display the "theory of the company" and can be evaluated and fine-tuned with many of the quanti-

FIGURE 4.3
The Four Perspectives in the Balanced Scorecard
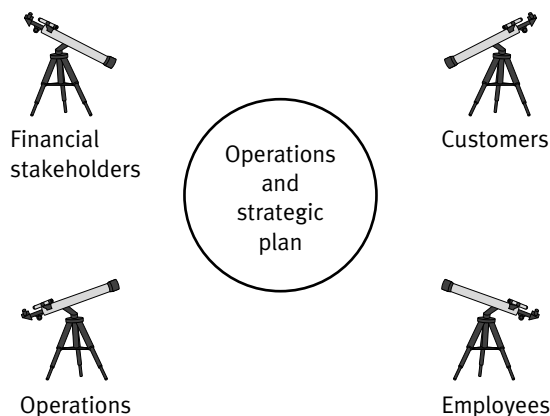
tative techniques described in Chapter 6. Kaplan and Norton (2001) have expanded their system of constructing strategy maps in *The Strategy-Focused Organization*.

The Balanced Scorecard in Healthcare

The balanced scorecard and its variations have been adopted by leading healthcare organizations, many of which are listed by the Balanced Scorecard Collaborative at www.bscol.com. The Collaborative is dedicated to the world-wide awareness, use, enhancement, and integrity of the balanced scorecard as a value-added management process. It has given its Hall of Fame award to two healthcare organizations: Duke Children's Hospital (Durham, NC) and Saint Mary's Duluth Clinic (Duluth, MN).

Inamdar and Kaplan (2002) reviewed the use of the balanced score-card in healthcare and concluded that many healthcare organizations are effectively using scorecards to improve their competitive marketing position, financial results, and customer satisfaction.

The Balanced Scorecard as Part of a Strategic Management System
Although it does not substitute for a complete strategic management system, the balanced scorecard is a key element in such a system and provides an effective tool to move an organization's strategy and vision into action. The development of a balanced scorecard leads to the clarification of strategy and communicates and links strategic measures throughout an organization. Organizational leaders can plan projects, set targets, and align strategic initiatives during the creation of the balanced scorecard. If used properly, the balanced scorecard can also enhance strategic feedback and learning.

Elements of the Balanced Scorecard System
A complete balanced scorecard system will have the following elements, explained in detail below:

- Organizational mission, vision, and strategy
- Perspectives
    - Financial
    - Customer
    - Internal business process
    - Learning and growing
- Strategy maps
- Strategic alignment—top to bottom
- Processes for identifying targets, resources, initiatives, and budgets
- Feedback and the strategic learning process

Mission and Vision

The balanced scorecard system presupposes that an organization has an effective mission, vision, and strategy in place. For example, the mission of VVH is "to provide high-quality, cost-effective healthcare to our community." Its vision is: "Within five years, we will be financially sound and will be considered the place to receive high-quality care by the majority of the residents of our community." To accomplish this vision, VVH has identified six specific strategies:

1. Recruit five new physicians;
2. Expand the outpatient imaging center;
3. Revise the VVH web site to allow self-scheduling by patients;
4. Increase the volume of obstetric care;
5. Renegotiate health plan contracts to include performance incentives; and
6. Improve emergency department operations and patient satisfaction.

Box 4.1 lists many common healthcare organizational strategies.

BOX 4.1
Common
Healthcare
Organizational
Strategies

In a study on the use of the balanced scorecard in healthcare delivery organizations, Inamdar and Kaplan (2002) identified the following strategies that connect to each organization's scorecard:

• Achieve financial strength.
• Develop reputation or brand image.
• Grow patient volume through market analysis and customer focus.
• Achieve operational excellence and demonstrate value through improved measurement systems.
• Form strategic alliances and partnerships, especially with physicians.
• Develop infrastructure to offer and integrate across the continuum of care through enhancing information technology capabilities.

Zelman, Pink, and Matthias (2003) found that rural hospitals were using balanced scorecards to support the following strategies:

• Modernize facilities
• Recruit and retain clinical staff
• Improve cash flow
• Recruit and retain physicians
• Improve inpatient census
• Upgrade financial and information systems
• Improve Medicaid reimbursement
• Improve the collection process

The VVH example is used throughout this chapter to demonstrate the use of the balanced scorecard. The two strategies that will be examined in depth are increasing the volume of obstetric care and improving emergency department operations and patient satisfaction.

With an effective strategic plan in place, the next step is to begin evaluating its implementation as viewed from each of the four perspectives (financial, customer, operational, and learning and growing). Placing a perspective at the top of a balanced scorecard strategy map means that results in this perspective contain the final outcomes desired by an organization. In most organizations, the financial view is the top-most perspective. Therefore, the initiatives undertaken in the other three perspectives should result in positive financial performance for the organization.

"No margin, no mission" is still a true statement for nonprofit healthcare organizations. Nonprofit healthcare institutions need operating margins to provide financial stability and capital. However, some organizations prefer to position the customer (patient) as the top perspective. In that case, the initiatives undertaken in the other three perspectives will result in positive patient outcomes. (Modifications to the classic balanced scorecard are discussed at the end of this chapter.)

Financial Perspective

Although the other three perspectives and their associated areas of activity should lead to outstanding financial performance, there are initiatives that can be undertaken within the financial perspective by themselves. Although the focus of this book is not directly on healthcare finance, some general strategies should always be under consideration by an organization.

If an organization is in a growth mode, the focus should be on increasing revenue to accommodate this growth. If it is operating in a relatively stable environment, the organization may choose to emphasize profitability. If the organization is both stable and profitable, the focus can shift to investment—in both physical assets and human capital. Another major strategy in the financial domain is the diversification of both revenues and expenditures to minimize financial risk.

Revenue growth

An organization that is in a growth mode should be engaged in developing and deploying new products. Imaging centers are a current example of the rapid introduction of ever more effective technologies. Another growth strategy is to find new uses for an existing technology. For example, VVH is planning to use its existing web site to allow patients to schedule their own appointments, expecting that this will increase ambulatory care revenue.

A growing organization will seek new customers and markets. An example is placing primary care clinics where the population is experiencing rapid growth. Developing partnerships is another growth strategy. The newest growth strategy in healthcare is consumer-directed pricing. If an organization

can price a consumer-sensitive service such as magnetic resonance imaging scans correctly, it will increase both volume and revenue. Public reporting of costs and quality were explored in depth in Chapter 3.

Cost reduction—productivity

In most cases, cost reductions will improve financial performance. Chapters 6 through 13 provide tools for improving processes and reducing costs. However, other important strategies should also be evaluated.

The first is to redefine the channel mix. In other words, deliver services in another mode. The use of e-mail and group visits are two examples redefining channel mix in primary care. The advanced use of new communication and information technologies (ITs) will allow creative healthcare organizations to rethink the channels they use to deliver services.

A second, frequently overlooked, cost management strategy is to reduce overhead costs. All nonoperating costs should be scrutinized carefully to ensure that they are contributing to the achievement of organizational outcomes.

Asset utilization and investment strategy

Balance sheet management is also part of the financial perspective. Managing working capital assets such as accounts payable, inventory, and accounts receivable is part of this perspective. One of the most complex processes in healthcare is that of sending and collecting a bill. These systems are amenable to the process improvement tools in Chapters 6 through 11.

Another balance sheet strategy is to improve asset allocations. Does one invest more in buildings or equipment? Can an IT system be shared by more than one department? The analysis of these questions is well documented in *Healthcare Finance: An Introduction to Accounting and Financial Management* (Gapenski 2005); the initiatives and projects that surround such trade-offs should be part of an organization's balanced scorecard.

Risk management through diversity

The final key financial strategy is to minimize risk by increasing diversity. The more diverse an organization's revenue sources, the less likely it is that a significant change in any one source will have a major impact on the organization. Diversification of payers is difficult to achieve but should always be attempted. Product lines can be expanded in both clinical areas (e.g., emergency, birthing center, internal medicine) and delivery models (e.g., inpatient, ambulatory, stand alone).

Geographic expansion is a classic diversification strategy. However, the greatest opportunity for diversification today may be innovative retail strategies to attract market share from the newly empowered consumer. Box 4.2 lists many common metrics used to measure performance from the financial perspective.

- Percent of budget—revenue
- Percent of budget—expense
- Days in accounts receivable
- Days of cash on hand
- Collection rate
- Return on assets
- Expense per relative value unit (RVU)
- Cost per surgical case
- Case-mix index
- Payer mix
- Growth, revenue, expense, and profit—product line
- Growth, revenue, expense, and profit—department
- Growth, revenue, and cost per adjusted patient day
- Growth, revenue, and cost per physician full-time equivalent (FTE)
- Price competitiveness on selected services
- Research grant revenue

BOX 4.2

Metrics to Measure Performance from the Financial Perspective

Customer Perspective and Market Segmentation

The second perspective is to view an organization's operations from the customer's point of view. In most healthcare operations, the customer is the patient. Integrated health organizations, however, may have insurance or health plan delivery vehicles; their customers are then employers or the government. Many hospitals and clinics also consider their community, in total, as the customer. The physician could also be seen as the customer in many hospital organizations.

Once the general customers are identified, it is helpful to segment them into smaller groups and determine the "value" proposition that will be delivered to each customer segment. Example market segments are patients with chronic illnesses (e.g., diabetes, congestive heart failure), obstetric care, sports medicine, cancer care, emergency care, Medicaid patients, small employers, and referring primary care physicians.

Customer measures

Once market segments have been determined, a number of traditional measures of marketplace performance may be applied, the most prominent being market share. Customers should be individually tracked and measured in terms of both retention and acquisition, as it is always easier to retain an existing customer than to attract a new one. Customer satisfaction and profitability are also useful measures. Box 4.3 displays a number of common customer metrics.

BOX 4.3

Metrics to
Measure
Performance
from the
Customer
Perspective

- Patient care volumes
  - By service, type, and physician
  - Turnover—new patients and those exiting the system
- Physician
  - Referral and admission rates
  - Satisfaction
  - Availability of resources (e.g., operating suite time)
- Market share by product line
- Clinical measures
  - Readmission rates
  - Complication rates
  - Compliance with evidence-based guidelines
  - Medical errors
- Customer service
  - Patient satisfaction
  - Waiting time
  - Cleanliness—ambience
  - Ease of navigation
  - Parking
  - Billing complaints
- Reputation
- Price comparisons relative to competitors

Customers: The value proposition

Organizations create value to retain old customers and attract new ones. Each market segment may require products to have different attributes to maximize the particular value proposition. For example, it may be important to be a price leader for outpatient imaging, as many patients will be paying for this service via a healthcare savings account. For another segment—emergency services, for example—speed of delivery may be critical. The personal relationship of provider to patient may be important in primary care but not as important in anesthesiology.

Image and reputation are particularly strong influences in consumer behavior and can be a competitive advantage for specialty healthcare services. Careful understanding of the value proposition in an organization will lead to effective metrics and strategy maps in the balanced scorecard system. Chapter 13 offers a number of examples of how the value proposition operates in competitive tiered systems.

Vincent Valley Hospital and Health System's value proposition

VVH has developed a value proposition for its obstetric services. Its market segment is "pregnant women, aged 18 to 35." VVH believes the product attributes for this market should be:

- quick access to care;
- warm and welcoming facilities;
- customer relations characterized by strong and personal relationships with nurses, midwives, and doctors; and
- an image of high-quality care that will by supported by an excellent system for referrals and air transport for high-risk deliveries.

VVH determined that the following metrics would be used to measure each of these attributes:

- the time from arrival to care in the obstetric suite;
- a patient survey of facility attributes;
- a patient survey of satisfaction with staff; and
- percent of high-risk newborns referred and transported, and the clinical outcomes of these patients.

The main value proposition for emergency care was identified as reduced waiting time. Following internal studies, competitive benchmarking, and patient focus groups, it was determined that VVH's goal would be to have fewer than 10 percent of its emergency department patients wait more than 30 minutes for care.

Internal Business Process Perspective

The third perspective in the balanced scorecard is that of internal business processes or operations—the primary focus of this book. According to Kaplan and Norton (1996), the internal business process perspective has three major components: innovation, ongoing process improvement, and post-sale service.

Innovation

A well-functioning healthcare organization will have a purposeful innovation process. Unfortunately, many health organizations today can only be characterized as reactionary. They respond to new reimbursement rules, government mandates, or technologies introduced through the medical staff. Bringing thoughtful innovation into the life cycle is one of the most pressing challenges contemporary organizations face.

The first step in an organized innovation process is to identify a potential market segment. Then, two primary questions need to be answered: (1) What benefits will customers value in tomorrow's market? and (2) How can the organization innovate to deliver these benefits? Once these questions have been researched and answered, product creation can commence.

Quality function deployment (Chapter 8) can be a useful tool for new product or service development. If a new service is on the clinical leading edge, it may require additional research and testing. A more mainstream service could

require competitor research and review of the clinical literature. The principles of project management (Chapter 5) should be used throughout this process until the new service is operational and stable.

Standard innovation measures used in many industries outside healthcare include percent of sales from new products, percent of sales from proprietary products, new product introductions per year, time to develop new products, and time to break even.

Healthcare operations tend toward stability (bordering on being rigid), and therefore, a major challenge is simply ensuring that all clinical staff use the latest and most effective diagnostic and treatment methodologies. However, in the coming era of consumer-directed healthcare, those organizations with a well-functioning new product development process will clearly have a competitive advantage.

Ongoing process improvement

The case for process improvement and operations excellence is made throughout this book. The project management system (Chapter 5) and process improvement tools (Chapters 6 through 11) are key to these activities. The strategic effect of process improvement and maintaining gains is discussed in Chapter 14.

Post-sale service

The final aspect of the operations perspective is the post-sales area, an area poorly executed in most healthcare delivery organizations. Sadly, the most common post-sale contact with a patient may be an undecipherable or incorrect bill.

Good post-service systems provide patients with follow-up information on the service they received. Patients with chronic diseases should be contacted periodically with reminders on diet, medication use, and the need to schedule follow-up visits. An outstanding post-sale system also finds opportunities for improvement in the service as well as possible innovations for the future. Open-ended survey questions, such as "From your perspective, how could our organization improve?" or "How else can we serve your healthcare needs?" can point to opportunities for improvement and innovation. Box 4.4 lists common metrics used to measure operational performance.

BOX 4.4
Metrics to
Measure
Performance
from the
Operational
Perspective

- Average length of stay—case-mix adjusted
- FTE/adjusted patient day
- FTE/diagnosis-related group (DRG)
- FTE/RVU
- FTE/clinic visit
- Waiting time inside clinical systems
- Access time to appointments

BOX 4.4
Metrics to
Measure
Performance
from the
Operational
Perspective
(continued)

- Percent value-added time
- Utilization of resources (e.g., operating room, imaging suite)
- Patients leaving emergency department without being seen
- Operating room cancellations
- Admitting process performance
- Billing system performance
- Medication errors
- Nosocomial infections
- National Quality Forum (2002) "never events"

Vincent Valley Hospital and Health System internal business processes

VVH decided to execute four major projects to move its birthing center and emergency department strategies forward. The birthing center projects were to remodel and redecorate labor and delivery suites, contract with a regional health system for emergency transport of high-risk deliveries, and begin pre-delivery tours of labor and delivery facilities by nursing staff. The emergency department project was to execute a Lean analysis and kaizen event to improve patient flow.

Learning and Growing Perspective

The final perspective from which to view an organization is learning and growing. To effectively execute a strategy, employees must be motivated and have the necessary tools to succeed. Therefore, a successful organization will make substantial investments in this aspect of their operations. Kaplan and Norton (1996) identified three critical aspects of learning and growing: employee skills and abilities, necessary IT, and employee motivation.

Employee skills and abilities

Although employees in healthcare usually come to their jobs with general training in their technical field, continuous updating of skills is necessary. Some healthcare organizations are effective in ensuring that clinical skills are updated but neglect training in other vital processes (e.g., purchasing systems, organization-wide strategies). A good measure of the attention paid to this area is the number of classes conducted by the organization or an outside contractor. Another important measure is the breadth of employee occupations attending these classes. For example, do all employees from doctors to housekeepers attend organization-wide training?

Necessary IT

Most healthcare workers are "knowledge workers." The more immediately and conveniently information is available to them, the more effectively they

will be able to perform their jobs. Process redesign projects frequently use IT as a resource for automation and information retrieval. Measures of automation include number of employees having easy access to IT systems, percentage of individual jobs that have an automation component, and speed of installation of new IT capabilities.

Employee motivation

A progressive culture and motivated employees are clearly competitive advantages; therefore, it is important to monitor these with some frequency. Measures of employee satisfaction include:

- Involvement with decisions
- Recognition for doing a good job
- Access to sufficient information to do the job well
- Active encouragement of creativity and initiative
- Support for staff-level functions
- Overall satisfaction with the organization
- Turnover
- Absenteeism
- Training hours per employee

Data for many of these measures are typically collected with employee surveys.

These three aspects of learning and growing—employee skills, IT, and motivation—all contribute to employee satisfaction. A satisfied employee is also productive and will remain with the organization. Employee satisfaction, productivity, and loyalty make outstanding organizational performance possible.

Vincent Valley Hospital and Health System learns and grows

VVH realized its employees needed new skills to successfully execute some of its projects, so it engaged training firms to provide classes for all staff (Table 4.1).

TABLE 4.1
VVH Improvement Projects and Associated Training

Project	Employees Involved	Training
Begin predelivery tours of labor and delivery facilities by nursing staff	Obstetric nursing and support staff	Customer service and sales
Execute a Lean analysis and kaizen event to improve patient flow in the emergency department	Managers and key clinicians in the emergency department	Lean tools (Chapter 9)

Linking Balanced Scorecard Measures to Strategy

Once expected objectives and their related measures are determined for each perspective, the initiatives to meet these goals must be developed. An initiative can be a simple action or a large project. However, it is important to logically link each initiative to the desired outcome through a series of cause-and-effect statements. These are usually constructed as "if-then" statements that tie each initiative together and contribute to the outcome, for example:

- *If* the wait time in the emergency department is decreased, *then* the patient will be more satisfied.
- *If* an admitting process is improved through the use of automation, *then* the final collection rate will improve.
- *If* an optically scanned wrist band is used in conjunction with an electronic health record, *then* medication errors will decline.

Each initiative should have measures associated with it, and every measure selected for a balanced scorecard should be an element in a chain of cause-effect relationships that communicate the organization's strategy.

Outcomes and Performance Drivers

Selecting appropriate measures for each initiative is critical. There are two basic types of indicators. Outcome indicators, familiar to most managers, are also termed "lagging indicators" because they result from earlier actions. Outcome indicators tend to be generic instead of tightly focused. Healthcare operations examples include profitability, market share, and patient satisfaction. The other type of indicator is a performance driver, or "leading indicator." These indicators predict the future and are specific to an initiative and the organization's strategy. For example, a performance driver measure could be waiting time in the emergency department. A drop in waiting time should predict an improvement in the outcome indicator, patient satisfaction.

A common pitfall in developing indicators is the use of measures associated with the improvement project rather than with the process improvement. For example, the fact that a project to improve patient flow in a department is 88 percent complete is not as good an indicator as a measure of the actual change in patient flow, a 12 percent reduction in waiting time. Outcome measures are always preferred, but in some cases, they may be difficult or impossible to obtain.

Because the number of balanced scorecard measures should be limited, identifying measures that are indicators for a complex process is sometimes useful. For example, a seemingly simple indicator such as "time to next appointment" for patient scheduling will track many complex processes within an organization.

Strategy Maps

As discussed, a set of initiatives should be linked together by if-then statements to achieve a desired outcome. Both outcome and performance driver indicators should be determined for each initiative. These can be displayed graphically in a strategy map, which may be most helpfully organized into the four perspectives with learning and growing at the bottom and financial at the top. A general strategy map for any organization would include:

- *If* employees have skills, tools, and motivation, *then* they will improve operations.
- *If* operations are improved and marketing is also improved, *then* customers will buy more products and services.
- *If* customers buy more products and services and operations are run efficiently, *then* the organization's financial performance will improve.

Figure 4.4 shows a strategy map in which these general initiatives are indicated.

The strategy map is enhanced if each initiative also contains the strategic objective, measure used, and target results that the organization hopes to achieve. Each causal pathway from initiative to initiative needs to be as clear and quantitative as possible.

FIGURE 4.4

General Strategy Map
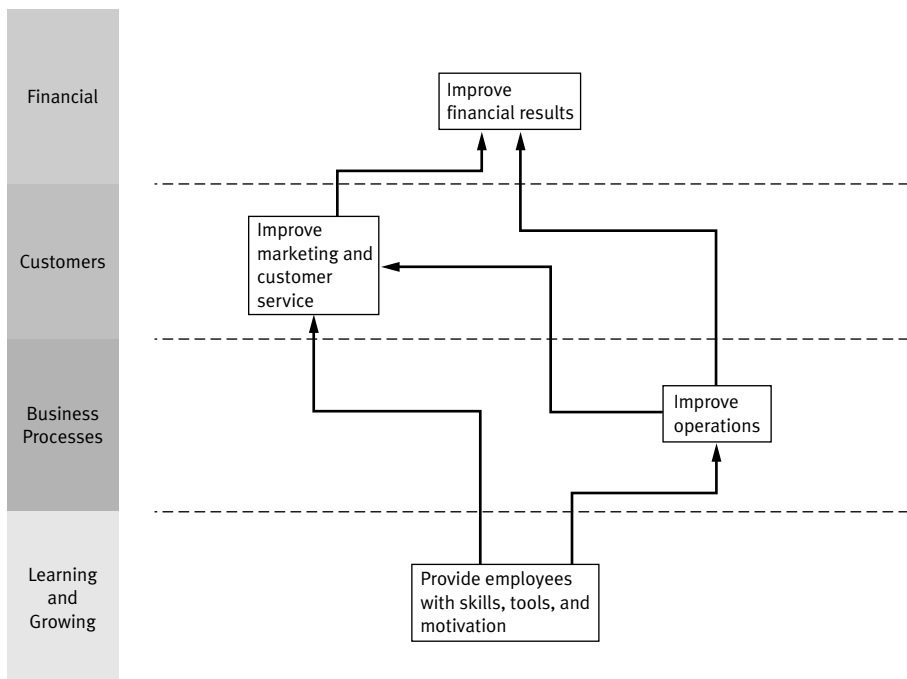
Vincent Valley Hospital and Health System Strategy Maps

VVH has two major areas of strategic focus—the birthing center and the emergency department. Figure 4.5 displays the strategy map for the birthing center.

Recall that VVH had decided to execute three major projects in this area. Other initiatives needed for the successful execution of each project are identified on the map. For instance, for nursing staff to successfully lead expectant mothers on tours of labor and delivery suites, they will need to participate in a customer service training program. After the tours begin, the birthing center will measure potential patients' satisfaction to ensure that the tours are being conducted effectively. Once patients deliver their babies in VVH's obstetric unit, they will again be surveyed on their experience with special questions on the effect of each of these major projects. These leading satisfaction indicators should predict the lagging indicators of increased market share and net revenue.

The second major strategy for VVH was to improve patient flow in the emergency department. Figure 4.6 shows the strategy map for the emergency department.

The first required steps in this strategy are forming a project team (Chapter 5) and learning how to use Lean process improvement tools (Chapter 9). Then, the team can begin analyzing patient flow and implementing changes to
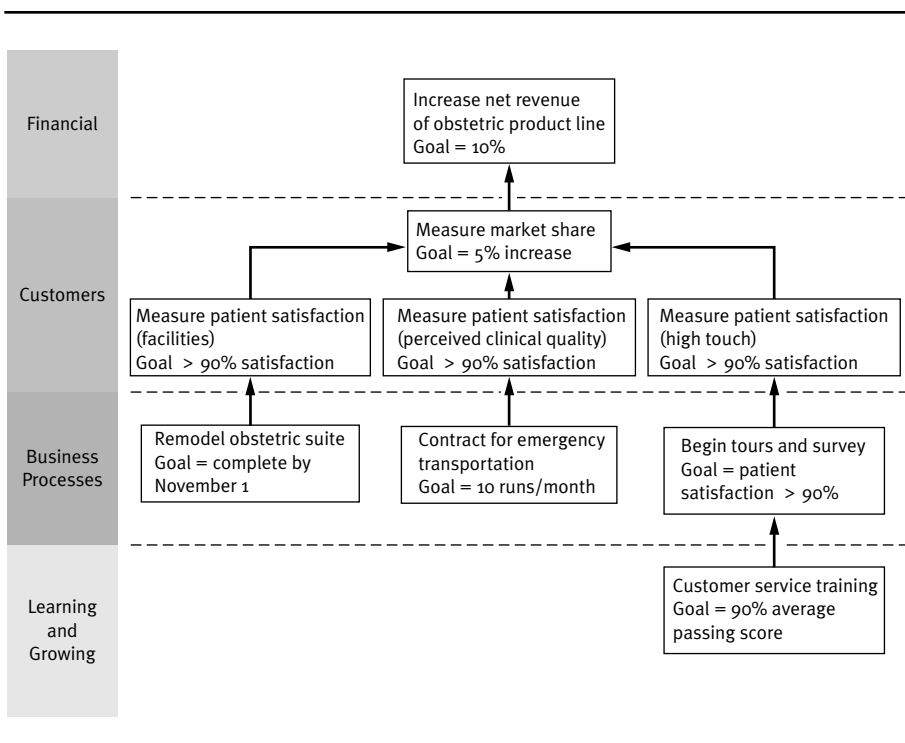
FIGURE 4.5
VVH Birthing Center Strategy Map

FIGURE 4.6
VVH
Emergency
Department
Strategy Map
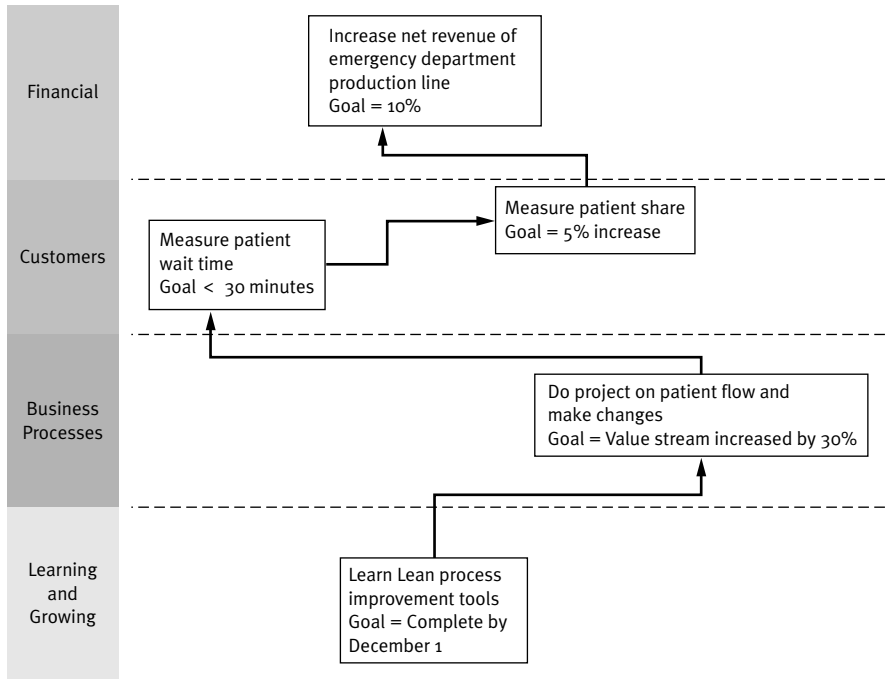
improve flow. VVH has set a goal of reducing the amount of "non–value-added" time by 30 percent. Once this is accomplished, waiting time for 90 percent of patients should not exceed 30 minutes. A reduced waiting time should result in patients being more satisfied and, hence, a growth in market share and increased net revenue. Following are more formal cause-and-effect statements:

- *If* emergency department staff undertakes educational activities to learn project management and Lean, *then* they can effectively execute a patient flow improvement project.
- *If* a patient flow project is undertaken and non–value-added time is reduced by 30 percent, *then* the waiting time for 90 percent of the patients should never exceed 30 minutes.
- *If* the waiting time for most patients never exceeds 30 minutes, *then* they will be highly satisfied and this will increase the number of patients and VVH's market share.
- *If* the emergency department market share increases, *then* net revenue will increase.

The companion web site, ache.org/books/OpsManagement, contains a down-loadable strategy map and linked scorecard. It also has a number of videos

that demonstrate how to use and modify these tools for both student and practitioner use.

Implementation of the Balanced Scorecard

Linking and Communicating

The balanced scorecard can be used at many different levels in an organization. However, departmental scorecards should link to the divisional, and ultimately the corporate, level. Each scorecard should be linked upward and downward. For example, an obstetric initiative to increase revenue from normal childbirth will be linked to the corporate-level objective of overall increased revenue. Sometimes it is difficult to specifically link a departmental strategy map to corporate objectives. In this case, the department head must make a more general linkage by stating how a departmental initiative will influence a particular corporate goal. For example, improving the quality of the hospital laboratory testing system will generally influence the corporate objective that patients should perceive that the hospital provides the highest level of quality care.

The development and operation of scorecards at each level of an organization requires disciplined communication, which can be an incentive for action. Balanced scorecards can also be used to communicate with an organization's external stakeholders. A well-implemented balanced scorecard system will be integrated with individual employee goals and the organization's performance management system.

Targets, Resources, Initiatives, and Budgets

A balanced scorecard strategy map consists of a series of linked initiatives. Each initiative should have a quantitative measure and a target. Initiatives can reside in one department, but they are frequently cross-departmental. Many initiatives are projects, and the process for successful project management (Chapter 5) should be followed. A well-implemented balanced scorecard will also link carefully to an organization's budget, particularly if initiatives and projects are expected to consume considerable operating or capital resources.

The use of the balanced scorecard does not obviate the use of additional operating statistics. Many other operating and financial measures still need to be collected and analyzed. If the performance of any of these measures deviates substantially from its expected target, a new strategy and initiative may be needed. For example, most healthcare organizations carefully track and monitor their accounts receivable. If this financial measure is within industry norms, it probably will not appear on an organization's balanced scorecard. However, if the accounts receivable balance drifts over time and

begins to exceed expectations, a balanced scorecard initiative may be started to address the problem.

Displaying Results

The actual scorecard tracks and communicates the results of each initiative. (Chapter 7 provides examples of many types of visual display.) A challenge for most organizations is to collect the data to display in the scorecard. Because the scorecard should have fewer than 20 measures, a simple solution is to assign this responsibility to one individual who develops efficient methods to collect the data and determines effective methods to display them.

The companion web site includes a straightforward balanced scorecard, built in Excel, that can store and display one year of data. Figure 4.7 shows the cover worksheet of this scorecard.

Ensuring that the Balanced Scorecard Works

The explicit purpose of the balanced scorecard is to ensure the successful execution of an organization's strategy. But what if it does not achieve the desired results? There are two possible causes for this problem.

The first, most obvious, problem is that the initiative itself is not achieving its targeted results. For example, VVH's patient flow project may not be able to decrease non–valued-added time by 30 percent. Therefore, VVH may have to employ another tactic, such as engaging a consultant. It will be important to monitor this measure frequently and post it on the scorecard.

The second, more complex, problem occurs when the successful execution of an initiative does not cause the achievement of the next linked target. For example, although patient satisfaction scores in VVH's obstetric department increased to target levels, VVH may not gain market share. The solution to this problem is to reconsider the cause-and-effect relationships. VVH may need to add an advertising campaign as an initiative to begin to shift market share.

The results and strategy map for an organization should be reviewed at least quarterly and must be reviewed and revised annually, usually as part of the budgeting process. The most advanced way to review the results of a balanced scorecard is to use quantitative tools such as correlation and regression. Pineno (2002) developed an incremental modeling approach to link the following performance measures as part of a hospital balanced scorecard: financial performance, efficiency, liquidity, capital, process quality, outcomes, clinical quality, number of hospital partners, housekeeping, information use, coordination of care, community linkages, readmissions, length of stay, complications, surgery rates, and procedure rates. By varying elements in this linked balanced scorecard model, financial performance can be predicted.

Net revenue

YTD	
Actual	2,877,842
Goal	3,266,667

Patient satisfaction

YTD	
Actual	88%
Goal	90%

Increase in admissions

YTD	
Actual	83
Goal	100

Customer service training tests

YTD	
Actual	94%
Goal	90%

Profit

YTD	
Actual	3.2%
Goal	3.0%

FT admission (%)

YTD	
Actual	16%
Goal	30%

Cost/unit

YTD	
Actual	134
Goal	115

Six Sigma training tests

YTD	
Actual	86%
Goal	90%

FIGURE 4.7
Balanced Scorecard Template (Contained on book companion web site)
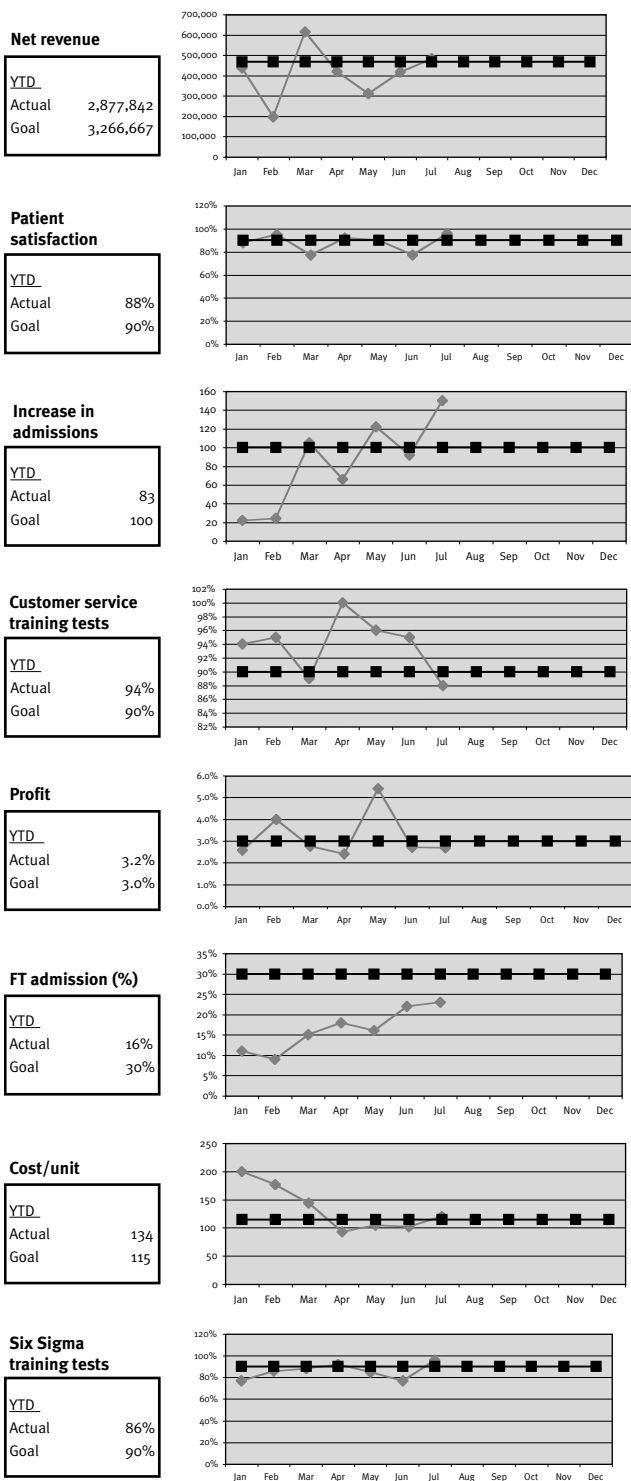
Modifications of the Classic Balanced Scorecard

The balanced scorecard has been modified by many healthcare organizations, most commonly by placing the customer or patient at the top of the strategy map (Figure 4.8). Finance then becomes a means to achieve superior patient outcomes and satisfaction.

Other modifications have been made by leading healthcare organizations. For example, the Mayo Clinic has added new perspectives—including mutual respect and diversity, social commitment, and external environmental assessments—to its scorecard (Curtright and Stolp-Smith 2000).

Implementation Issues

Two common challenges occur when implementing balanced scorecards: (1) determination and development of metrics, and (2) initiative prioritization.

The balanced scorecard is a quantitative tool and, therefore, requires data systems that generate timely information for inclusion. Each initiative on a strategy map should have quantitative measures, which should represent an even mix of leading and lagging measures. Each initiative should have a target as well. However, setting targets is an art: Too timid a goal will not move the organization forward, and too aggressive a goal will be discouraging.

FIGURE 4.8
Rotated
General
Strategy Map
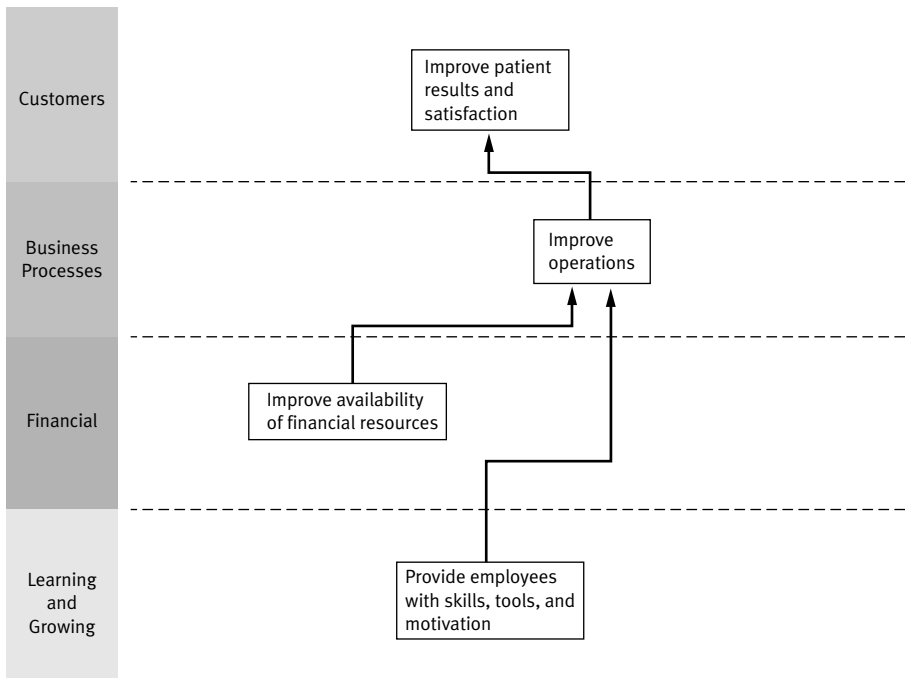
Niven (2002) suggests that a number of sources should be used to construct targets. These include internal company operating data, executive interviews, internal and external strategic assessments, customer research, industry averages, and benchmarking data. Targets can be incremental based on current operating results (e.g., increase productivity in a nursing unit by 10 percent in the next 12 months), or they can be "stretch goals," which are possible but will require extraordinary effort to achieve (e.g., improve compliance with evidence-based guidelines for 98 percent of patients with diabetes). Too many measures and initiatives will confuse a scorecard, and even the most sophisticated organizations therefore limit their measures to 20 or fewer.

The second major implementation challenge is the prioritization of initiatives. Most organizations do not lack for current initiatives or projects, and influential leaders in the organization often propose many more. Niven (2002, 190) suggests a methodology to manage this phenomenon:

1. Inventory all current initiatives taking place within the organization.
2. Map those initiatives to the objectives of the balanced scorecard.
3. Consider eliminating nonstrategic initiatives, and develop missing initiatives.
4. Prioritize the remaining initiatives.

Most organizations will never be able to achieve perfect alignment with their balanced scorecard goals for all of their initiatives. However, the closer the alignment, the more likely the organization's strategic objectives will be achieved.

Conclusion

This text is about how to get things done. The balanced scorecard provides a powerful tool to that end because it:

- links strategy to action in the form of initiatives;
- provides a comprehensive communication tool inside and outside an organization; and
- is quantitatively based, providing a tool for ongoing strategy analysis and improvement.

Discussion Questions

1. What other indicators might be used in each of the four perspectives for public health agencies? For health plans?
2. If you were to add another perspective, what would it be? Draw a strategy map of a healthcare delivery organization and include this perspective.

3. How do you manage the other operations of an organization, those that do not appear on a strategy map or balanced scorecard?
4. How would a department link its balanced scorecard to a corporate scorecard?
5. What methods could be used to involve the customer or patient in identifying the key elements of the balanced scorecard?

Chapter Exercise

View the web videos on ache.org/books/OpsManagement and download the PowerPoint strategy map and Excel worksheet. Develop a strategy map and balanced scorecard for a primary care dental clinic. Do Internet research to determine the challenges facing primary care dentistry, and develop a strategy map for success in this environment.

Make sure that the strategy map includes at least eight initiatives and that they touch the four perspectives. Include targets, and be sure the metrics are a mix of leading and lagging indicators. Develop a plan to periodically review your map to ascertain its effectiveness.

Case Study: St. Mary's Duluth Clinic

An innovative leader in healthcare for northeastern Minnesota and northwestern Wisconsin, St. Mary's Duluth Clinic Health System (SMDC) encompasses 20 clinics, a 350-bed tertiary medical center, two community hospitals, and a specialty care facility. SMDC's medical team of more than 400 physicians and 200 allied healthcare providers work with an experienced staff of more than 6,000 to provide primary care, specialty services, and medical technology to families in their own communities. SMDC began using the balanced scorecard when it was a newly merged organization facing decreased revenues as a result of financial constraints in the healthcare environment, such as the Balanced Budget Act. Since then, the balanced scorecard has become the cornerstone for all strategic decisions, providing direction for daily decision making.

Not only has SMDC made the balanced scorecard the framework for all leadership sessions, but it has also used the balanced scorecard to align its service lines and regional community clinics, link its budget to the strategy, and disseminate strategic awareness to every employee. In addition to improved fiscal strength, SMDC's patients are also feeling better; they now enjoy easier access to the primary care clinics, and their overall satisfaction with both hospitals and clinics continues to climb. With such significant gains, SMDC has created a promising prognosis for its own institution and for those it serves.

FIGURE 4.9 Corporate Strategy Map with Measures: Duluth Clinic Focus, Fiscal Years 2006–2008

FY 06–08 **Corporate Strategy Map with Measures**—Duluth Clinic Focus

Vision:

SMDC will be the best place to work and the best place to receive care

We will pursue our vision through a focus on Quality, Safety, and Value

Customer
To achieve our Quality Vision, how should we appear to our internal and external customers?

C1 Quality Relationships
• Timely Care
• Patient-centered Care
• Equitable Care
• Pt Satisfaction score
• Pt Perception overall quality of doctor care

C2 Clinical Expertise
• Effective Care
• Safe Care

C3 Customer Value
• Efficient Care

Internal Processes
To satisfy our customers, at which operational and quality processes must we excel?

Service Excellence

P2 Provide easy, timely, coordinated access to healthcare services
• Specialty sections meeting access standard (%)
• Primary care open access

P4 Create direct access to specific programs and services

Clinical Excellence

P1 Right patient, right care, right process
• **Pts on continuous opioid treatment who have opioid agreements in force (%)**
• **Pts overdue for INR check (%)**

P5 Design and implement coordinated care models to effectively manage disease processes
• **Pts with optimal diabetes control (%)**
• **Hypertension measure**
• **Well-child measure**

Management Excellence

P6 Optimized physician and staff productivity
• Monthly RVU volume

P7 Excel in efficient and effective operations

P3 Capital investment emphasis in technology and facilities to support clinical and financial objectives
• Performance to epic implementation plan   • Performance to technology replacement plan

Learning and Growth
How will we sustain our ability to change and improve as a system?

L2 Emphasize entity and system missions

L1 Create an environment that has an expectation of consistently delivering quality healthcare

L3 Recruit and develop people to outstanding levels of performance
• Physicians recruited in targeted areas (%)
• Clinical education section meetings held (#)

L4 Engage physician leaders as partners in the success with SMDC
• Sections conducting monthly section/site meetings (%)
• Physician leaders attending leadership sessions (%)

Financial
To financially sustain our mission, on what must we focus?

*Cancer, Cardiovascular, Digestive, Neuromusculoskeletal

F2 Grow key specialty services and programs and stimulate demand for primary care
• Procedure volume for targeted areas
• Surgery volume
• New DC Main specialty patients in target growth areas (#)
• Encounters in all sections (#)
• New Duluth/Sup primary care patients (#)

F3 Restructure regional clinic business and clinical models

F1 Achieve a 3% operating margin by FY08 to sustain our mission and achieve our vision
• DC margin fully allocated
• DC margin without indirect allocations

F4 Redesign Duluth and Superior primary care strategy

F5 Capture earned revenue

SOURCE: St. Mary's/Duluth Clinic Health System. Used with permission.

Examination of the strategy map shows that SMDC has rotated the financial perspective to the bottom and put the customer at the top (Figure 4.9). In addition, many of the initiatives mirror the improvement goals from *Crossing the Quality Chasm* (Institute of Medicine 2001), as discussed in Chapter 1. SMDC has only 19 initiatives on its strategy map, indicating that the organization is focused on those items that are key to moving it forward.

References

Curtright, J. W., and S. C. Stolp-Smith. 2000. "Strategic Performance Management: Development of a Performance Measurement System at the Mayo Clinic." *Journal of Healthcare Management* 45 (1): 58–68.

Gapenski, L. C. 2005. *Healthcare Finance: An Introduction to Accounting and Financial Management*. Chicago: Health Administration Press.

Inamdar, N., and R. S. Kaplan. 2002. "Applying the Balanced Scorecard in Healthcare Provider Organizations." *Journal of Healthcare Management* 47 (3): 179–95.

Institute of Medicine. 2001. *Crossing the Quality Chasm—A New Health System for the 21st Century*. Washington, D.C.: National Academies Press.

Kaplan, R. S., and D. P. Norton. 2001. *The Strategy-Focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment*. Boston: Harvard Business School Press.

———. 1996. *The Balanced Scorecard—Translating Strategy into Action*. Boston: Harvard Business School Press.

Mankins, M. C., and R. Steele. 2005. "Turning Great Strategy into Great Performance." *Harvard Business Review* 83 (7): 64–72.

Mountain States Group. 2003. *Balanced Scorecards for Small Rural Hospitals: Concept Overview and Implementation Guidance*. Publication No. ORHP00346. Health Resources and Services Administration, U.S. Department of Health and Human Services. [Online information; retrieved 8/15/06.] http://tasc.ruralhealth.hrsa.gov/documents/Final%20BSC%20Manual%20edits%2010.18F.pdf.

National Quality Forum. 2002. *Serious Reportable Events in Healthcare: A National Quality Forum Consensus Report*. Publication No. NQFCR01-02. Washington, D.C.: National Quality Forum.

Niven, P. R. 2002. *Balanced Scorecard Step-by-Step: Maximizing Performance and Maintaining Results*. New York: John Wiley & Sons.

Pineno, C. J. 2002. "The Balanced Scorecard: An Incremental Approach Model to Health Care Management." *Journal of Health Care Finance* 28 (4): 69–80.

Zelman, W. N., G. H. Pink, and C. B. Matthias. 2003. "Use of the Balanced Scorecard in Health Care." *Journal of Health Care Finance* 29 (4): 1–15.

Further Reading

Bilkhu-Thompson, M. K. 2003. "A Process Evaluation of a Health Care Balanced Scorecard." *Journal of Health Care Finance* 30 (2): 37–64.

Cleverley, W. O., and J. O. Cleverley. 2005. "Scorecards and Dashboards." *Healthcare Financial Management* 59 (7): 64–69.

Gumbus, A., B. Lyons, and D. E. Bellhouse. 2002. "Journey to Destination 2005." *Strategic Finance* 84 (2): 46–50.

MacStravic, S. 1999. "A Really Balanced Scorecard." *Health Forum Journal* 42 (3): 64–67.

Meyers, S. 2004. "Data in, Safety out." *Trustee* 57 (7): 12–19.

Tarantino, D. P. 2003. "Using the Balanced Scorecard as a Performance Management Tool." *Physician Executive* 29 (5): 69–72.

Wyatt, J. 2004. "Scorecards, Dashboards, and KPIs: Keys to Integrated Performance Measurement." *Healthcare Financial Management* 58 (2): 76–80.

5

PROJECT MANAGEMENT

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

actual cost of work performed (ACWP)

budgeted cost of work performed (BCWP)

budgeted cost of work scheduled (BCWS)

cost performance index (CPI)

critical index (CI)

critical path method

earned value analysis

estimate at completion (EAC)

Gantt chart

Microsoft Project

mitigation plan

network diagram

program evaluation and review technique (PERT)

procurement

project charter

project closure

project control

Project Management Body of Knowledge (PMBOK)

Project Management Professional (PMP)

RASIC chart

request for information (RFI)

request for proposal (RFP)

risk management

schedule performance index (SPI)

slack

stakeholder

statement of work (SOW)

strengths, weaknesses, opportunities, and threats analysis

variance at completion

work breakdown structure (WBS)

Operations Management in Action

The risk of poor project management can be seen in many organizations struggling to implement electronic health records (EHRs). One of the most publicized failures of a large-scale project was a $34 million EHR project at a major West Coast teaching hospital. Although this hospital had an outstanding reputation and delivered leading-edge care, the medical staff voted to turn off their new system after three months and return to paper charting. One leading physician said, "A task that once took three minutes to scribble shorthand at the patient's bedside suddenly devoured 30 to 40 minutes. Who's got five extra hours in a day?"

SOURCE: Connolly 2005.

Overview

Everyone manages projects, whether painting a bedroom at home or adding a 100-bed wing to a hospital. This chapter provides grounding in the science of project management. The major topics covered include:

- Selecting and chartering projects;
- Using stakeholder analysis to set project requirements;
- Developing a work breakdown structure and schedule;
- Using Microsoft Project to develop project plans and monitor cost, schedule, and earned value;
- Managing project communications, change control, and risk; and
- Creating and leading project teams.

After reading this chapter and completing the associated exercises, readers should be able to:

- Create a project charter with a detailed plan for costs, schedule, scope, and performance;
- Monitor the progress of a project, make changes as required, communicate to stakeholders, and manage risks; and
- Develop the skills to successfully lead a project team.

If everyone manages projects, why is there a need to devote a chapter in a healthcare operations book to this topic? The answer lies in the question: Although everyone has life experiences in project management, few healthcare professionals take the time to understand and practice the science and discipline of project management. The ability to successfully move a project forward while meeting time and budget goals is a distinguishing characteristic of a high-quality, highly competitive healthcare organization.

Effective project management provides an opportunity for progressive healthcare organizations to quickly develop new clinical services, fix major operating problems, reduce expenses, and provide new consumer-directed products to their patients.

The problems with poor project management became apparent in the defense industry after World War II. Many new weapons systems were wildly over budget, were late, and did not perform as expected. The automated baggage conveyor system at Denver International Airport is another frequently cited example of poor project management. In 2005, after 10 years of malfunctions and high maintenance costs, it was turned off and baggage is now handled manually.

A response to this problem was the gradual development of project management as a discipline, culminating in the establishment of the Project Management Institute (PMI) in 1969 (www.PMI.org). Today, PMI has more than 110,000 members and more than 50,000 of those are certified as Project Management Professionals (PMPs).

PMI members have developed the Project Management Body of Knowledge (PMBOK) (PMI 2004), which details best practices for successful project management. Much as evidence-based medicine delineates the most effective methods to care for specific clinical conditions, the PMBOK provides science-based, field-tested guidelines for successful project management. This chapter is based on PMBOK principles as applied to healthcare. Healthcare professionals who spend much of their time leading projects should consider using resources available through PMI; for some, PMP certification may be appropriate.

Definition of a Project

A project is a one-time set of activities that culminates in a desired outcome. Therefore, activities that occur repeatedly, for example, making appointments for patients in a clinic, are not projects. However, the installation of new software to upgrade this capability would be a project. A major process improvement effort to reduce phone hold time for patients would also qualify as a project.

Slack (2005) provides a useful tool for determining the need for formal project management (Figure 5.1). Operating issues arise frequently; when simple, they can be fixed immediately by operating staff. More complicated problems can be addressed by using the tools detailed in Chapter 6. However, projects that are complex and have high organizational value need the discipline of formal project management. Many of the strategic initiatives on an organization's balanced scorecard should use the project management methodology.

A well-managed project will include a specified scope of work, expected outcomes and performance levels, budget, and detailed work breakdown tied to a schedule. It will also include a formal change procedure, communications plan, and plan to deal with risk. Finally, all good projects will include a project conclusion process and plan for redeployment of staff.

FIGURE 5.1
When to Use
Project
Management

Complex

↑

Level of
detail and
problem
solving

↓

Simple

Find it,   Problem-solving   Project
Fix it   process   management
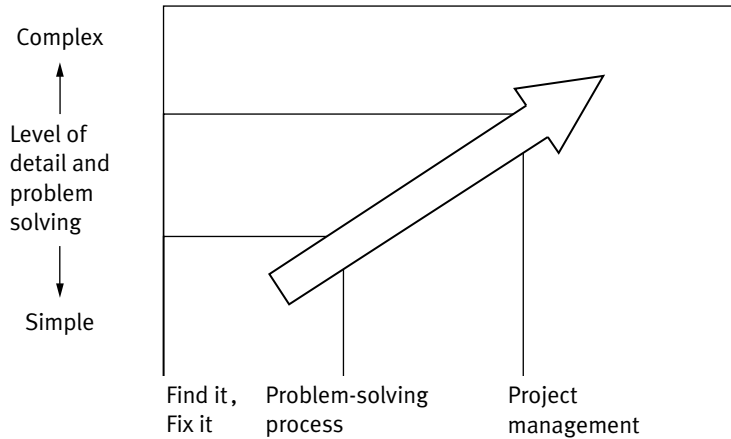
SOURCE: Slack (2005). Used with permission.

Many high-performing organizations will also have a formal executive-level chartering process for projects and a project management office to monitor enterprise-wide project activities. Some healthcare organizations (e.g., health plans) can have a substantial share of their operating resources invested in projects at any one time.

For effective execution of a project, PMI recommends that three elements must be present. A project charter begins the project and addresses stakeholder needs. A project scope statement identifies project outcomes, timelines, and budget in detail. Finally, to execute the project, a project plan must be developed; the plan includes scope management, work breakdown, schedule management, cost management, quality control, staffing management, communications, risk management, procurement, and close-out process. Figure 5.2 displays the relationships among these elements.

Project Selection and Chartering

Project Selection

Most organizations have many projects vying for attention, funding, and senior executive support. The annual budget and strategic planning process serves as a useful vehicle for prioritizing projects in many organizations. The balanced scorecard (Chapter 4) will help guide the identification of worthwhile strategic projects. Other external forces (e.g., new Medicare rules) or clinical innovations (e.g., new imaging technologies), however, will conspire to present an organization's leadership with a list of projects too long for successful implementation. Niven (2005) provides a useful tool to prioritize projects (Table 5.1).

TABLE 5.1
Project
Prioritization
Matrix
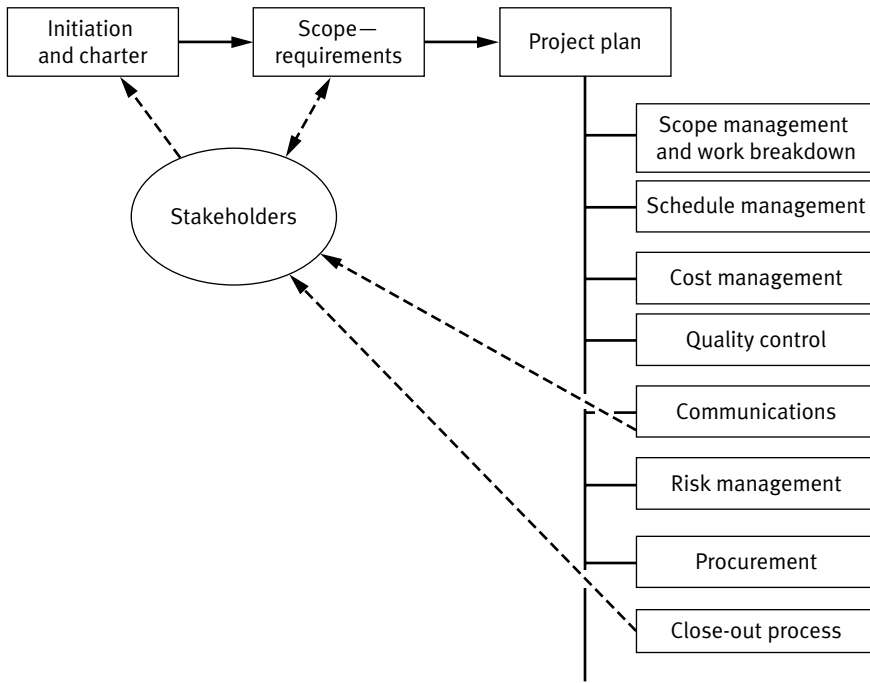
Criteria	Weight	Project A points	Project A score	Project B points	Project B score
Linkage to strategy	45%	7	3.15	1	0.45
Financial gain	15%	5	0.75	10	1.5
Project cost	10%	5	0.50	10	1.0
Key personnel required	10%	8	0.80	10	1.0
Time to complete	10%	8	0.80	10	1.0
Affects other projects	10%	3	0.30	10	1.0
Total			6.30		5. 95

SOURCE: Niven, P. R. 2002. *Balanced Scorecard Step by Step.* Figure 7.2: Prioritizing Balanced Scorecard Initiatives, page 194. Used with permission of John Wiley & Sons, Inc.

To use this tool, each potential project should be scored by a senior planning group based on how well it fits into the organization's strategy, financial benefit and cost, need for key personnel, time required, and positive effect on other projects. A scale of one (low) to ten (high) is usually used. Each criterion is also weighted; the scores are multiplied by their weight for each criterion and summed over all of the criteria. In Table 5.1, Project A has a higher total score due to its importance to the organization's strategy. Such a ranking methodology helps organizations avoid committing resources to projects that may have a powerful internal champion but do not advance the organization's overall strategy. This matrix can be modified with other categories and weights based on an organization's current needs.

Another, less quantitative methodology for evaluating clinical quality improvement projects has been suggested by Mosser (2005):

- How frequently does the disease or condition occur?
- What is the likelihood of success? (For example, is there broad evidence-based clinical research to support a new care process?)
- How large is the performance gap (today versus the ideal) to be closed?

The answers to these questions will guide the prioritization of clinical quality improvement projects.

Project Charter

Once a project is identified for implementation, it needs to be chartered. Four factors interact to constrain the execution of a project charter: time, cost, scope, and performance. A successful project will have a scope that specifies the resulting performance level, how much time it will take, and its budgeted cost. A change in any one of these factors will affect the other three. This can be expressed mathematically as follows:

$$\text{Scope} = f(\text{Time, Cost, Performance})$$

Similarly:

$$\text{Time} = f(\text{Cost, Scope, Performance})$$

and so on.

Figure 5.3 demonstrates these relationships graphically. Here, the area of the triangle is a measure of the scope of the project. The length of each side of the triangle indicates the amount time, money, or performance needed in the project. Because each side of the triangle is connected, changing any of these parameters affects the others. Figure 5.4 shows this same

Cost = f (Performance, Time, Scope)

Performance

Cost

Scope

Time

project with an increase in required performance level and shortened time-lines. With the same scope, this "new" project will incur additional costs.

Although it is difficult to specifically and exactly determine the relationship between all four factors, the successful project manager understands this general relationship well and communicates it to project sponsors. A useful analogy is the balloon: If you push hard on part of it, a different part will bulge out. The classic project management dilemma is an increase in scope without additional time or funding (sometimes termed "scope creep"). Many project failures are directly attributable to ignoring this unyielding formula.

Stakeholder identification and dialogue

The first step in developing a project charter is to identify the stakeholders, in general, anyone who has a stake in the outcome of the project. Key stakeholders on a project include the project manager, customers, users, project team members, any contracted organizations involved, project sponsor, those who can influence the project, and the project management office, if one exists in the organization.

The project manager is the individual held accountable for the project's success and, therefore, forms the core of the stakeholder group. The customer or user of the service or product is an important stakeholder who will influence and help determine the performance of the final product. Even if project team members serve on the project in a limited part-time role, the success of the project reflects on them and, therefore, they become stakeholders. A common

Performance

Cost

Scope

Time

contracting relationship in healthcare involves large information technology (IT) installations provided through an outside vendor, which would also be included as a project stakeholder. A project should always have a sponsor with enough executive-level influence to clear roadblocks as the project progresses; hence, such individuals need to be included in the stakeholder group. A project may be aided or hindered by many individuals or organizations that are not directly part of it; a global systems analysis should be performed (Chapter 1) to identify which of these should be included as stakeholders.

Once stakeholders have been identified, they need to be interviewed by the project manager to develop the project charter. If an important stakeholder is not available, the project manager should interview someone who represents her interests. At this point, it is important to differentiate between the needs and wants of the stakeholders; however, enough detail needs to be gathered to construct the project charter. When the project team is organized, it need not include all stakeholders, but the team should be vigilant in attempting to meet all stakeholder needs. The project team should also be cognizant of the culture of the organization, sometimes defined as "how things get done around here." Projects that challenge an organization's culture will encounter frequent difficulties.

"The project charter is the document that formally authorizes a project. The project charter provides the project manager with the authority to apply organizational resources to project activities" (PMI 2004, 81). A project initiator, or sponsor external to the project, issues the charter and signs it to authorize the start of the project.

Feasibility analysis

An important part of the project charter is determining the project's feasibility. Because the project should have already had an initial prioritization by the senior management team, the link to the organization's strategy has likely already been made. However, this link should be documented in the feasibility analysis. The operational and technical feasibility should also be examined. For example, if a new clinical project requires the construction of new facilities, this may impede its execution. An initial schedule should also be considered, as a needed completion date may be clearly impossible. Finally, both financial benefit and marketplace demand should be considered here. For details on conducting a financial feasibility analysis, see Gapenski (2005). All elements of the feasibility analysis should be included in the project charter document.

Project charter document

The project charter authorizes the project and serves as an executive summary. A formal charter document should be constructed with the following elements:

- Project mission statement;
- Project purpose or justification and linkage to strategic goals;

- High-level requirements that satisfy customers, sponsors, and other stakeholders;
- Assigned project manager and authority level;
- Summary milestones;
- Stakeholder influences;
- Functional organizations and their participation;
- Organizational, environmental, and external assumptions and constraints;
- Financial business case, budget, and return on investment (ROI); and
- Project sponsor with approval signature.

A project charter template is contained on the companion web site.

The initial description of the "scope" of the project is found in the Requirements, Milestones, and Financial sections of the project charter.

A project charter can be illustrated with an example from Vincent Valley Hospital and Health System (VVH). The hospital operates a primary care clinic (Riverview Clinic) in the south suburban area of Bakersville. Recently, the three largest health plans in the area instituted pay-for-performance programs in the areas of diabetes, asthma, congestive heart failure, and generic drug use. The health plans will pay primary care clinics bonuses if they achieve specific levels of performance in these areas. Riverview staff have decided to embark on a project to increase their use of generic drugs; their project charter is displayed in Figure 5.5.

FIGURE 5.5

Project Charter for VVH Generic Drug Project

Project Mission Statement

This project will increase the level of generic drug prescriptions to lower the costs to our patients and increase reimbursements to the clinic.

Project Purpose and Justification

Health plans in Bakersville have begun to provide additional funding to clinics that meet pay-for-performance guidelines. Although a number of chronic conditions are covered by these new payment systems, it is felt that generic drug use should be the first project executed because it is likely to be accomplished in a reasonable time frame with the maximum financial benefit to our patients and the clinic. Once this project has been executed, the clinic will move on to more complex clinical conditions. The team will be able to incorporate what they have learned about some of the barriers to success and methods to succeed on pay-for-performance projects. This project is a part of the larger VVH strategic initiative of maximizing pay-for-performance reimbursement.

High-Level Requirements

Once completed, a new prescribing process will

- Continue to meet patients' clinical needs and provide high-quality care; and
- Increase generic drug use by 4 percent from baseline within six months.

Assigned Project Manager and Authority Level

Sally Humphries, RN, will be the project manager.

Sally has authority to make changes in budget, time, scope, and performance by 10 percent. Any larger change requires approval from the clinic operating board.

Summary Milestones

- The project will commence on January 1.
- A system to identify approved generic drugs will be available on February 15.
- The system will go live on March 15.

Stakeholder Influences

The following stakeholders will influence the project:

- *Clinicians* will strive to provide the best care for their patients.
- *Patients* will need to understand the benefits of this new system.
- *Clinic staff* will need training and support tools.
- *Health plans* should be a partner in this project as part of the supply chain.
- *Pharmaceutical firms* should provide clinical information on the efficacy of certain generic drugs.

Functional Organizations and Their Participation

- Clinic management staff will lead.
- Compcare EHR vendor will perform software modifications.
- VVH IT department will support.
- VVH main pharmacy department will support.

Organizational, Environmental, and External Assumptions and Constraints

- Success depends on appropriate substitution of generic for brand-name drugs.
- Patients need to understand the benefits of this change.
- Health plans need to continue to fund this project over a number of years.
- IT modifications need to be approved rapidly by the VVH central IT department.

Financial Business Case—ROI

The project budget is $61,000 for personnel. Software modifications are included in the master VVH contract and, therefore, have no direct cost to this project. If the 4 percent increase in generic drug use is achieved, the two-year revenue increase should be approximately $75,000.

Project Sponsor with Approval Signature

Dr. Jim Anderson, Clinic President

James Anderson, MD

Project Scope and Work Breakdown

Once a project has been chartered, the detailed work of planning can begin.

Tools

At this point, the project manager should consider acquiring two important tools. The first is the lowest of low tech, the humble three-ring binder. All projects need a continuous record of progress reports, team meetings, approved changes, and so on. A complex project will require many binders, but they will prove invaluable to the project manager. The classic organization of the binders is by date, so the first pages will be the project charter. Of course, if the organization has an effective imaging and document management system, this can substitute for the binders.

The second tool is project management software. Although many options are available, the market leader is Microsoft Project, which is referred to throughout the remainder of the chapter. Microsoft Project is part of the Microsoft Office suite and may already be on many computers. If not, a demonstration copy can be downloaded from Microsoft. The companion web site for this book provides additional explanation and videos related to the use of Project, along with detailed illustrations of the software's use for the Riverview Clinic generic drug project. Go to ache.org/books.OpsManagement, Chapter 5, to view a video on starting Project and setting its global parameters.

Project management software is not essential for small projects, but it is helpful and almost required for any project that lasts longer than six months and involves a large team of individuals. Although the Riverview Clinic generic drug project is relatively small, Project software is used to manage it to provide an illustration of the program's applicability.

Scope

The project scope determines what falls inside and outside the scope of a project. The starting point for developing a scope document is the project charter, although the scope statement is much more detailed than the description contained in the project charter. The project manager will want to revisit many of the same stakeholders to acquire more detailed inputs and requirements. A simple methodology suggested by Lewis (2000) is to interview stakeholders and ask them to list the three most important outcomes of the project, which can be combined into project objectives. Lewis also suggests that objectives be specific, achievable, measurable, and comprehensible to stakeholders. In addition, they should be stated in terms of time-limited "deliverables." The objective "improve the quality of care to patients with diabetes" is a poor one. "Improve the rate of foot exams by 25 percent in one year for patients with diabetes" is a much better objective.

Austin and Boxerman (2003) provide a detailed interview methodology for clinical IT projects in *Information Systems for Health Care Management*. Quality function deployment is also a useful tool for specifying objectives and customer requirements (Chapter 8).

In scope creation, it is important to avoid expanding the scope of the project: "While we are at it, we might as well ____." These ideas, sometimes called "gold plating," tend to be some of the most dangerous in the world of project management. The scope document should also provide detailed requirements and descriptions of expected outcomes. A good scope document is also specific about project boundaries. The Riverside Clinic project scope document might include a statement that the project *does not* include access to online pharmacological databases.

The scope document should specify deliverables such as implementation of a new process, installation of a new piece of equipment, or presentation of a paper report. The project organization is also specified in the scope document, including the project manager, team members, and specific relationships to all parts of the organization.

An initial evaluation of potential risks to the project should be enumerated in the scope document. The schedule length and milestones should be more detailed in the scope statement than in the charter. As discussed in the next section, however, the final schedule will be developed based on the work breakdown structure. Finally, the scope document should include methods to monitor progress and make changes where necessary, including the formal approvals required.

Work Breakdown Structure

The second major component of the scope document is the work breakdown structure (WBS), considered the engine of the project because it determines how its goals will be accomplished. The WBS lists the tasks that need to be accomplished, including an estimate of the resources required (e.g., staff time, services, equipment). For complex projects, the WBS is a hierarchy of major tasks, subtasks, and work packages. Figure 5.6 demonstrates this graphically.

The size of each task should be constructed carefully. A task should not be so small that monitoring would consume a disproportionate share of the task itself. However, an overly large task cannot be effectively monitored and should be divided into subtasks and then work packages. The task should have enough detail associated with it that the individual responsible, the cost, and duration can be identified. A reasonable guideline is that a task should have a duration of one to three weeks to be effectively monitored.

The completion of some tasks is critical to the success of the project. These tasks should be identified as "milestones." The completion of milestones provides a convenient shorthand method to communicate overall project progress to stakeholders.
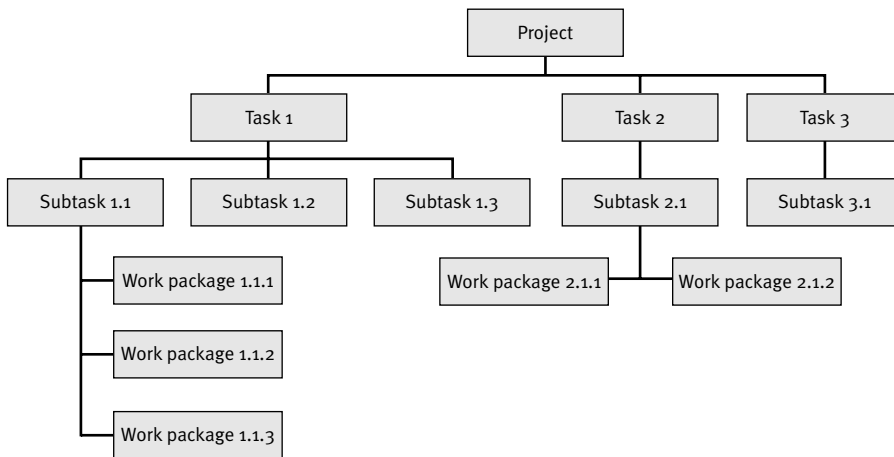
FIGURE 5.6
General Format
for WBS

NOTE: This type of diagram can be easily generated in Microsoft Word and other Microsoft Office products by using the commands Insert → Picture → Organization Chart.

The WBS can be developed by the project team itself or with the help of outside experts who have executed similar projects. At this point in the project, the WBS is the best estimate of how the project will be executed. It is almost always inaccurate in some way, so the formal control and change procedures described in this section are essential to successful project management.

After the WBS has been constructed, the resources required and estimated time for each element must be determined. Estimating the time a task will require is an art. It is best done by a team of individuals. Any previous experiences and data can be helpful. One group process that has proved useful is the program evaluation and review technique (PERT) time estimation. Team members individually estimate the time a task will take as best, worst, and most likely. After averaging the team's response for each of the times, the final PERT time estimate is:

$$\text{Estimated task time} = \frac{\text{Best} + (4 \times \text{Most likely}) + \text{Worst}}{6}$$

After a number of meetings, the Riverview Clinic team determined that the generic drug project included three major tasks, each with two subtasks, that needed to be accomplished to meet the goals of the project. These subtasks are:

- Develop a clinical strategy that maintains quality care with the increased use of generics;
- Develop a system to inform clinicians of approved generics;

- Update systems to ensure that timely patient medication lists are available to clinicians;
- Develop and deploy a staff education plan;
- Develop a system to monitor performance; and
- Develop and begin to use patient education materials.

The WBS is displayed in Figure 5.7. In actuality, these actions represent the higher-level tasks for this project. For a project of this scope to proceed effectively, many more subtasks, perhaps 50 to 100, would be required; to illustrate the principles of project management, this WBS has been held to higher-level tasks.

It is important to note that the time estimate for each task is the total time needed to accomplish a task, not the calendar time it will take—a three-day task can be accomplished in three days by one person or in one day by three people.

The next step is to determine what resources are needed to accomplish these tasks. Riverview Clinic has decided that this project will be accomplished by four existing employees and the purchase of consulting time from VVH's IT supplier. The individuals involved are:

- Tom Simpson, clinic administrator
- Dr. Betsey Thompson, family physician
- Sally Humphries, RN, nursing supervisor
- Cindy Tang, billing manager
- Bill Onku, IT vendor support consultant

The Project software provides a convenient window to enter these individuals and their cost per hour. The program also provides higher levels of detail, such as the hours an individual can devote to the project and actual calendar days when they will be available. When using clinicians, the project manager should consider the revenue per hour from these individuals as opposed to their salaries

FIGURE 5.7
WBS for
Riverview
Generic Drug
Project

FIGURE 5.8
Resources for
the Riverview
Clinic Generic
Drug Project
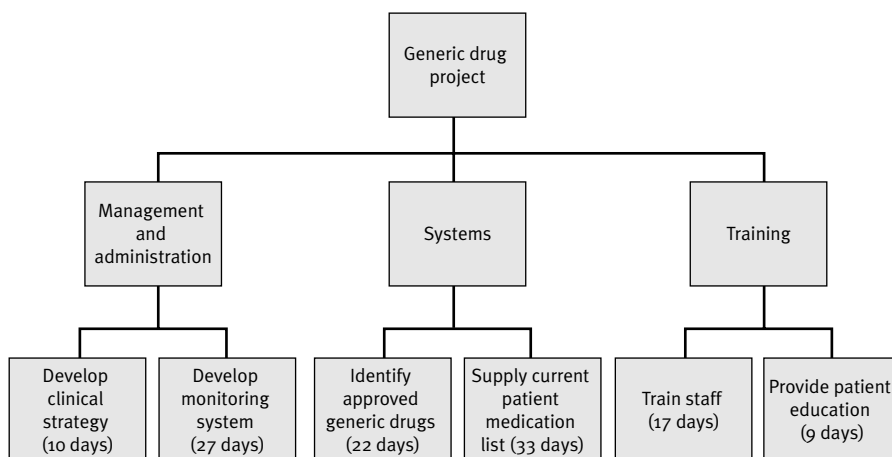
	ⓘ	Resource Name	Type	Material Label	Initials	Group	Max. Units	Std. Rate	Ovt. Rate	Cost/Use	Accrue At	Base Ca
1		Dr. Betsey Thomp	Work		D		100%	$90.00/hr	$0.00/hr	$0.00	Prorated	Standa
2		Sally Humphries F	Work		S		100%	$60.00/hr	$0.00/hr	$0.00	Prorated	Standa
3		Tom Simpson	Work		T		100%	$75.00/hr	$0.00/hr	$0.00	Prorated	Standa
4		Cindy Tang	Work		C		100%	$40.00/hr	$0.00/hr	$0.00	Prorated	Standa
5		Bill Onku	Work		B		100%	$130.00/hr	$0.00/hr	$0.00	Prorated	Standa

and benefits, because most organizations will lose this revenue if the clinician has a busy practice. Figure 5.8 shows the Project window for the Riverview staff who will work on the generic drug project. A video on ache.org/books/ OpsManagement shows how to enter these data; find it in Chapter 5 on the site.

Team members should be clear about their accountability for each task. A functional responsibility chart (sometimes called RASIC) is helpful; the Riverview project RASIC is displayed in Figure 5.9. The RASIC diagram is a matrix of team members and tasks from the WBS. For each task, one individual is responsible (R) for ensuring that the task is completed. Other team members may need to approve (A) the completion of the task. Additional team members may work on the task as well, so they are considered support (S.) The obligation to inform (I) other team members helps a team communicate effectively. Finally, some team members need to be consulted (C) as a task is being implemented.

Scheduling

Network Diagrams and Gantt Charts

Because the WBS was developed without a specific sequence, the next step is scheduling each task to accomplish the total project. First, the logical order of the tasks must be determined. For example, the Riverview project team determined that the system to identify appropriate generic drugs must be developed before the training of staff and patients can begin. Other constraints must also be considered in the schedule, including required start or completion dates and resource availability.

Two tools are used to visually display the schedule. The first is a network diagram that connects each task in precedence order. This is essentially a process map (Chapter 6) where the process is performed only once. However, network diagrams never have paths that return to the beginning (as happens frequently in process maps). A practical way to develop an initial network diagram is to place each task on a sticky note and begin arranging them on a

WBS Task	Clinic Board of Directors	Lead M.D. Betsey Thompson	Administrator Tom Simpson	Project Manager Sally Humphries	Billing Cindy Tang	IT Bill Onku
Develop clinical strategy	A	R	C	C	I	I
System to identify approved generics		A	R	S	R	S
Updated medication lists		R	I	S	I	S
Patient education	A	S	S	R	I	I
Staff education		A	R	C	S	I
Monitoring system	A	C	R	C	S	C

NOTE: R = responsible; A = approval; S = support; I = inform; C = consult.

set of flip charts until they meet the logical and date constraints. The tasks can then be entered into a project management software system.

Figure 5.10 is the network diagram developed by the team for the Riverview Clinic generic drug project. This schedule can be entered into Project to generate a similar diagram. Another common scheduling tool is the Gantt chart, which lists each task on the left side of the page with a bar indicating the start and end times. The Gantt chart for the Riverview project, generated by Project, is shown in Figure 5.11. Each bar indicates the duration of the task, and the small arrows connecting the bars indicate the predecessor–successor
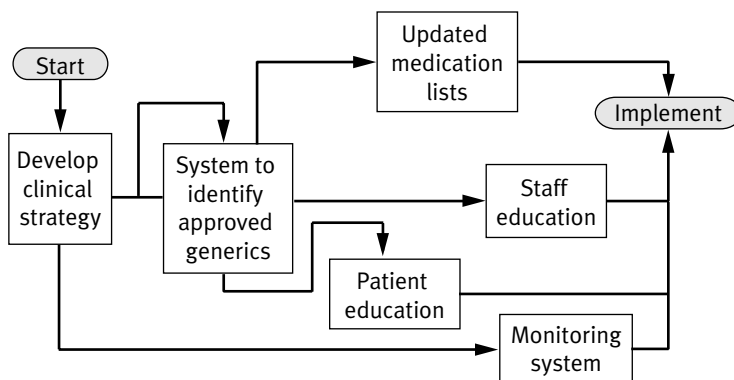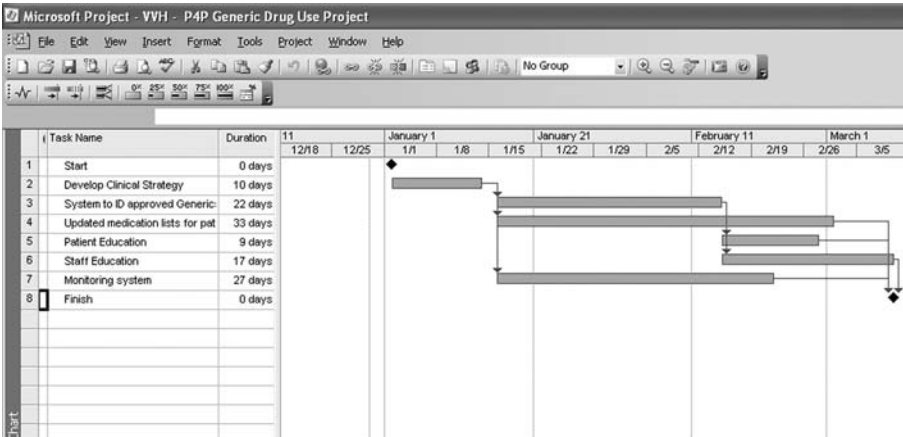
FIGURE 5.11
Riverview
Generic Drug
Project Gantt
Chart

relationship of the tasks. Chapter 5 on the companion web site includes videos on how to enter tasks into Project and establish their precedence, which will generate the schedule. Also shown are the many ways in which the schedule and staff assignments can be viewed in Project.

The next step is to assign resources to each task. Figure 5.12 shows how the resources are assigned for each day in the project. Care must be taken when assigning resources, as no person works 100 percent of the time. A practical limit is 80 percent, so it is helpful that Project generates a resource use graph (Figure 5.13) for each individual. If any single individual is allocated at more than 80 percent in any time period, the schedule may need to be adjusted to

FIGURE 5.12
Riverview
Generic Drug
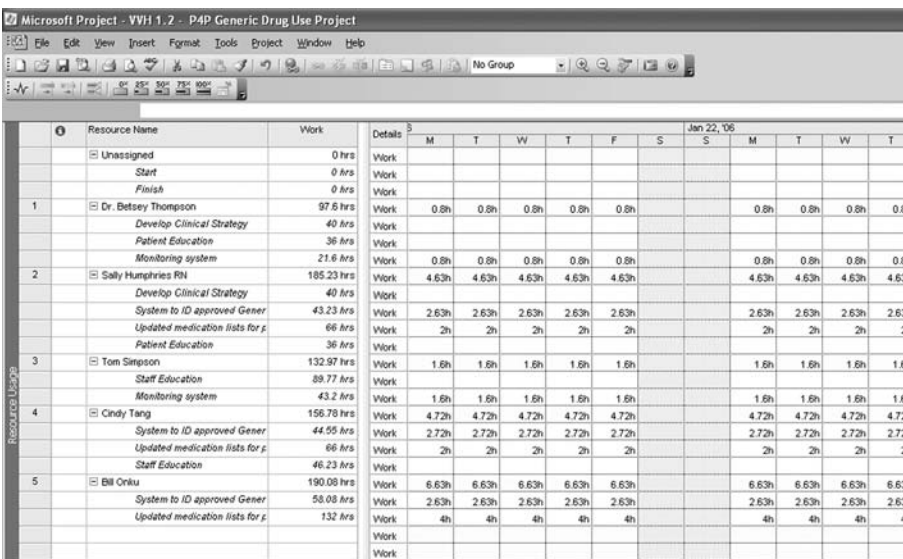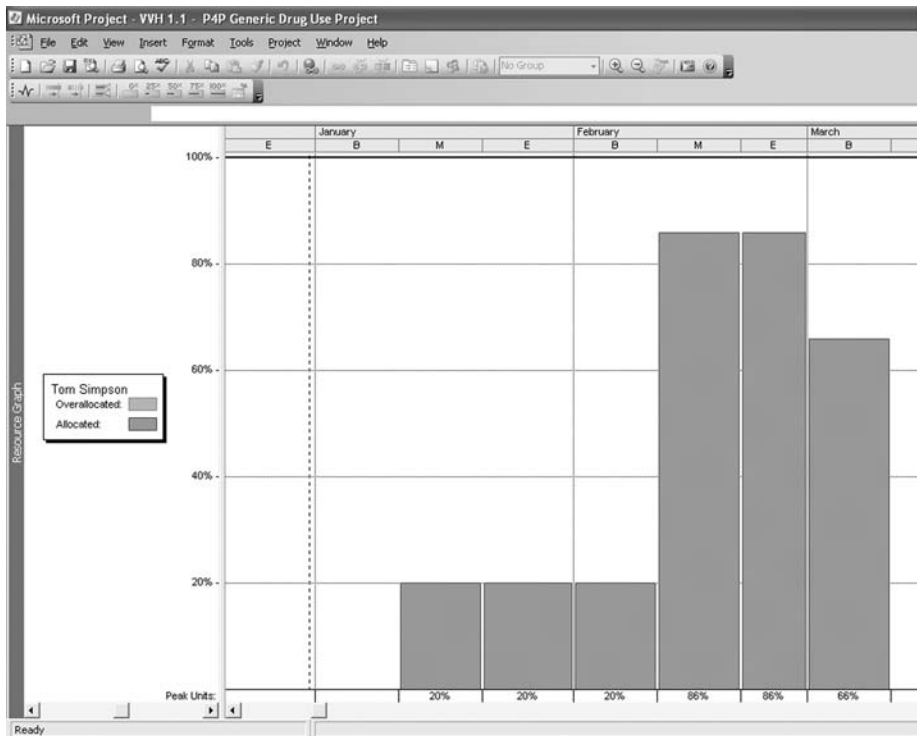Project, Tasks
with Resources
Assigned

NOTE: As Tom's assignment represents more than 80 percent of his time for some weeks, the schedule or assignment should be revised.

reduce this allocation. Adjusting the schedule to accommodate this constraint is known as "resource leveling." Go to ache.org/books/OpsManagement, Chapter 5, to see a video on how to use Project to adjust staff time.

A final review of this initial schedule is made to assess how many tasks are being performed in parallel (simultaneously). A project with few parallel tasks will take longer to accomplish than one with many parallel tasks. Another consideration may be date constraints. Examples include a task that cannot begin until a certain date because of staff availability, or a task that must be complete by a certain date to meet an externally imposed deadline (e.g., new Medicare billing policy). The Project software provides tools to set these constraints inside the schedule.

Slack and the Critical Path
To optimize a schedule, the project manager must pay attention to slack in the schedule and to the critical path. If a task takes three days but does not need to be completed for five days, there would be two days of slack. The critical path is the longest sequence of tasks with no slack, or the shortest possible completion time of the project.

Slack is determined by the early finish and late finish dates. The *early finish date* is the earliest date that a task could possibly be completed, based on the early finish dates of predecessors. The *late finish date* is the latest date that a task can be completed without delaying the finish of the project; it is based on the late start and late finish dates of successor tasks. The difference between early finish and late finish dates determines the amount of slack. For critical path tasks (which have no slack), the early finish and late finish dates are identical. Tasks with slack can start later based on the amount of slack they have available. In other words, if a task takes three days and the earliest the task could be completed is day 18, based on its predecessors, and a late finish date of day 30, based on it successors, the slack for this task is 12 days; this task could start as late as day 27 without affecting the completion date of the project. The critical path, which determines the duration of a project, is the connected path through a project of critical tasks. Go to Chapter 5 on ache.org/books/OpsManagement for a video that provides a simple way to understand this concept.

Calculating slack and the critical path can be complex and time consuming (see Moder, Phillips, and Davis [1995] for a more detailed explanation). Fortunately, Project does this automatically.

In some cases (e.g., a basic clinical research project), it is difficult to estimate the duration of tasks. If a project has many tasks with high variability in their expected durations, the PERT estimating system should be used. PERT employs probabilistic task times to estimate slack and critical paths. PERT is good for time estimation prior to the start of the project, but the critical path method is better suited for project management once a project has begun. It is not particularly useful to have a range of start dates for a task—what is really important is when a task should have started and whether the project is ahead or behind.

Although Project provides a PERT scheduling function, the use of PERT is infrequent in healthcare and beyond the scope of this book. Figure 5.14 displays a Gantt chart for the Riverview generic drug project with both slack and critical path calculated.

Crashing the Project

Consider the following scenario. The clinic president has been notified by one health plan that if the Riverview generic drug project is implemented by March 1, the clinic will receive a $20,000 bonus. He asks the project manager to consider speeding up, or "crashing," the project.

The term "project crashing" has negative associations, as the thought of a computer crashing stirs up dire images. However, a crashed project is simply one that has been sped up. Crashing a project requires reducing the length of the critical path, which can be done by any of the following:

- Shortening the duration of work on a task on the critical path.
- Changing a task constraint to allow for more scheduling flexibility.

FIGURE 5.14

Gantt Chart for
Riverview
Generic Drug
Project with
Slack and
Critical Path
Calculated
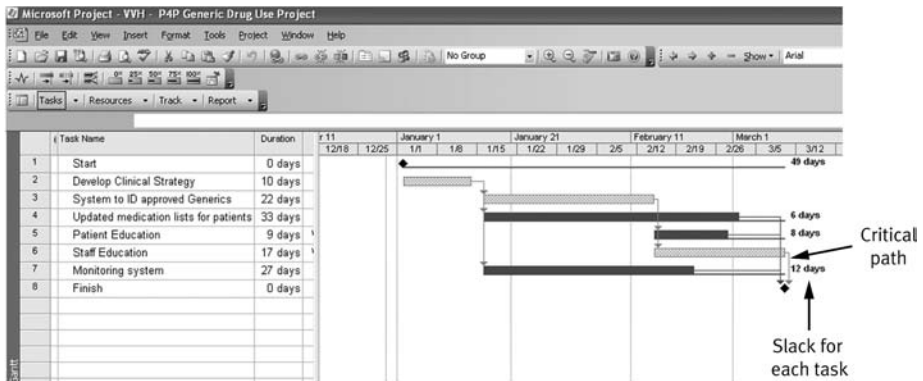
- Breaking a critical task into smaller tasks that can be worked on simultaneously by different resources.
- Revising task dependencies to allow more scheduling flexibility.
- Setting lead time between dependent tasks where applicable.
- Scheduling overtime.
- Assigning additional resources to work on critical-path tasks.
- Lowering performance goals (not recommended without strong stakeholder consultation) (Microsoft Corp. 2003).

The scope, time, duration, and performance relationships need to be considered in a crashed project. A crashed project has a high risk of costing more than the original schedule predicted, so the formal change procedure, discussed in the next section, should be used.

Project Control

It would be convenient if every project's schedule and costs occurred according to the initial project plan. However, because this is almost never the case, an effective project monitoring and change control system needs to be operating throughout the life of a project.

Monitoring Progress
The first important monitoring element is a system to measure schedule completion, cost, and expected performance against the initial plan. Microsoft Project provides a number of tools to assist the project manager. After the plan's initial scope document, WBS, staffing, and budget have been determined, they are saved as the "baseline plan." Any changes during the project can be compared to this initial baseline.

On a disciplined time basis (e.g., once per week), the project manager needs to receive a progress report from each task manager—the individual designated as "responsible" on the RASIC chart (Figure 5.9)—regarding schedule completion and cost. The enterprise version of Project contains some helpful tools to automate this sometimes-tedious data-gathering task. Figure 5.15 shows a Project report on the progress of the generic drug project after three weeks. Go to Chapter 5 on ache.org/books/OpsManagement for a video that shows how to generate progress reports.

Earned Value Analysis

For large projects, earned value analysis provides a comprehensive vehicle to monitor progress. This tool provides a way to combine the monitoring of both schedule and cost and is particularly useful in the early stages of a project.

The first step in an earned value analysis is to determine a status date, usually close to the project team's meeting date. Once the status date is determined, three fundamental values are calculated for each task. The first is the budgeted cost of tasks as scheduled in the project plan, based on the costs of resources that have been planned to complete the task. Called the *budgeted cost of work scheduled* (BCWS), this is the baseline expected cost up to the status date. The actual cost of completing all or some portion of the task, up to the status date, is the *actual cost of work performed* (ACWP).

The final variable is the value of the work performed by the status date, measured in currency. This is literally the value earned by the work performed, called the *budgeted cost of work performed* (BCWP). BCWP is also called the earned value. For example, assume three people have been assigned to a task for a week, and all have been paid at $1,000/week for a total of

FIGURE 5.15

Status of Riverview Generic Drug Project at Three Weeks

	Task Name	Act. Start	Act. Finish	% Comp.	Phys. %	Act. Dur.	Rem. Dur.	Act. Cost	Act. Work
1	Start	NA	NA	0%	0%	0 days	0 days	$0.00	0 hrs
2	Develop Clinical Strategy	Mon 1/2/06	NA	90%	0%	9 days	1 day	$5,400.00	72 hrs
3	System to ID approved Generics	Mon 1/16/06	NA	13%	0%	2.88 days	19.12 days	$1,754.90	23 hrs
4	Updated medication lists for pati	Mon 1/16/06	NA	10%	0%	3.3 days	29.7 days	$2,376.00	26.4 hrs
5	Patient Education	NA	NA	0%	0%	0 days	9 days	$0.00	0 hrs
6	Staff Education	NA	NA	0%	0%	0 days	17 days	$0.00	0 hrs
7	Monitoring system	Mon 1/16/06	NA	15%	0%	4.05 days	22.95 days	$777.60	9.72 hrs
8	Finish	NA	NA	0%	0%	0 days	0 days	$0.00	0 hrs

$3,000. However, one of the workers has only accomplished 50 percent of what he was assigned to do, so the *value* of his work is only $500. Therefore, $2,500 is the BCWP, or earned value. In this case, the ACWP is $3,000.

Project performance can be analyzed with earned value analysis (Microsoft Corp. 2003). Assume a task has a budgeted cost (BCWS) of $1,000 and, by the status date, is 40 percent complete. The earned value (BCWP) is $400, but the scheduled value (BCWS) at the status date is $500. This indicates that the task is behind schedule—less value has been earned than was planned. Assume the task's actual cost (ACWP) at the status date is $600, perhaps because a more expensive resource was assigned to the task. Therefore, the task is also over budget—more cost has been incurred than was planned. The earlier in a project's life cycle discrepancies between ACWP, BCWP, and BCWS can be identified, the sooner steps can be taken to remedy the problem.

Earned value analysis is a powerful monitoring tool, especially for large and complex projects. More detail and examples of this technique can be found in Lewis (2000). The Project program can perform an earned value analysis like that displayed in Figure 5.16 for the Riverview generic drug project. The BCWP is less than the BCWS for three tasks, indicating that they are behind schedule. However, the AWCP is the same as the BWCP, so it does not appear that costs are currently a problem.

Three final columns are included in this report. The first is the projection for the estimate at completion (EAC), which is the expected total cost of a task or project based on performance as of the status date. EAC is also called forecast at completion, calculated as:

$$EAC = ACWP + (BAC - BCWP)/CPI$$

The CPI is the cost performance index—the ratio of budgeted, or baseline, costs of work performed to actual costs of work performed (BCWP/ACWP). The budget at completion (BAC) shows an estimate of the total project cost. The variance at completion shows the difference between BAC and EAC. In Project, the EAC is the Total Cost field and the BAC is the Baseline Cost field from the associated baseline.

In addition to the CPI, a schedule performance index (SPI) can be calculated:

$$SPI = BCWP/BCWS$$

The two can be combined into one number—the critical index (CI)—which indicates the overall performance of a project:

FIGURE 5.16
Riverview
Generic Drug
Project Earned
Value Analysis

	Task Name	BCWS	BCWP	ACWP	SV	CV	EAC	BAC	VAC
1	Start	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2	Develop Clinical Strategy	$6,000.00	$5,400.00	$5,400.00	($600.00)	$0.00	$6,000.00	$6,000.00	$0.00
3	System to ID approved Generics	$3,662.39	$1,756.17	$1,754.90	($1,906.22)	$1.27	$11,917.45	$11,926.05	$8.60
4	Updated medication lists for patients	$4,320.00	$2,376.00	$2,376.00	($1,944.00)	$0.00	$23,760.00	$23,760.00	$0.00
5	Patient Education	$0.00	$0.00	$0.00	$0.00	$0.00	$5,400.00	$5,400.00	$0.00
6	Staff Education	$0.00	$0.00	$0.00	$0.00	$0.00	$8,581.60	$8,581.60	$0.00
7	Monitoring system	$1,152.00	$777.60	$777.60	($374.40)	$0.00	$5,184.00	$5,184.00	$0.00
8	Finish	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

$$CI = CPI \times SPI$$

If the CI dips below 0.8 or above 1.2, the project may be in serious trouble, and active intervention is needed by the project team.

Change Control

The project manager should have a status meeting at least once a month, and preferably more frequently. At this meeting, the project team should review the actual status of the project based on task completion, expenses, personnel utilization, and progress toward expected project outcomes. The majority of time in these meetings should be devoted to problem solving, not reporting.

Once deviations are detected, their source and causes must be determined by the team. For major or complex deviations, diagnostic tools such as fishbone diagrams (Chapter 6) can be used. Three courses of action are now available: Ignore the deviation if it is small, take corrective action to remedy the problem, or modify the plan by using the formal change procedure developed in the project charter and scope document.

One major cause of deviations is an event that occurs outside the project. The environment will always be changing during a project's execution, and modifications of the project's scope or performance level may be necessary. For example, the application of a new clinical breakthrough may take priority over projects that improve support systems, or a competitor may initiate a new service that requires a response.

Using a formal change mechanism is one of the key characteristics of high-performing project managers. It is human nature to resist communicating a schedule or cost problem to project sponsors and stakeholders. However, the consequences of this inaction can be significant, if not fatal, to large

projects. The change process also forces all parties involved in a project to subject themselves to disciplined analysis of options and creates disincentives for scope creep. Changes to the initial plan should be documented in writing and signed off on by the project sponsor as appropriate. They should be included in the project records (three-ring binders or equivalent).

The Riverview project charter (and subsequent scope document) states that changes in plan of less than 10 percent can be made by project manager Sally Humphries. Therefore, she could adjust the schedule by up to 4.9 days, the cost by up to $6,100, and the performance goal by 0.4 percent. For deviations greater than these amounts, Sally would need the clinic board to review and sign off. The companion web site contains project change documentation and a sign-off template.

Communications

A formal communication plan was developed as part of scope creation. Communications to both internal and external stakeholders are critical to the success of a project. Many communications media can be used, including simple oral briefings, e-mails, and formal reports. A reasonable contemporary mix used by many organizations is a web-based intranet that contains detailed information on the project. An e-mail is sent to stakeholders periodically, with a summary progress report and links back to the web site for more detailed information. A sophisticated communications plan will be fine-tuned to meet stakeholder needs and interests and will communicate only those issues of interest to each stakeholder. As part of the communications strategy, feedback from stakeholders should always be solicited, as changes in the project plan may affect the stakeholder in ways unknown to the project manager.

The project update communications should contain information gathered from quantitative reports. At a minimum, these communications should provide progress against baseline on schedule, cost, scope, and expected performance. Any changes to project baseline, as well as to the approval process, should be noted. Any issues that need resolution, or those that are being resolved, should also be noted. The expected completion date is always of interest to all stakeholders and should be a prominent part of any project plan communication.

Risk Management

Comprehensive prospective risk management is another characteristic of successful projects. Like many other aspects of project management, it takes dis-

cipline to develop a risk management plan at the beginning of a project and to update it continuously as the project progresses. A risk is an event that will cause the project to have a substantial deviation from planned schedule, cost, scope, or performance.

The most direct way to develop a risk management plan is to begin with the WBS. Each task in the WBS should be assessed for risks, both known and unknown. Risks can occur for each task in its performance, duration, or cost; if a project has 50 tasks, it will have 150 potential risks.

A number of techniques can be used to identify risks, but the most straightforward is a brainstorming exercise by the project team. (Some of the tools found in Chapter 6—e.g., mind mapping, root cause analysis, force field analysis—could also be used in risk assessment.) Another useful technique is to interview stakeholders to identify risks to the project as viewed from the stakeholders' perspective. The organization's strategic plan is also a resource, as the plan will frequently contain a strengths, weaknesses, opportunities, and threats analysis. The Weaknesses and Threats sections may contain clues as to potential risks to a task within a project.

Once risks have been identified for each task in the WBS structure, the project team should also assign a risk probability to each. Those risks with the highest probability, or likelihood, of occurring during the project should be analyzed in depth and a risk management strategy devised. The failure mode and effects analysis method (Chapter 6) can also be used for a more rigorous risk analysis.

A quantitative analysis can also be conducted for tasks that have high risk or are critical to project execution. If data can be collected for similar tasks in multiple circumstances, probability distributions can be created and used for simulation and modeling. An example of this technique would be remodeling space in an older building. If an organization reviewed a number of recent remodeling projects, it might determine that the average cost per square foot of remodeled space is $200/foot with a normal distribution. This information could be used as the basis of a Monte Carlo simulation (Chapter 10) or as part of a decision tree (Chapter 6). The results of these simulations would provide the project manager with quantitative boundaries on the possible risks associated with the task and project and would be useful in constructing mitigation strategies.

Tasks with the following characteristics should be looked at closely, as they may be high risk:

- Have a long duration
- Are subject to highly variable estimates of duration
- Depend on external organizations
- Require a unique resource (e.g., a physician who is on call)
- Are likely to be affected by external governmental or payer policies

The management strategy for each identified risk should have three components. First, risk avoidance initiatives should be identified. It is always better to avoid an adverse event than to have to deal with its consequences. An example of a risk avoidance strategy is to provide mentoring to a young team member who has responsibility for key tasks in the project plan.

The second element of the risk management strategy is to develop a mitigation plan. An example of a mitigation response would be to bring additional people and financial resources to a task. Another might be to call on the project sponsor to help break an organizational logjam. Third, a project team may decide to transfer the risk to an insurance entity. This strategy is common in construction projects through the use of bonding for contractors.

All identified risks and their management plans should be outlined in a *risk register*, a listing of each task, identified risks, and prevention and mitigation plans. This risk management plan should be updated throughout the life of the project.

The Riverview project team identified three serious risks, which are listed in Table 5.2 with their mitigation plans.

Quality Management, Procurement, the Project Management Office, and Project Closure

Quality Management

The majority of focus in this chapter has been on managing the scope, cost, and schedule of a project. The performance, or quality, of an operational project is the fourth key element in successful project management. In general, quality can be defined as meeting specified performance levels with minimal variation and waste.

TABLE 5.2
Risk Mitigation Plan for Riverview Generic Drug Project

Risk	Mitigation Plan
Generic drug use decreases quality	Assistance will be sought from • VVH hospital pharmacy • Pharmaceutical firms • Health plans
Computer systems do not work	• IT vendor has specialists on call who will be flown to Riverview Clinic • Assistance will be sought from VVH IT department
Software modifications are more expensive than budgeted	Contingency funding has been earmarked in clinic budget

The fundamental tools for accomplishing these goals are described in Chapters 6 and 8. More advanced techniques for reducing variation in outcomes can be found in Chapter 8 (quality and Six Sigma), and Chapter 9 discusses tools for waste reduction (Lean).

Throughout the life of a project, the project team should monitor the expected quality of the final product. Individual tasks that are part of a quality management function within a project should be created in the WBS. For example, one task in the Riverside generic drug project is to develop a monitoring system. This system will not only track the use of generic drugs but will also ascertain whether their use has any negative clinical effects.

Procurement

Many projects depend on outside vendors and contractors, so a procurement system integrated with an organization's project management system is essential. A purchasing or procurement department can be helpful in this process. Procurement staff will have developed templates for many of the processes described in the following sections. They will also have knowledge of the latest legal constraints an organization may face. However, the most useful attribute of the procurement department may be the frequency with which it executes the purchasing cycle. By performing this task frequently, its staff has developed expertise in the process and is aware of common pitfalls to avoid.

Contracting

Once an organization has decided to contract with a vendor for a portion of a project, three basic types of contracting are available. The *fixed price contract* is a lump sum for the performance of specified tasks. Fixed price contracts sometimes contain incentives for early delivery.

Cost reimbursement contracts provide payment to the vendor based on the vendor's direct and indirect costs of delivering the service for a specified task. It is important to clearly document in advance how the vendor will calculate its costs.

The most open-ended type of contract is known as *time and materials.* Here, the task itself may be poorly defined, and the contractor is reimbursed for her actual time, materials, and overhead. A time and materials–type contract is commonly used for remodeling an older building, where the contractor is not certain of what she will find in the walls. Great caution and monitoring are needed when an organization uses this type of contracting.

Any contract should contain a statement of work (SOW). The SOW contains a detailed scope statement, including WBS, for the work that will be performed by the contractor. It also includes expected quantity and quality levels, performance data, task durations, work locations, and other details that will be used to monitor the work of the contractor.

Selecting a vendor

Once a preliminary SOW has been developed, the organization will solicit proposals and select a vendor. A useful first step is to issue a request for information (RFI) to as many possible vendors as the project team can identify. The RFIs generate responses from vendors on their products and experience with similar organizations. Based on these responses, the number of feasible vendors can be reduced to manageable set.

A more formal request for proposal (RFP) can then be issued. The RFP will ask for a detailed proposal, or bid. The following criteria should be considered in awarding the contract:

- Does the vendor clearly understand the organization's requirements?
- What is the total cost?
- Does the vendor have the capability and correct technical approach to deliver the requested service?
- Does the vendor have a management approach to monitor successful execution of the SOW?
- Can the vendor provide maintenance or meet future requirements and changes?
- Does the vendor provide references from clients that are similar to the contracting organization?
- Does the vendor assert intellectual or proprietary property rights in the products it supplies?

Payment based on earned value

Vendor performance should be monitored and payments made based on the contract as described previously. The most sophisticated payment system for contractors employs earned value. This can be a useful tool in making payments, particularly to consultants or IT service vendors. Many of these vendors will initially request that customers pay them based on the hours their staff has worked; when using the earned value mechanism, the contractor is paid only for work actually accomplished.

The Riverview generic drug project task of providing updated patient medication lists is expected to require 132 hours of Bill Onku's time, at $130/hour. Therefore, the BCWS of this task is $17,160. The project team initially determined that this task would require 48 modifications to the existing EHR system. At the three-week status meeting, project manager Sally Humphries reports that the task is 10 percent complete; however, Bill has only completed 2 of the 48 modifications, or 4.1 percent. Although Bill's employer sent Riverside Clinic an invoice for 10 percent of his time ($1,716), the clinic could reasonably make the case that it would pay only the BCWP, or earned value. The earned value here is 4.1 percent, or $703.56. Of course, payment based on earned value must be a part of the contract with the vendor.

The Project Management Office

Many organizations outside the healthcare industry (e.g., architects, consultants) are primarily project oriented. Such organizations have a centralized project management office (PMO) to oversee the work of their staff. Because healthcare delivery organizations are primarily operational, the majority do not use this structure.

However, departments within large hospitals and clinics, such as IT and quality, have begun to use a centralized project office approach. In addition, some organizations have designated and trained project leaders in Six Sigma or Lean techniques. These project leaders are assigned from a central PMO.

PMOs provide a central structure to monitor progress on all projects in an organization and reallocate resources as needed when projects encounter problems. They also provide a resource for the training and development of project managers.

Project Closure

A successful project should have an organized closure process, which will include a formal stakeholder presentation and approval process. In addition, the project sponsor should sign off at project completion to signify that performance levels have been achieved and all deliverables have been received. During the close-out process, special attention should be paid to project staff, who will be interested in their next assignment. A disciplined handoff of staff from one project to the next will allow successful completion of the closure process.

All documents related to the project should be indexed and stored. This can be helpful if outside vendors have participated in the project and a contract dispute arises in the future. Historical documents can also provide a good starting point for the next version of a project.

The project team should have a final session to identify lessons learned—both good and bad—in the execution of the project. These lessons should be included in the project documentation and shared with other project managers within the organization.

The Project Manager and Project Team

The project manager's role is pivotal to the success of any project. Selecting, developing, and nurturing high-functioning team members are also critical. The project manager's team skills include both running effective meetings and facilitating optimal dialogue within these meetings.

Team Skills

A project manager can take on many roles within a project. In many smaller healthcare projects, the project manager is actually the person who accomplishes

many of the project tasks. In other projects, the project manager's job is solely leadership and the management of the many individuals performing the tasks. Slack (2005) provides a useful matrix to determine what role a project manager should assume in projects of varying size (Table 5.3).

Team Structure and Authority

The members and structure of a project team may be selected by the project manager, but in many cases are outlined by the project sponsor and other members of senior management. It is important to formally document the team makeup and how team members were assigned in the project charter and scope documents. Care should be taken to avoid overscheduling team members, as all members must have the needed time available to work on the project.

A number of key issues need to be addressed as the project team is formed. The most important is the project manager's level of authority to make decisions. Can the project manager commit resources, or must he ask senior management or department heads each time a new resource is needed? Is the budget controlled by the project manager, or does a central financial authority control it? Finally, is administrative support available to the team, or do the project team members need to perform these tasks themselves?

Team Meetings

A weekly or biweekly project team meeting is highly recommended to keep a project on schedule. At this meeting, the project's progress can be monitored and discussed and actions initiated to resolve deviations and problems.

All good team meetings include comprehensive agendas and a complete set of minutes. Minutes should be action oriented (e.g., "The schedule slippage for task 17 will be resolved by assigning additional resources from the temporary pool."). In addition, the individual accountable for following through on the issue should be identified. If the meeting's deliberations and actions are confidential, everyone on the team should be aware of the policy and adhere to it uniformly.

TABLE 5.3
Project Manager's Role Based on Effort and Duration of a Project

Variable	Small Project	Medium Project	Large Project
Effort range	40–360 hours	360–2,400 hours	2,400–10,000 hours
Duration	5 days–3 months	3–6 months	6–12+ months
Project leader role	"Doer" with some help	Manage and "do some"	Manage and lead

SOURCE: Slack (2005). Used with permission.

The decision-making process should be clear and understood by all team members. In some situations, all major decisions will be made by the project manager. In others, team members may have veto power if they represent a major department that may need to commit resources. Some major decisions may need to be reviewed and approved by individuals external to the project team. The use of data and analytical techniques is strongly encouraged as a part of the decision process.

Team members need to take responsibility for the success of the team. They can demonstrate this behavior by following through on commitments, contributing to the discussion, actively listening, and giving and accepting feedback. Everyone on a team should feel that she has a voice, and the project manager needs to lead the meeting in such a way as to balance the "air time" between team members. This means politely and artfully interrupting the wordy team member and summarizing his point; it also means calling on the silent team member to solicit input.

At the end of a meeting, it is useful to evaluate the meeting itself. The project manager and team can spend a few minutes reviewing questions such as:

- Did we accomplish our purpose?
- Did we take steps to maintain our gains?
- Did we document actions, results, and ideas?
- Did we work together successfully?
- Did we share our results with others?
- Did we recognize everyone's contribution and celebrate our achievements?

Dialogue

The core of the project team meeting is the conversation that occurs among team members. A productive team will engage in dialogue, not unfocused discussion or debate. The study of dialogue has advanced, and much is now known about how effective dialogue fuels productive teams.

Yankelovich (1999) identifies three distinctive features that differentiate productive dialogue from mere discussion. The first is equality within the team and the absence of coercive influences. As most project teams are made up of members from many parts of an organization, equality and camaraderie are important to make team meetings enjoyable and productive. A second feature of productive dialogue is the ability of team members to listen with empathy. The ability to think like another member of a team helps broaden the dialogue and keeps any disagreement focused on issues rather than personalities. The third key feature of productive dialogue is the ability to bring assumptions into the open. Once assumptions are on the floor, they can be considered with respect, debated, and resolved honestly.

Losada and Heaphy (2004) provide a specific formulation for the content of dialogue in high-performing teams. They studied project team interactions in detail over many meetings and rated their performance based on the metrics of profitability, customer satisfaction, and 360-degree reviews. The teams were then ranked as high, medium, and low performers. Those teams with the highest performance were those with high "Nexi." Losada and Heaphy (2004) define Nexi as strong and sustained interlocking behaviors by team members. In other words, a conversation with crisp interactions between team members clearly focused on a team goal produced high Nexi. The relationship of Nexi to team performance is displayed in Figure 5.17.

Three other characteristics were also measured: inquiry versus advocacy, external versus internal viewpoint, and positive versus negative comments. Low-performing teams were characterized by high levels of advocacy ("Let me convince you why my idea is so good") versus inquiry ("Can you please explain your idea in more depth?"). High-performing teams had an equal mix of advocacy and inquiry.

Low-performing teams had a high degree of internal focus ("How can we do that with our current IT department?"), whereas high-performing teams mixed in an equal blend of external environmental review ("What are similar firms doing with their IT function?").

Finally, optimism and good cheer triumphed in this study. High-performing teams had a 6:1 ratio of positive ("Great idea!") to negative comments ("We tried that before and it didn't work"). Figure 5.18 demonstrates the linkage of these three dialogue dimensions to the connecting Nexi for high-performing teams.

FIGURE 5.17
Relationship of
Nexi to Team
Performance
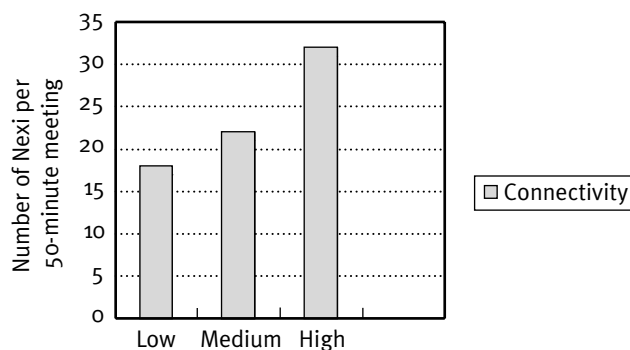
Performance: Profitability, customer satisfaction, 360° assessments

SOURCE: Losada, M., and E. Heaphy. 2004. "The Role of Positivity and Connectivity in the Performance of Business Teams." *American Behavioral Scientist* 47 (6): 752. Copyright 2008 by Sage Publications, Inc. Reprinted with permission of Sage Publications, Inc.
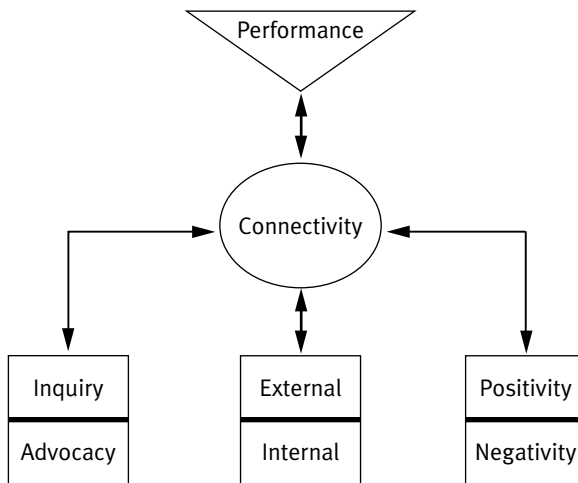
Leadership

Although this book is not primarily concerned with leadership, clearly the project manager must be able to lead a project forward. Effective project leadership requires the following skills:

- The ability to think critically using complex information;
- The strategic capability to take a long-term view of the organization;
- A systems view of the organization and its environment (Chapter 1);
- The ability to create and lead change;
- An understanding of oneself to permit positive interactions, conflict resolution, and effective communication;
- The ability to mentor and develop employees into high-performing teams; and
- The ability to develop a performance-based culture.

Two widely known models are relevant in healthcare environments and provide a foundation for developing these skills. Kotter (1996) describes an eight-step method to lead change in an organization, with an emphasis on employee engagement and communication. Heifetz (1994) presents a different, complementary view of leadership. He distinguishes between routine technical problems, which can be solved through expertise, and adaptive problems, such as major health system changes, which require innovative approaches. His strategies for confronting these problems include a focus on values, an understanding of the stress caused by adaptive problems, and inclusion of stakeholders in solutions.

Conclusion

This chapter provides a basic introduction to the science and discipline of project management. The field is finding a home in healthcare IT departments and has a history in construction projects. Successful healthcare organizations of the future will use this rigorous methodology to make significant changes and improvements throughout their operations.

Discussion Questions

1. Who should constitute members of the project team, key stakeholders, and project sponsors in a clinical project in a physician's office? Support your choices. In a hospital? Again, support your choices.
2. Identify five common risks in healthcare clinical projects and develop contingency responses for each.

Chapter Exercises

1. Download the project charter and project schedule from ache.org/books/OpsManagement. Complete the missing portions of the charter. Develop a risk assessment and mitigation plan. Add tasks to the schedule for those areas that require more specificity. Apply resources to each task, determine the critical path, and determine a method to crash the project to reduce its total duration by 20 percent.
2. Review the Institute for Healthcare Improvement web site and identify and select a quality improvement project (www.ihi.org/IHI/Results/ ImprovementStories/). Although you will not know all the details of the organization that executed this project, create a charter document for your chosen project.
3. For the project identified above, create a feasible WBS and project schedule. Enter the schedule into Microsoft Project.
4. Conduct a meeting with colleagues. Have an observer measure Nexi, advocacy and inquiry comments, internal and external comments, and positive and negative comments. Develop a plan to move toward higher performance based on the research findings of Losada and Heaphy.

References

Austin, C. J., and S. B. Boxerman. 2003. *Information Systems for Health Care Management*, 6th ed. Chicago: Health Administration Press.

Connolly, C. 2005. "Cedars-Sinai Doctors Cling to Pen and Paper." *Washington Post* March 21, A01.

Gapenski, L. C. 2005. *Health Care Finance: An Introduction to Accounting and Financial Management.* Chicago: Health Administration Press.

Heifetz, R. A. 1994. *Leadership Without Easy Answers.* Boston: Belknap Press.

Kotter, J. P. 1996. *Leading Change.* Boston: Harvard Business School Press.

Lewis, J. P. 2000. *The Project Manager's Desk Reference*, 2nd ed. Boston: McGraw Hill.

Losada, M., and E. Heaphy. 2004. "The Role of Positivity and Connectivity in the Performance of Business Teams." *American Behavioral Scientist* 47 (6): 740–65.

Microsoft Corp. 2003. *Microsoft Office Project Professional, Help Screens.* Redmond, WA: Microsoft Corp.

Moder, J. J., C. R. Phillips, and E. W. Davis. 1995. *Project Management with CPM, Pert & Precedence Diagramming*, 3rd ed. Middleton, WI: Blitz Publishing.

Mosser, G. 2005. Personal communication, July 10.

Niven, P. R. 2005. *Balanced Scorecard Diagnostics: Maintaining Maximum Performance.* New York: John Wiley & Sons.

———. 2002. *Balanced Scorecard Step-by-Step: Maximizing Performance and Maintaining Results.* New York: John Wiley & Sons.

Project Management Institute. 2004. *A Guide to the Project Management Body of Knowledge.* Newtown Square, PA: Project Management Institute.

Slack, M. P. 2005. Personal communication, August 15.

Yankelovich, D. 1999. *The Magic of Dialogue: Transforming Conflict into Cooperation*, 2nd ed. New York: Simon and Schuster.

III

PERFORMANCE IMPROVEMENT TOOLS, TECHNIQUES, AND PROGRAMS

6

TOOLS FOR PROBLEM SOLVING AND DECISION MAKING

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

activity mapping
advanced access scheduling
capacity utilization
cause-and-effect diagram
cycle time
decision analysis
decision tree
define-measure-analyze-improve-
control (DMAIC)
diagnosis-related group (DRG)
failure mode and effects analysis
(FMEA)
fishbone diagram, see cause-and-
effect diagram
five whys
flowchart
force field analysis
Institute for Healthcare
Improvement (IHI)
Ishikawa diagram, see cause-and-
effect diagram
Joint Commission (formerly the
Joint Commission on Accredita-
tion of Healthcare Organizations)

Lean
linear programming
mathematical programming
Microsoft Excel Solver
mind mapping
optimization
Palisade Precision Tree
Pareto analysis
Plan-do-check-act (PDCA)
process mapping
risk analysis
root-cause analysis (RCA)
sensitivity analysis
service blueprinting
Six Sigma
slack variables
theory of constraints (TOC)
throughput time
value-added time

Operations Management in Action

At Allegheny General Hospital in Pittsburgh, the two intensive care units had been averaging about 5.5 infections per 1,000 patient days, mostly bloodstream infections from catheters. That infection rate was a bit higher than the Pittsburgh average but a bit lower than the national average, says Dr. Richard Shannon, chairman of medicine at Allegheny General.

Over the prior 12 months, 37 patients, already some of the sickest people in the hospital, had 49 infections. Of those, 51 percent died. Dr. Shannon and the staff in the two units—doctors, residents, and nurses—applied the Toyota root-cause analysis system, investigating each new infection immediately.

Their main conclusion was that femoral intravenous lines, inserted into an artery near the groin, had a particularly high rate of infections. The team made an all-out effort to replace these lines with less risky ones in the arm or near the collarbone. Dr. Shannon, who oversees the two units, gave the directive to keep femoral lines to an absolute minimum. The result was a 90 percent decrease in the number of infections after just 90 days of using the new procedures.

SOURCE: Adapted from Wysocki 2004.

Overview

This chapter introduces the basic tools associated with problem solving and decision making. Much of the work of healthcare professionals is just that—making decisions and solving problems—and in an ever-changing world that work must be accomplished well and quickly. A structured approach can enable efficient, effective problem solving and decision making. Major topics in this chapter include:

- The decision-making process, with a focus on framing the problem or issue;
- Mapping techniques, including mind mapping, process mapping, activity mapping, and service blueprinting;
- Problem identification tools, including root-cause analysis (RCA), failure mode and effects analysis (FMEA), and the theory of constraints (TOC);
- Analytical tools such as optimization using linear programming and decision analysis; and
- Force field analysis to address implementation issues.

This chapter gives readers a basic understanding of various problem-solving tools and techniques to enable them to:

- Frame questions or problems;
- Analyze the problem and various solutions to it; and
- Implement those solutions.

The tools and techniques outlined in this chapter should provide a basis for tackling difficult, complicated problems.

Decision-Making Framework

A structured, rational approach to problem solving and decision making includes the following steps:

- Identifying and framing the issue or problem;
- Generating or determining possible courses of action and evaluating those alternatives;
- Choosing and implementing the best solution or alternative; and
- Reviewing and reflecting on the previous steps and outcomes.

Decision Traps: The Ten Barriers to Brilliant Decision-Making and How to Overcome Them (Russo and Schoemaker 1989) outlines these steps (Table 6.1) and the barriers encountered in decision making (Box 6.1).

The plan-do-check-act process for continuous improvement (Chapters 8 and 9), the define-measure-analyze-improve-control process of Six Sigma (Chapter 8), and the outline for analysis (Chapter 11) all follow the same basic steps as outlined in the decision-making process. The tools and techniques found in this book can be used to help in gathering the *right* information to make optimal decisions and learn from those decisions, as well as in the process of making those decisions. Often, the learning step in the decision-making process is neglected, but it should not be. It is important to evaluate and analyze both the decision made and the process(es) used in coming to the decision to ensure learning and enable continuous improvement.

Framing
The frame of a problem or decision encompasses the assumptions, attitudes, and preconceived limits that an individual or a team brings to the analyses. These assumptions can limit the ability to solve the problem by reducing or eliminating creativity and causing the decision maker(s) to overlook possibilities. Alternatively, these assumptions can aid in problem solving by eliminating wildly improbable paths, but they usually hinder finding the best solution or finding a possible solution.

TABLE 6.1

Decision
Elements and
Activities

Framing	Structuring the question. This means defining what must be decided and determining in a preliminary way what criteria would cause you to prefer one option over another. In framing, good decision makers think about the viewpoint from which they and others will look at the issue and decide which aspects they consider important and which they do not. Thus, they inevitably simplify the world.
Typical amount of time: 5%	
Recommended amount of time: 20%	
Gathering intelligence	Seeking both the knowable facts and the reasonable estimates of "unknowables" that you will need to make the decision. Good decision makers manage intelligence gathering with deliberate effort to avoid such failings as overconfidence in what they currently believe and the tendency to seek information that confirms their biases.
Typical amount of time: 45%	
Recommended amount of time: 35%	
Coming to conclusions	Sound framing and good intelligence don't guarantee a wise decision. People cannot consistently make good decisions using seat-of-the-pants judgment alone, even with excellent data in front of them. A systematic approach forces you to examine many aspects and often leads to better decisions than hours of unorganized thinking would.
Typical amount of time: 40%	
Recommended amount of time: 25%	
Learning from feedback	Everyone needs to establish a system for learning from the results of past decisions. This usually means keeping track of what you expected would happen, systematically guarding against self-serving explanations, then making sure you review the lessons your feedback has produced the next time a similar decision comes along.
Typical amount of time: 10%	
Recommended amount of time: 20%	

Millions of dollars and working hours are wasted in finding solutions to the wrong problems. An ill-defined problem or mistaken premise can eliminate promising solutions before they can even be considered. People tend to identify convenient problems and find solutions that are familiar to them rather than looking more deeply.

People also have a tendency to want to do something; quick and decisive action is seen as necessary in today's rapidly changing environment. Leaping to the solutions before taking the time to properly frame the problem will usually result in suboptimal solutions.

Framing the Question

Plunging in—Beginning to gather information and reach conclusions without first taking a few minutes to think about the crux of the issue you're facing.

Frame blindness—Setting out to solve the wrong problem because you have created a mental framework for your decision with little thought, which causes you to overlook the best options or lose sight of important objectives.

Lack of frame control—Failing to consciously define the problem in more ways than one or being unduly influenced by the frames of others.

Gathering Intelligence

Overconfidence in your judgment—Failing to correct key factual information because you are too sure of your assumptions and opinions.

Shortsighted shortcuts—Relying inappropriately on "rules of thumb," such as implicitly trusting the most readily available information or anchoring too much on convenient facts.

Coming to Conclusions

Shooting from the hip—Believing you can keep straight in your head all the information you've discovered, and therefore you "wing it" rather than following a systematic procedure.

Group failure—Assuming that with many smart people involved, good choices will follow automatically, and therefore you fail to manage the group decision process.

Learning/Failing to Learn from Feedback

Fooling yourself about feedback—Failing to interpret the evidence from past outcomes for what it really says, either because you're protecting your ego or because you are tricked by hindsight.

Not keeping track—Assuming that experience will make its lessons available automatically, and therefore you fail to keep systematic records to track results of your decisions and fail to analyze these results in ways that *will* reveal their true lessons.

Failure to audit your decision process—You fail to create an organized approach to understanding your own decision making, so you remain constantly exposed to all the aforementioned mistakes.

SOURCE: *Decision Traps* by J. Edward Russo and Paul J. H. Schoemaker, copyright © 1989 by J. Edward Russo and Paul J. H. Schoemaker. Used by permission of Doubleday, a division of Random House, Inc.

Potential solutions to any problem are directly related to, and limited by, the definition of the problem itself. However, framing the problem can be difficult, as it requires an understanding of the problem. If the problem is well understood, the solution is more likely to be obvious; when framing a problem, it is therefore important to be expansive, solicit many different viewpoints, and consider many possible scenarios, causes, and solutions. The tools outlined in this chapter are designed to help with this process.

Mapping Techniques

Mind Mapping

Tony Buzan is credited with developing the mind-mapping technique (Buzan 1991; Buzan and Buzan 1994). Mind mapping develops thoughts and ideas in a nonlinear fashion and typically uses pictures or phrases to organize and develop thoughts. In this structured brainstorming technique, ideas are organized on a "map" and the connections between them are made explicit. Mind mapping can be an effective technique for problem solving because it is not necessary to think linearly. Making connections that are not obvious or linear can lead to innovative solutions.

Mind mapping starts with the issue to be addressed placed in the center of the map. Ideas on causes, solutions, and so on radiate from the central theme. Questions such as who, what, where, why, when, and how are often helpful for problem solving. Figure 6.1 illustrates a mind map related to high accounts receivables.

Process Mapping

A process map, or flowchart, is a graphic depiction of a process showing inputs, outputs, and steps in the process. Depending on the purpose of the map, it can be high level or detailed. Figure 6.2 shows a high-level process map for the Riverview Clinic, and Figure 6.3 shows a more detailed map of the check-in process at the clinic. A process map gives a clear picture of what activities are carried out as part of the process, where the activity happens, and how activities are performed. Typically, process maps are used to understand and optimize a process. The process is commonly charted from the viewpoint of the material, information, or customer being processed (often the patient in healthcare) or the worker carrying out the work. Process mapping is one of the seven basic quality tools and an integral part of most improvement initiatives, including Six Sigma, Lean, balanced scorecard, RCA, and FMEA.

The steps for creating a process map or flowchart are:

1. *Assemble and train the team.* The team should consist of people from all areas and levels within the process of interest to ensure that the real process is captured.
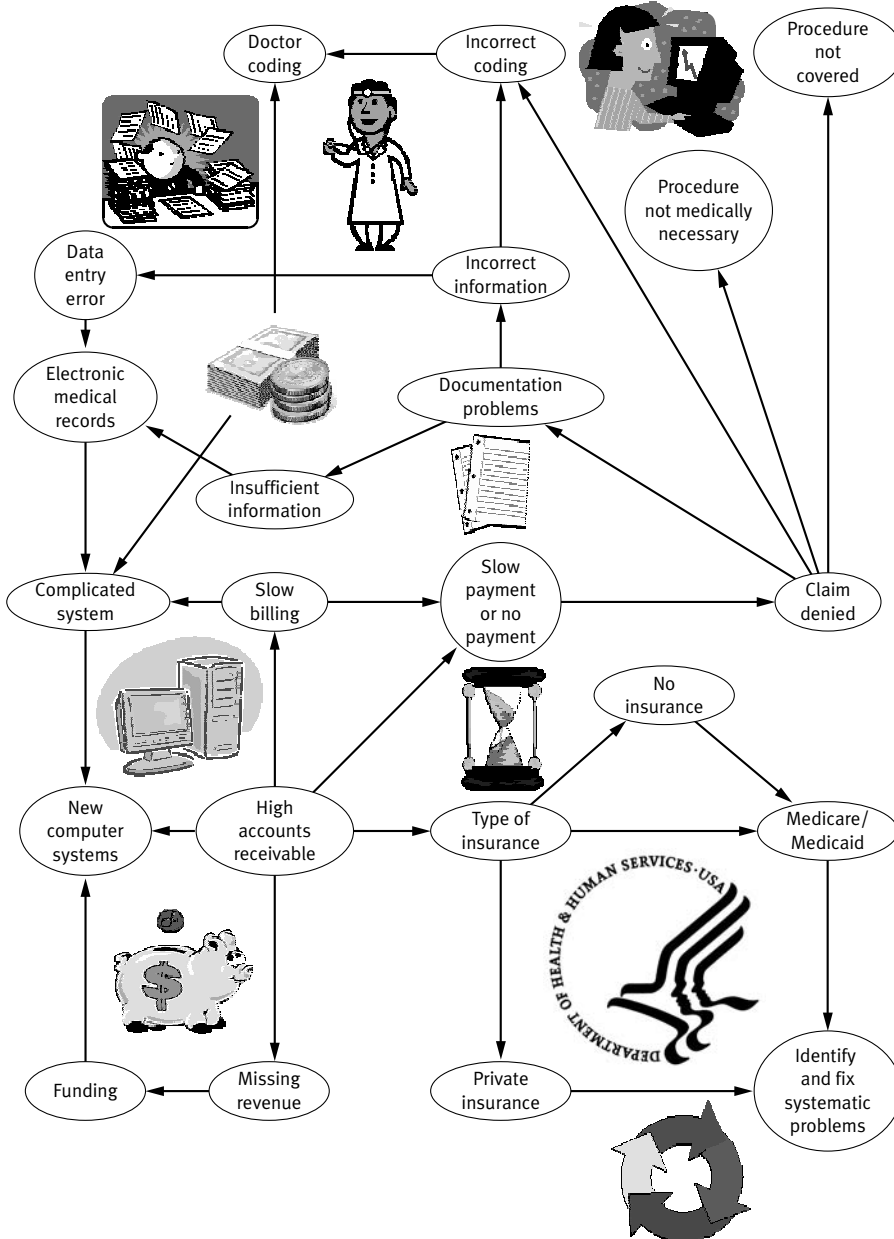
NOTE: Diagram created in Inspiration by Inspiration Software, Inc.

2. *Determine the boundaries of the process (where does it start and end?) and the level of detail desired.* The level of detail desired, or needed, will depend on the question or problem the team is addressing.

3. *Brainstorm the major process tasks and subtasks.* List them and arrange them in order. (Sticky notes are often helpful here.)
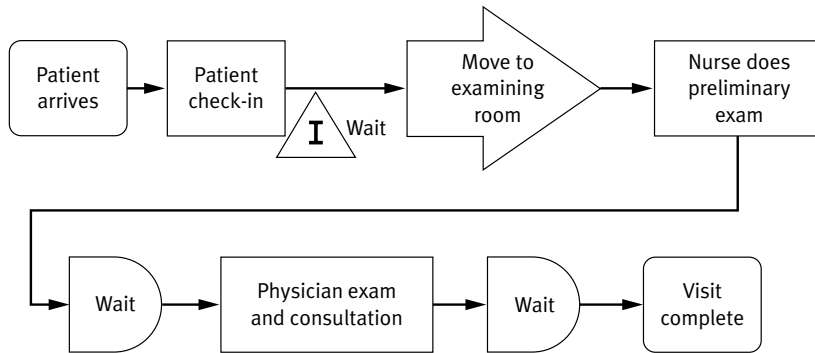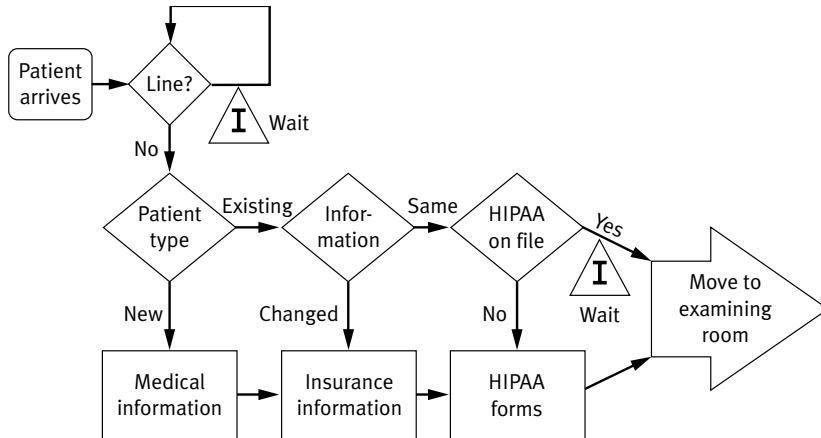
4. *Create a formal chart.* Once an initial flowchart has been generated, the chart can be formally drawn using standard symbols for process mapping (Figure 6.4). This can be done most efficiently using software such as Microsoft Visio. Note that when first developing a flowchart it is more important to obtain an accurate picture of the process than to worry about using the correct symbols.

5. *Make corrections.* The formal flowchart should be checked for accuracy by all relevant personnel. Often, inaccuracies will be found in the flowchart that need to be corrected in this step.

6. *Determine additional data needs.* Depending on the purpose of the flowchart, data may need to be collected, or more information may need to be added. Often, data on process performance are collected and added to the flowchart.
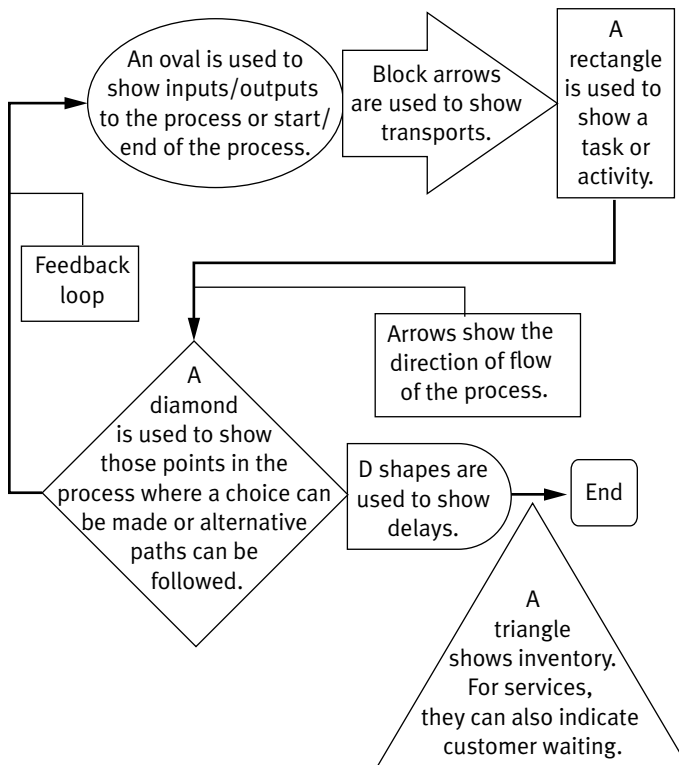
Measures of process performance

Measures of process performance include throughput time, cycle time, and percentage of value-added time (Chapter 9). Another important measure of process, subprocess, task, or resource performance is capacity utilization. Capacity is the maximum possible amount of output (goods or services) that a process or resource can produce or transform. Capacity measures can be based on outputs or on the availability of inputs. For example, if a hospital food service can provide, at most, 1,000 meals in one day, the food service has a capacity of 1,000 meals/day. If all magnetic resonance images (MRIs) take one hour to perform, the MRI machine would have a capacity of 24 MRIs/day. The choice of appropriate capacity measure varies with the situation.

Ideally, demand and capacity are perfectly matched. If demand is greater than capacity, some customers will not be served. If capacity is greater than demand, resources will be underutilized. In reality, perfectly matching demand and capacity can be difficult to accomplish because of fluctuations in demand. In a manufacturing environment, inventory can be used to compensate for demand fluctuations. In a service environment, this is not possible; therefore, excess capacity or a flexible workforce is often required to meet demand fluctuations. Advanced-access scheduling (Chapters 9 and 12) is one way for healthcare operations to more closely match capacity and demand.

Capacity utilization is the percentage of time that a resource (worker, equipment, space, etc.) or process is actually busy producing or transforming output. If the hospital food service only provides 800 meals/day, the capacity utilization is 80 percent. If the MRI machine only operates 18 hours/day, the capacity utilization is 75 percent ($18/24 \times 100$). Generally, higher capacity utilization is better, but caution must be used in evaluation. If the hospital food service had a goal of 95 percent capacity utilization, it could meet that goal by producing 950 meals/day, even if only 800 meals/day were actually consumed and 150 meals were discarded. Obviously, this would not be an effective use of resources, but food service would have met its goal.

Typically, the more costly the resource, the greater the importance of maximizing capacity utilization. For example, in a hospital emergency department the most costly resource is often the physician, and other resources (nurses, housekeeping, clerical staff, etc.) are less expensive. In this case, maximizing the utilization of the physicians is more important than maximizing the utilization of the other resources. It is often more economical to underutilize less expensive resources to maximize the utilization of more expensive resources. Simulation (Chapter 11) can be used to help determine the most effective use of various types of resources.

Activity and Role Lane Mapping

Activity and role lane mapping can be a useful exercise to include in process mapping. List the process activities and the roles involved, and ask who performs the activity now. Then, take the role out of the activity so that "nurse records vital signs" becomes "record vital signs" and record this as is shown in Table 6.2. This type of analysis can help with process redesign and streamlining.

Service Blueprinting

Service blueprinting (Shostack 1984) is a special form of process mapping (as is value stream mapping, covered in Chapter 9). Service blueprinting begins

TABLE 6.2
Activity and Role Lane Mapping

	Role			
Activity	Clerk	Nurse	Porter	Doctor
Take insurance information	x			
Move patient		x	x	
Record vital signs		x		x
Take history		x		x
Examine patient				x
Write pathology request				x
Deliver pathology request	x			

with mapping the process from the point of view of the customer. The typical purpose of a service blueprint is to identify points where the service might fail to satisfy the customer and then redesign or add controls to the system to reduce or eliminate the possibility of failure. The service blueprint separates onstage actions (those visible to the customer) and backstage actions and support processes (those not visible to the customer). A service blueprint specifies the line of interaction, where the customer and service provider come together, and the line of visibility, that is, what the customer sees or experiences, the tangible evidence that influences perceptions of the quality of service (Figure 6.5).

Problem Identification Tools

Root-Cause Analysis

Root-cause analysis (RCA) is a generic term used to describe structured, step-by-step techniques for problem solving. It aims to determine and correct the ultimate cause(s) of a problem, not just the visible symptoms, to ensure that the problem does not happen again. RCA consists of determining what happened, why it happened, and what can be done to prevent it from happening again.

The Joint Commission (2005b) requires all accredited organizations to conduct an RCA of any sentinel event (an unexpected occurrence involving death or serious physical or psychological injury, or the risk thereof) and provides some tools (Joint Commission 2005a) to help an organization conduct that analysis. These tools are not only useful for sentinel events and Joint Commission requirements, but they also provide a framework for any RCA. A variety of commercial software is also available for RCAs.
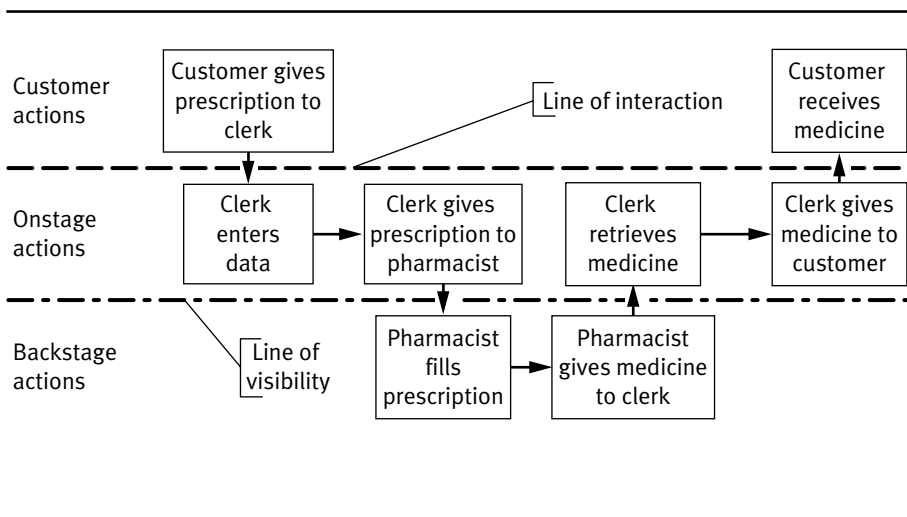

FIGURE 6.5
Service
Blueprint

Although an RCA can be done in many different ways, it is always based on asking why something happened, again and again, until the ultimate cause is found. Typically, something in the system or process, rather than human error, is found to be the ultimate cause. The five whys technique and cause-and-effect diagrams are examples of tools used in RCA.

Five whys technique

The five whys technique is simple but powerful. It consists of asking why the condition occurred, noting the answer, and then asking why for each answer over and over (five times is a good guide) until the "root" causes are identified. Often, the reason for a problem is only a symptom of the real cause—this technique can help eliminate the focus on symptoms, discover the root cause, and point the way to eliminating the root cause and ensuring that the problem does not occur again. For example:

- A patient received the wrong medication. Why?
- The doctor prescribed the wrong medication. Why?
- There was information missing from the patient's chart. Why?
- The patient's most recent lab test results had not been entered into the chart. Why?
- The lab technician sent the results, but they were in transit and the patient's record had not been updated.

The root cause here is the time lag between the test and data entry. Identifying the root cause leads to different possible solutions to the problem than simply concluding that the doctor made a mistake. The system could be changed to increase the speed with which lab results are recorded or, at least, a note could be made on the chart that lab tests have been ordered but not yet recorded.

Cause-and-effect diagram

Using only the five whys technique for an RCA can be limiting. There is an assumption that the effect is a result of a single cause at each level of why. Often, a set of causes is related to an effect. A cause-and-effect diagram can overcome these limits.

One of the seven basic quality tools, this type of graphic is used to explore and display all of the potential causes of a problem. The cause-and-effect diagram is sometimes called an Ishikawa diagram (after its inventor, Kaoru Ishikawa [1985]) or a fishbone diagram (because it looks like the skeleton of a fish).

Typically, a team uses a cause-and-effect diagram to investigate and eliminate a problem. The problem should be stated or framed as clearly as possible, including who is involved and where and when the problem

Service (Four Ps)	Manufacturing (Six Ms)
Policies	Machines
Procedures	Methods
People	Materials
Plant/technology	Measurements
	Mother nature (environment)
	Manpower (people)

BOX 6.2
Typical Cause-and-Effect Diagram Categories

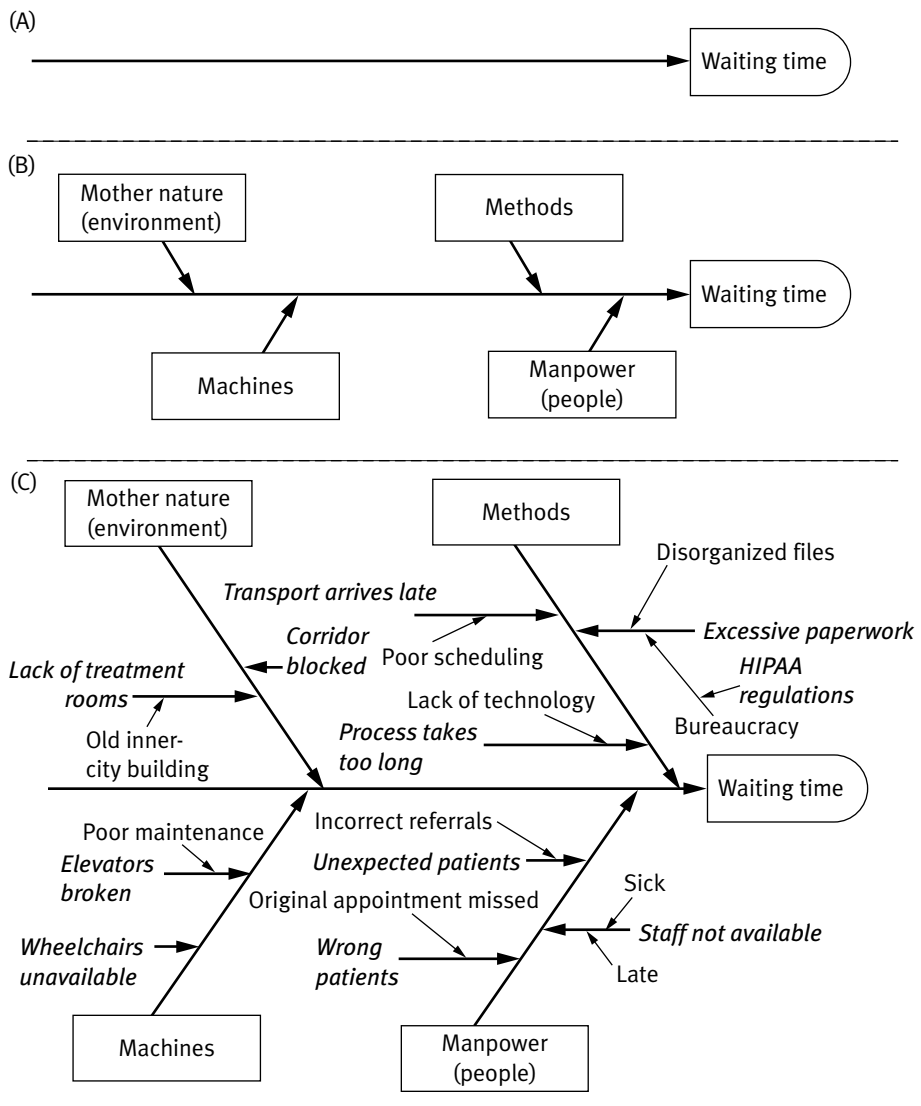occurs, to ensure that everyone on the team is attempting to solve the same problem.

The problem, or outcome of interest, is the "head" of the fish. The rest of the fishbone consists of a horizontal line leading to the problem statement and several branches, or "fishbones," vertical to the main line. The branches represent different categories of causes. The categories chosen may vary according to the problem, but there are some common choices (Box 6.2).

Possible causes are attached to the appropriate branches. Each possible cause is examined to determine if there is a deeper cause behind it (stage c in Figure 6.6); subcauses are attached as more bones. In the final diagram, causes are arranged according to relationships and distance from the effect. This can help in identifying areas to focus on and comparing the relative importance of different causes.

Cause-and-effect diagrams can also be drawn as tree diagrams. From a single outcome, or trunk, branches extend to represent major categories of inputs or causes that create that single outcome. These large branches then lead to smaller and smaller branches of causes all the way down to twigs at the ends. A process-type cause-and-effect diagram (Figure 6.7) can be used to investigate causes of problems at each step in a process. A process RCA is similar to a Failure Mode and Effect Analysis (FMEA), but less quantitative in nature.

An example from Vincent Valley Hospital and Health System (VVH) illustrates the cause-and-effect diagramming process. The hospital identified excessive waiting time as a problem, and a team was assembled to address the issue. The problem is placed in the head of the fish, as shown in Figure 6.6, stage a. Next, branches are drawn off the large arrow representing the main categories of potential causes. Typical categories are shown in Figure 6.6, stage b, but the chosen categories should suit the particular situation. Then, all of the possible causes inside each main category are identified. Each of these causes should be thoroughly explored to identify the causes of causes. This process continues, branching off into more and more causes of causes, until every possible cause has been identified (stage c in Figure 6.6).

FIGURE 6.6

Cause-and-Effect Example

(A)

Waiting time

(B)

Mother nature (environment)

Methods

Waiting time

Machines

Manpower (people)

(C)

Mother nature (environment)

Methods

Disorganized files

Transport arrives late

Corridor blocked

Poor scheduling

Excessive paperwork

HIPAA regulations

Lack of treatment rooms

Lack of technology

Bureaucracy

Old inner-city building

Process takes too long

Waiting time

Poor maintenance

Incorrect referrals

Elevators broken

Unexpected patients

Sick

Original appointment missed

Staff not available

Wheelchairs unavailable

Wrong patients

Late

Machines

Manpower (people)

Much of the value gained from building a cause-and-effect diagram comes from going through the exercise with a team of people. A common and deeper understanding of the problem develops, enabling ideas for further investigation.

Once the cause-and-effect diagram is complete, an assessment of the possible causes and their relative importance should be made. Obvious, easily fixable causes can be dealt with quickly. Data may need to be collected to assess the more complex possible causes and solutions. A Pareto analysis (Chapter 7) of the various causes is often used to separate the vital few from the trivial many. Building a cause-and-effect diagram is not necessarily a one-time exercise. The diagram can be used as a working document and updated as more data are collected and various solutions are tried.
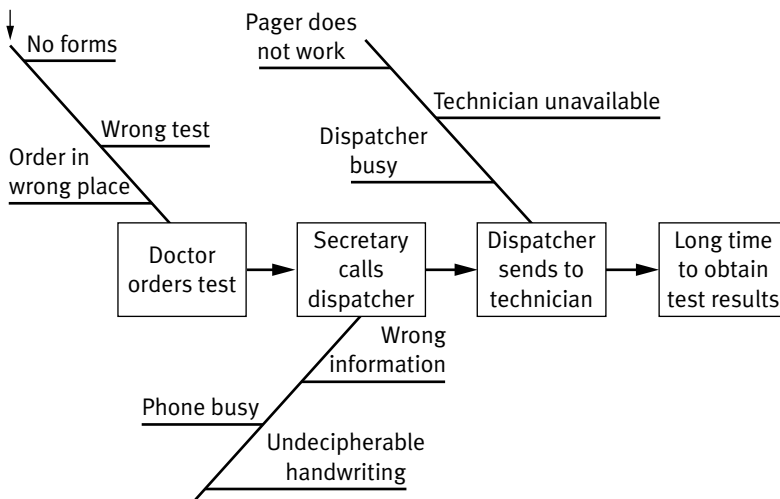
FIGURE 6.7
Process-Type
Cause-and-
Effect Diagram

Failure Mode and Effects Analysis

The failure mode and effects analysis (FMEA) process was originally developed by the U.S. military in the late 1940s, originally aimed at equipment failure. More recently, FMEA has been adopted by many service industries, including healthcare, to evaluate process failure. Hospitals accredited by the Joint Commission are required to conduct at least one FMEA or similar proactive analysis annually (Joint Commission 2001). Where RCA is used to examine the underlying causes of a particular event or failure, FMEA is used to identify the ways in which a process (or piece of equipment) might potentially fail, and its goal is eliminating or reducing the severity of such a potential failure.

A typical FMEA consists of the following steps:

1. Identify the process to be analyzed. Typically, this is a principal process for the organization.
2. Assemble and train the team. Processes usually cross functional boundaries; therefore, the analysis should be performed by a team of relevant personnel. No one person or persons from a single functional area will have the knowledge needed to perform the analysis.
3. Develop a detailed process flowchart, including all steps in the process.
4. Identify each step (or function) in the process.
5. Identify potential failures (or failure modes) at each step in the process. Note that there may be more than one potential failure at each step.
6. Determine the worst potential consequence (or effect) of each possible failure.

7. Identify the cause(s) (contributory factors) of each potential failure. An RCA can be helpful in this step. Note that there may be more than one cause for each potential failure.
8. Identify any failure "controls" that are currently present. A control reduces the likelihood that causes or failures will occur, reduces the severity of an effect, or enables the occurrence of a cause or failure to be detected before it leads to the adverse effect.
9. Rate the severity of each effect (on a scale of 1 to 10, with 10 being the most severe). This rating should reflect the impact of any controls that reduce the severity of the effect.
10. Rate the likelihood (occurrence score) that each cause will occur (on a scale of 1 to 10, with 10 being certain to occur). This rating should reflect the impact of any controls that reduce the likelihood of occurrence.
11. Rate the effectiveness of each control (on a scale of 1 to 10, with 1 being an error-free detection system).
12. Multiply the three ratings by one another to obtain the risk priority number (RPN) for each cause or contributory factor.
13. Use the RPNs to prioritize problems for corrective action. All causes that result in an effect with a severity of 10 should be high on the priority list, regardless of RPN.
14. Develop an improvement plan to address the targeted causes (who, when, how assessed, etc.).

Figure 6.8 shows an example FMEA for patient falls from the Institute for Healthcare Improvement (IHI). IHI has an online interactive tool for FMEA and offers many real-world examples that can be used as a basis for FMEAs in other organizations (IHI 2005). The Veterans Administration National Center for Patient Safety (2006) has developed a less complex FMEA process based on rating only the severity and probability of occurrence and using the resulting number to prioritize problem areas.

Theory of Constraints

The theory of constraints (TOC) was first described in the business novel *The Goal* (Goldratt and Cox 1986). The TOC maintains that every organization is subject to at least one constraint that limits it from moving toward or achieving its goal. For many organizations, the goal is to make money now as well as in the future. Some healthcare organizations may have a different, but still identifiable, goal. Eliminating or alleviating the constraint can enable the organization to come closer to its goal. Constraints can be physical (e.g., the capacity of a machine) or nonphysical (e.g., an organizational procedure). Five steps are involved in the TOC:

1. Identify the constraint or bottleneck. What is the limiting factor stopping the system or process from achieving the goal?

FIGURE 6.8
Patient Falls
FMEA

> fall prevention 3E

United States
Hospital-Community

Aim: Reduction of preventable falls by 50% for 2005

Process Data

Date: 03/28/2005

Step	Description
1	Fall assessment completed upon admission

Failure Mode	Causes	Effects	Occ	Det	Sev	RPN	Actions
Potential to fall	Effects of anesthesia, analgesia.	Potential injury	1	1	10	10	Patients are ambulated with assistance for first 24 hours per policy. Placed on fall risk precautions.
Patient is not assessed at time of admission.	Complete information not available regarding patient history. Patient may not be able or willing to cooperate with interview process	Inaccurate fall risk assigned to patient	2	2	8	32	24 hour chart audits to assure completion of admission evaluation

Step	Description
2	Inaccurate fall assessment

Failure Mode	Causes	Effects	Occ	Det	Sev	RPN	Actions
Potential to fall	Slip, trip, equipment, IV tubing, drains, drainge bags, liquid on floor, urinary urgency, diarrhea	No injury to severe injury	1	1	8	8	All patients are assigned fall risk category
Patient not identified as a fall risk through current process	Not using assessment tool(s) properly	Fall interventions are not implemented correctly.	2	2	7	28	Provide in orientation training on Fall prevention. Monitor Fall events for specific criteria.

Step	Description
3	Interventions not able to be implemented

Failure Mode	Causes	Effects	Occ	Det	Sev	RPN	Actions
Slip, trip fall	Tangled in tubing, trip on tubing, trip on drain bag, forget bag attached to bed, slip on drainage leaking form bag.	no injury to severe injury	1	10	3	30	Educate patient, monitor for leaking drains, assist patient to ambulate with IV and drain tubes.
Due to safety issues of a psychiatric unit, interventions may cause more harm than good.	Failure to implement safe alternatives for behavioral patients who are at risk of falls.	Patients are more unstable	2	2	8	32	Focused education with staff to review safe alternatives for fall prevention. Charge Nurse to include fall prevention in patient shift assessments

Step	Description
4	Medication Assessment/evaluations

Failure Mode	Causes	Effects	Occ	Det	Sev	RPN	Actions
Patients are overmedication -potential for falls	Patients are admitted agitated requiring stronger medication approach.	Patients become quickly drowsy and fall.	3	2	8	48	Medication training to identify sedative potentials. Post alerts on patients with high medication potential. Charge Nurse to include fall risk in shift assessment
Medications may slow judgement or increase ataxia	Medications that are being administered have sedating and ataxic effects	Slips, falls	8	2	9	144	Staff education regarding medications Charge Nurse to include fall risk in shift assessment

Calculated Totals

Total Risk Priority Number for the process	332

Occ: Likelihood of Occurrence (1-10)
Det: Likelihood of Detection (1-10)
  NOTE: 1 = Very likely it WILL be detected
      10 = Very likely it WILL NOT be detected
Sev: Severity (1-10)
RPN: Risk Priority Number (Occ × Det × Sev)

Annotation
None

SOURCE: IHI (2005). This material was accessed from the Institute for Healthcare Improvement's web site, IHI.org. Web page address: http://www.ihi.org/ihi/workspace/tools/fmea/ViewTool.aspx?ToolId=1248.

2. Exploit the constraint. Determine how to get the maximum performance out of the constraint without major system changes or capital improvements.
3. Subordinate everything else to the constraint. Other nonbottleneck resources (or steps in the process) should be synchronized to match the

output of the constraint. Idleness at a nonbottleneck resource costs nothing, and nonbottlenecks should never produce more than can be consumed by the bottleneck resource. For example, if the operating room is a bottleneck and there is a surgical ward associated with it, a traditional view might encourage filling the ward. However, nothing would be gained (and operational losses would be incurred) by putting more patients on the ward than the operating room could process. Thus, the TOC solution is to lower ward occupancy to match the operating room's throughput, even if resources (heating, lighting, fixed staff costs, etc.) seem to be wasted.

4. Elevate the constraint. Do something (expend capital, hire more people, etc.) to increase the capacity of the constraining resource until it is no longer the constraint. Something else will be the new constraint.
5. Repeat the process for the new constraint.

The process must be reapplied, perhaps many times. It is important not to let inertia become a constraint. Many constraints are of an organization's own making—they are the entrenched rules, policies, and procedures that have developed over time.

TOC defines three operational measurements for organizations:

1. *Throughput*: the rate at which the system generates money. This is selling price minus the cost of raw materials. Labor costs are part of operating expense rather than throughput.
2. *Inventory*: the money the system invests in things it will sell. This includes inventories and buildings, land, and equipment.
3. *Operating expense*: the money the system spends turning inventory into throughput. This includes what would typically be called overhead.

The following four measurements are then used to identify results for the organization:

- Net profit = Throughput − Operating expense
- Return on investment (ROI) = (Throughput − Operating expense)/Inventory
- Productivity = Throughput/Operating expense
- Turnover = Throughput/Inventory

These measurements can help employees make local decisions. A decision that results in increasing throughput, decreasing inventory, or decreasing the operating expense will generally be a good decision for the organization.

The TOC has been used in healthcare at both a macro- and microlevel to analyze and improve systems. Wolstenholme (1999) developed a model that showed that providing additional intermediate care enabled hospitals to

more quickly discharge patients and was more effective at increasing overall throughput than providing more hospital beds.

Womack and Flowers (1999) describe the use of TOC in the 366th Medical Group to decrease waiting time for routine primary care appointments. Initially, the waiting time was reduced from an average of 17 days to an average of 4.5 days without any significant dollar investment. They also found that elevating the constraint of waiting time, at a cost of less than $200,000, could significantly increase capacity.

The Radcliff Infirmary in Oxford, England, used the TOC to improve waiting times for ophthalmology (Reid 2000). That organization experienced a 100 percent reduction in cancellations as well as an increase in throughput of 20 percent without adding resources or a major reengineering of the process.

Another way to manage constraints in a system is to acknowledge that there will always be a bottleneck and determine *where* it should be. Designing the system so that the bottleneck can be best managed or controlled can be a powerful way to deal with the bottleneck.

Analytical Tools

Optimization

Optimization, or mathematical programming, is a technique used to determine the optimal allocation of limited resources given a desired goal. For example, the resources might be people, money, or equipment. Of all possible resource allocation(s), the goal or objective is to find the allocation(s) that maximizes or minimizes some numerical quantity such as profit or cost.

Optimization problems are classified as linear or nonlinear depending on whether the problem is linear with respect to the variables. In many cases, it is not practically possible to determine an exact solution for optimization problems; a variety of software packages offer algorithms to find good solutions.

Optimization models have three basic elements:

1. An objective function—the quantity that needs to be minimized or maximized;
2. The controllable inputs or decision variables that affect the value of the objective function; and
3. Constraints that limit the values that the decision variables can take on.

A solution where all of the constraints are satisfied is called a feasible solution. Most algorithms used to solve these types of problems begin by finding feasible solutions and trying to improve on them until a maximum or minimum is found.

Healthcare organizations need to maintain financial viability while working within various constraints on their resources. Optimization techniques can

	Respiratory	Coronary Surgery	Birth/ Delivery	Alcohol/ Drug Abuse	Available
Resources					
Diagnostic services (hours)	7	10	2	1	325
ICU bed days	1	2.5	0.5	0	55
Routine bed days	5	7	2	7	420
Nursing care (hours)	50	88	27	50	3,800
Margin	$400.00	$2,500.00	$300.00	$50.00	
Minimum cases	15	10	20	10	

help these organizations make the best allocation decision. An example of how linear programming could be used in a healthcare organization using Microsoft Excel Solver follows.

Linear programming

VVH wants to determine the optimal case mix for diagnosis-related groups (DRGs) that will maximize profits. Limited resources (space, qualified employees, etc.) are available to service the various DRGs, and minimum levels of service must be offered for each DRG (Table 6.3)

Table 6.3 shows that the respiratory DRG (DRGr) requires 7 hours of diagnostic services, 1 intensive care unit (ICU) bed day, 5 routine bed days, and 50 hours of nursing care. The profit for DRGr is $400, and the minimum service level is 15 cases.

The goal is to maximize profit, and the objective function is:

$$(\$400 \times DRGr) + (\$2,500 \times DRGcs) + (\$300 \times DRGbd) + (\$50 \times DRGada)$$

The constraints are as follows.
Diagnostic services:

$$(7 \times DRGr) + (10 \times DRGcs) + (2 \times DRGbd) + (1 \times DRGada) \leq 325 \quad (1)$$

ICU bed days:

$$(1 \times DRGr) + (2.5 \times DRGcs) + (0.5 \times DRGbd) \leq 55 \quad (2)$$

Routine bed days:

$$(5 \times DRGr) + (7 \times DRGcs) + (2 \times DRGbd) + (7 \times DRGada) \leq 420 \qquad (3)$$

Nursing care:

$$(50 \times DRGr) + (88 \times DRGcs) + (27 \times DRGbd) + (50 \times DRGada) \leq 3,800 \qquad (4)$$

Respiratory minimum case level:

$$DRGr \geq 15 \qquad (5)$$

Coronary surgery minimum case level:

$$DRGcs \geq 10 \qquad (6)$$

Birth/delivery minimum case level:

$$DRGbd \geq 20 \qquad (7)$$

Alcohol/drug abuse minimum case level:

$$DRGada \geq 10 \qquad (8)$$

Figure 6.9 shows the Excel Solver setup of this problem. Solver (Figure 6.10) finds that the hospital should service 15 DRGr cases, 12 DRGcs cases, 20 DRGbd cases, and 29 DRGada cases. The total profit at the optimal case mix is:

$$(15 \times \$400) + (12 \times \$2,500) + (20 \times \$300) + (29 \times \$50) = \$43,450$$

Information relating to the resource constraints is found in the computer solution (Figure 6.10). The amounts reported as slack provide a measure of resource utilization. All available ICU bed days and hours of nursing care will be used. However, 17 routine bed days and almost 31 hours of diagnostic services will be unused. VVH may want to consider eliminating some hours of diagnostic services.

Constraints 5 through 8 relate to the minimum service level for each DRG category. Slack, or surplus, values represent services that should be provided in excess of a minimum level. Only the minimum levels for birth/delivery

FIGURE 6.9
Excel Solver
Setup for DRG
Linear
Programming
Problem
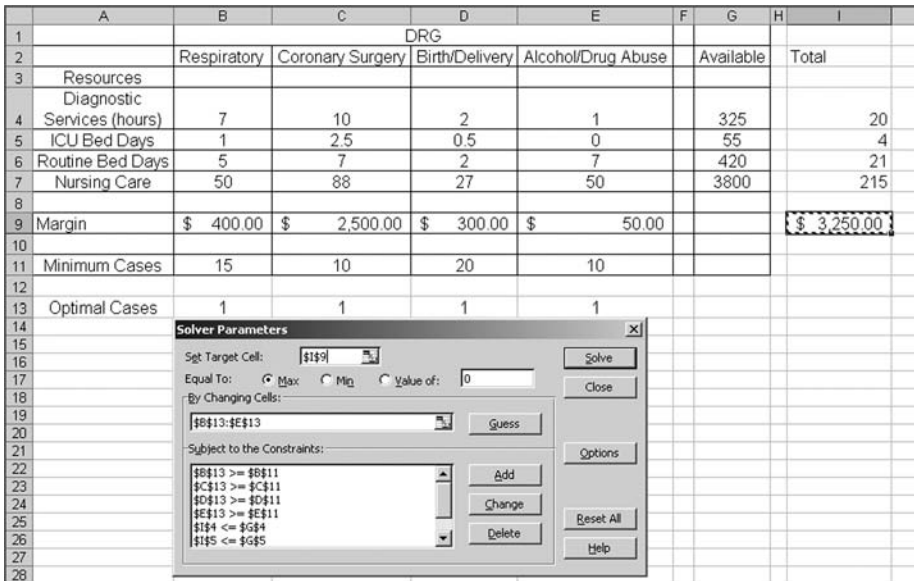
and respiratory care should be provided. However, two additional coronary surgery and 19 alcohol/drug abuse cases should be taken.

Sensitivity analysis

Sensitivity analysis (Figure 6.11) examines the effect of varying the assumptions, or input variables, on the output of a model. Here, a sensitivity analy-

FIGURE 6.10
Excel Solver
Solution for
DRG Linear
Programming
Problem

Target Cell (Max)

Cell	Name	Original Value	Final Value
$I$9	Margin Total	$ 3,250.00	$ 43,454.00

Adjustable Cells

Cell	Name	Original Value	Final Value
$B$13	Optimal Cases Respiratory	1	15
$C$13	Optimal Cases Coronary Surgery	1	12
$D$13	Optimal Cases Birth/Delivery	1	20
$E$13	Optimal Cases Alcohol/Drug Abuse	1	29.08

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$I$4	Diagnostic Services (hours) Total	294.08	$I$4 < =$G$4	Not Binding	30.92
$I$5	ICU Bed Days Total	55	$I$5 < =$G$5	Binding	0
$I$6	Routine Bed Days Total	402.56	$I$6 < =$G$6	Not Binding	17.44
$I$7	Nursing Care (hours) Total	3800	$I$7 < =$G$7	Binding	0
$E$13	Optimal Cases Alcohol/Drug Abuse	29.08	$E$13 > =$E$11	Not Binding	19.08
$D$13	Optimal Cases Birth/Delivery	20	$D$13 > =$D$11	Binding	0
$C$13	Optimal Cases Coronary Surgery	12	$C$13 > =$C$11	Not Binding	2
$B$13	Optimal Cases Respiratory	15	$B$13 > =$B$11	Binding	0

Sensitivity
Analysis for
DRG Linear
Programming
Problem

Adjustable Cells

Cell	Name	Final Value	Reduced Gradient
$B$13	Optimal Cases Respiratory	15	−614.8
$C$13	Optimal Cases Coronary Surgery	12	0
$D$13	Optimal Cases Birth/Delivery	20	−209.4
$E$13	Optimal Cases Alcohol/Drug Abuse	29.08	0

Constraints

Cell	Name	Final Value	Lagrange Multiplier
$I$4	Diagnostic Services (hours) Total	294.08	0
$I$5	ICU Bed Days Total	55	964.8
$I$6	Routine Bed Days Total	402.56	0
$I$7	Nursing Care (hours) Total	3800	1

sis is used to analyze the allocation and utilization of resources (diagnostic service hours, ICU bed days, routine bed days, nursing care) in relation to the objective function (total profit). Shadow prices (the Lagrange multiplier in Figure 6.11) show the dollar effect on total profit of adding or deleting one unit of the resource. This allows the organization to weigh the relative benefits of adding more resources. In this example, adding one ICU bed day would increase total profit by $964.80, and adding one hour of nursing care would increase total profit by $1. If the cost of either of these options is less than the additional profit, the hospital should increase those resources. Because there is slack in routine bed days and diagnostic services, adding more of either of these resources would not change the total profit; there is already an excess of these resources.

Shadow price information is also presented for the DRG minimum service-level requirements (the reduced gradient in Figure 6.11). The shadow price is a negative $614.80 for DRGr; total profit will decrease by $614.80 for each case taken above the minimum level required in the DRGr category. The DRGr category has a higher profit ($400) than the DRGada and, without this analysis, the hospital might have mistakenly tried to serve more DGRr cases to the detriment of DRGada cases.

Optimization can also allow organizations to run "what if" analyses. For example, if a hospital wants to investigate the possibility of increasing beds in its ICU, perhaps by decreasing routine beds, it could use optimization to analyze the available choices.

Decision Analysis

Decision analysis is a process for examining and evaluating decisions in a structured manner. A decision tree is a graphic representation of the order

of events in a decision process. It is a structured process that enables an evaluation of the risks and rewards of choosing a particular course of action.

In constructing a decision tree, events are linked from left to right in the order in which they would occur. Three types of events, represented by nodes, can occur: decision or choice events (squares), chance events (circles), and outcomes (triangles). Probabilities of chance events occurring and benefits or costs for event choices and outcomes are associated with each branch extending from a node. The result is a tree structure with branches for each event extending to the right.

A simple example will help to illustrate this process. A health maintenance organization (HMO) is considering the economic benefits of a preventive flu vaccination program. If the program is not offered, the estimated cost to the HMO if there is a flu outbreak is $8 million with a probability of 0.4 (40 percent), and $12 million with a probability of 0.6 (60 percent). The program is estimated to cost $7 million, and the probability of a flu outbreak occurring is 0.7 (70 percent). If a flu outbreak does occur and the HMO offers the program afterward, it will still cost the organization $7 million, but the resulting costs to the HMO would be reduced to $4 million with a probability of 0.4 (40 percent) or $6 million with a probability of 0.6 (60 percent). What should the HMO decide? The decision tree for the HMO vaccination program is shown in Figure 6.12.

FIGURE 6.12
HMO
Vaccination
Program
Decision Tree 1
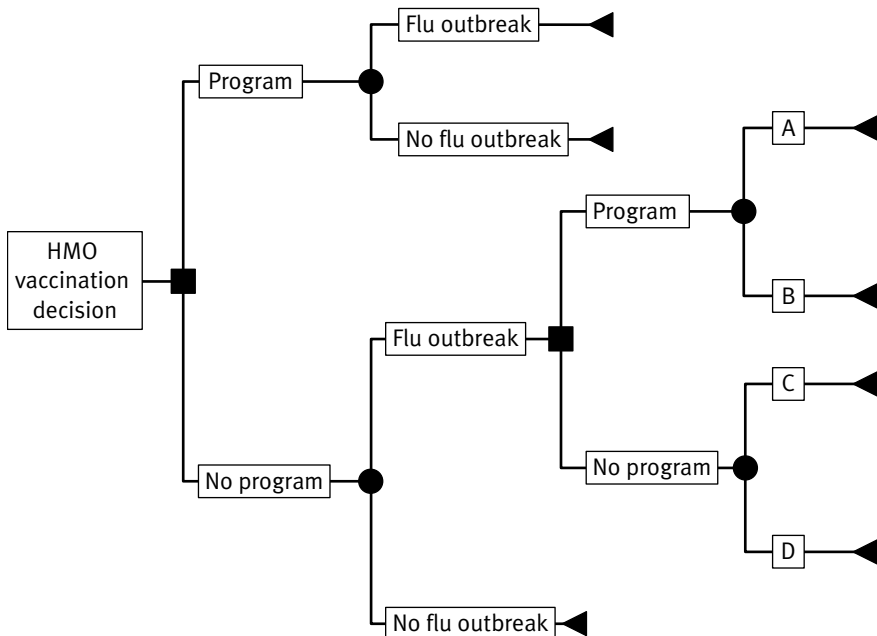
NOTE: The tree diagrams in Figures 6.12 to 6.15 were drawn with the help of PrecisionTree, a software product of Palisade Corp., Ithaca, NY: www.palisade.com.
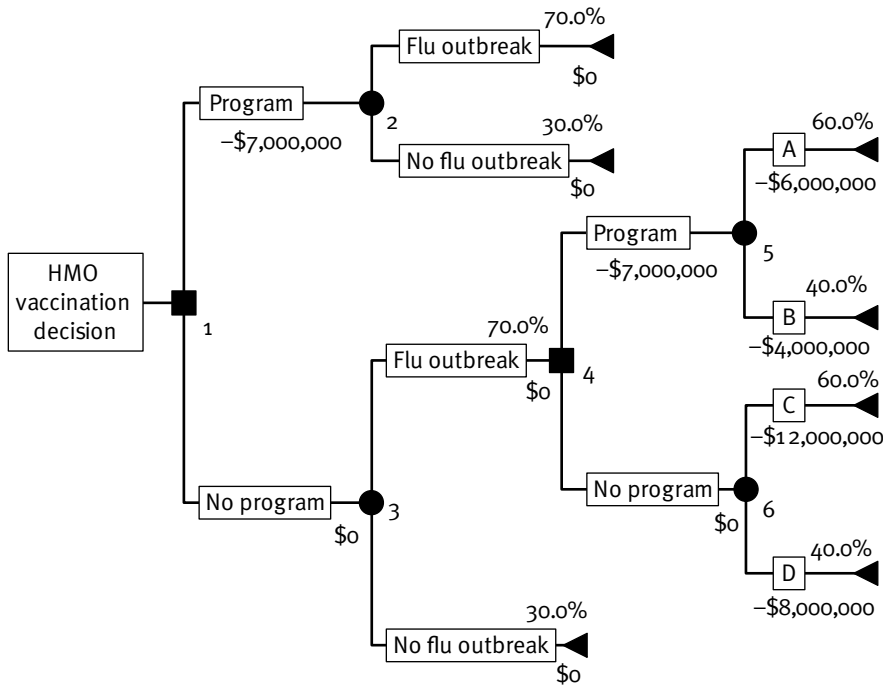
HMO
Vaccination
Program
Decision Tree 2

The probability estimates for each of the chance nodes, benefits (in this case costs) of each decision branch, and outcome branch are added to the tree (Figure 6.13).

The value of a node can be calculated once the values for all subsequent nodes are found. The value of a decision node is the largest value of any branch out of that node. The assumption is that the decision that maximizes the benefits will be made. The value of a chance node is the expected value of the branches out of that node. Working from right to left, the value of all nodes in the tree can be calculated. The expected value of chance node 6 is $[0.6 \times (-12)] + [0.4 \times (-8)] = -10.4$. The expected value of chance node 5 is $[0.6 \times (-6)] + [0.4 \times (-4)] = -5.2$. The expected value of the secondary vaccination program is $-7 + (-5.2) = -12.2$, and the expected value of not implementing the secondary vaccination program is -10.4. Therefore, at decision node 4 the choice would be to not implement the secondary vaccination program.

At chance node 3 (no initial vaccination program), the expected value is $0.7 \times (-10.4) + 0.3 \times 0 = -7.28$. The expected value at chance node 2 is $0.7 \times 0 + 0.3 \times 0 = 0$, and the expected value of the initial vaccination program branch is $-7 + 0 = -7$. Therefore, at decision node 1 the choice would be to implement the initial vaccination program at a cost of $7 million. In contrast, choosing not to implement the initial vaccination program has an expected cost of $7.28 million (Figure 6.14).

FIGURE 6.14
HMO
Vaccination
Program
Decision Tree 3
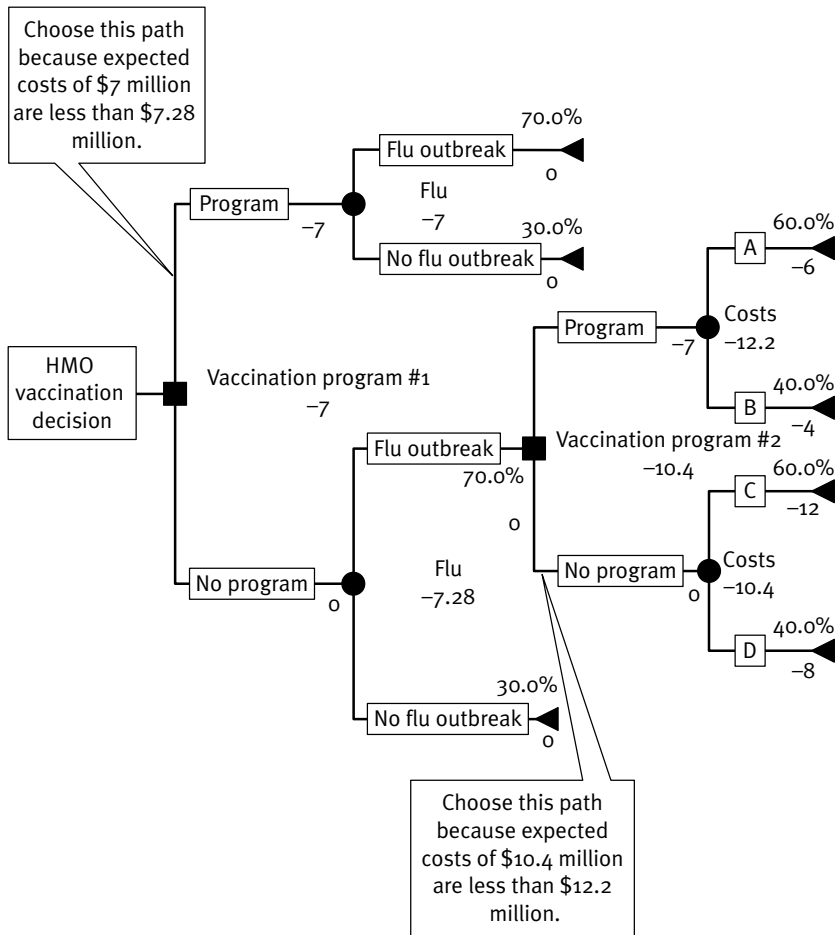
A risk analysis on this decision analysis can be conducted (Table 6.4). Choosing to implement the vaccination program results in a cost of $7 million with a probability of 1. Choosing not to implement the initial vaccination program results in a cost of $12 million with a probability of 0.42, $8 million with a probability of 0.28, and no cost with a probability of 0.3. Choosing not to implement the vaccination program would be less costly 30 percent of the time, but 70 percent of the time it would be less costly to implement the vaccination program.

A sensitivity analysis might also be conducted to determine the effect of changing some or all of the parameters in the analysis. For example, if the risk of a flu outbreak was 0.6 rather than 0.7 (and all other parameters stayed the same), the optimal decision would be to not offer either vaccination program (Figure 6.15).

For this example, dollars were used to represent costs (or benefits), but any type of score could also be used. In the medical field, decision trees are often used in deciding among a variety of treatment options using a measure or score for the outcome of the treatment (Detsky et al. 1997; Ruland 2002).

TABLE 6.4
Risk Analysis for HMO Vaccination Program Decision

	Initial Vaccination Program		No Initial Vaccination Program	
Number	*X*	*P*	*X*	*P*
1	−7	1	−12	0.42
2			−8	0.28
3			0	0.3

X = Cost in millions of dollars; P = Probability
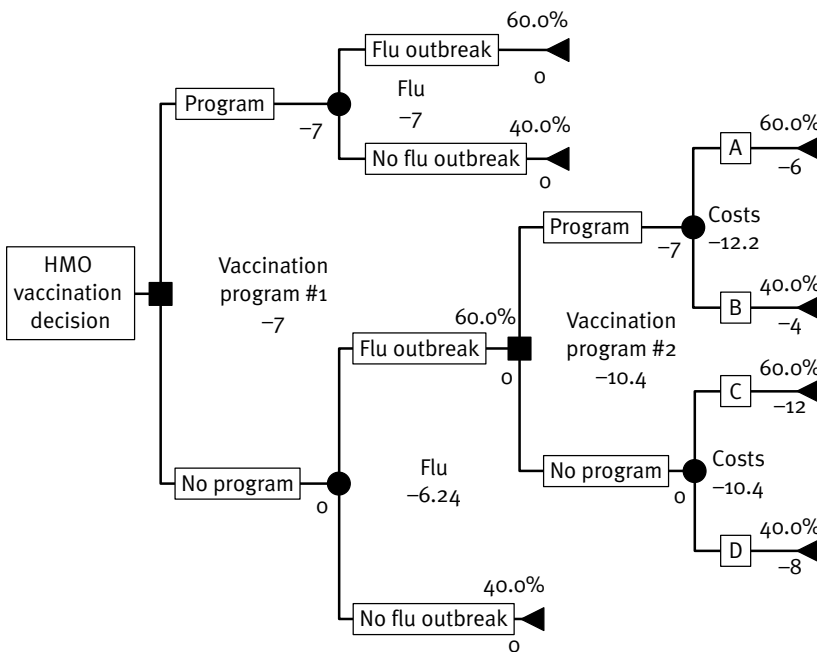
FIGURE 6.15
Decision Analysis Sensitivity to Change in Risk of Flu Outbreak

Decision trees can be a powerful aid to evaluating and choosing the optimal course of action. However, care must be taken when using them. Possible outcomes and the probabilities and benefits associated with them are only estimates, and these estimates could differ greatly from the reality. Also, when using expected value (or expected utility) to choose the optimum path, there is also an underlying assumption that the decision will be made over and over. On average the expected payout is received, but in each individual situation different amounts are received.

Implementation: Force Field Analysis

Derived from the work of Kurt Lewin (1951), force field analysis is a technique for evaluating all of the various forces for and against a proposed

Available resources	Present or past practices
Costs	Institutional policies or norms
Vested interests	Personal or group attitudes and
Regulations	needs
Organizational	Social or organizational norms and
structures	values

change. It can be used to decide if a proposed change can be successfully implemented. Alternatively, if a decision to change has already been made, force field analysis can be used to develop strategies that will enable the change to be implemented successfully.

In any situation, *driving forces* will help to achieve the change and *restraining forces* will work against the change. Force field analysis identifies these forces and assigns relative scores to each. Box 6.3 lists typical forces that should be considered. If the total score of the restraining forces is greater than the total score of the driving forces, the change may be doomed to failure. Force field analysis is typically used to determine how to strengthen or add driving forces or weaken the restraining forces to enable successful implementation of a change.

Patients at VVH believed that they were insufficiently involved in and informed about their care. After analyzing this problem, hospital staff believed that the problem could be solved (or lessened) by moving shift handover from the nurses' station to the patient's bedside. A force field analysis was conducted and is illustrated in Figure 6.16.

Although the restraining forces were greater than the driving forces in this example, a decision was made to implement the change in handover procedures. To improve the project's chances for success, a protocol was developed for the actual procedure, making explicit the following:

- Develop and disseminate the protocol (new driving force +2).
- Confidential information will be exchanged at the nurses' station, not at the bedside handover (decrease fear of disclosure by 2).
- Lateness was addressed and solutions were developed and incorporated into the protocol (decrease problems associated with late arrivals by 2).

These changes increased the driving forces by 2, to 21, and decreased the restraining forces by 4, to 17. The change was successfully implemented; more importantly, patients felt more involved in their care and complaints were reduced.
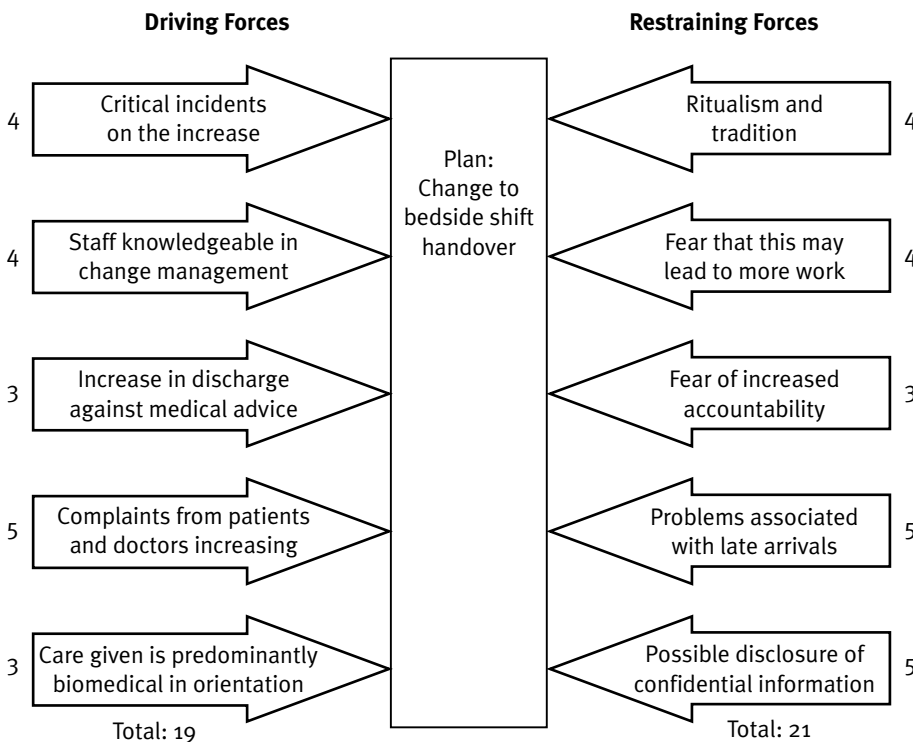
FIGURE 6.16
Force Field
Analysis

Driving Forces		Restraining Forces

4 — Critical incidents on the increase

Plan: Change to bedside shift handover

Ritualism and tradition — 4

4 — Staff knowledgeable in change management

Fear that this may lead to more work — 4

3 — Increase in discharge against medical advice

Fear of increased accountability — 3

5 — Complaints from patients and doctors increasing

Problems associated with late arrivals — 5

3 — Care given is predominantly biomedical in orientation

Possible disclosure of confidential information — 5

Total: 19   Total: 21

SOURCE: Adapted from Kassean and Jagoo (2005).

Conclusion

The tools and techniques outlined in this chapter are intended to help organizations along the path of continuous improvement. The choice of tool and when to use that tool is dependent on the problem to be solved; in many situations, several tools from this and other chapters should be used to ensure that the best possible solution has been found.

Discussion Questions

1. Answer the following questions quickly for a fun illustration of some of the ten decision traps:
   • Can a person living in Milwaukee, Wisconsin, be buried west of the Mississippi?
   • If you had only one match and entered a room where there was a lamp, an oil heater, and some kindling wood, which would you light first?
   • How many animals of each species did Moses take along on the ark?

- If a doctor gave you three pills and said to take one every half hour, how long would they last?
- If you have two U.S. coins totaling 55 cents and one of the coins is not a nickel, what are the two coins?

What decision traps did you fall into when answering these questions?

2. Discuss a problem your organization has solved or a suboptimal decision the organization made because the frame was incorrect.

Chapter Exercises

1. In the HMO vaccination program example, analyze the situation if the probability of a flu outbreak is only 65 percent and the cost of the vaccination program is $8 million. What would your decision be in this case?
2. In the DRG case-mix problem, VVH has determined that it could convert 15 of its routine beds to ICU beds for a cost of $2,000. What should VVH do and why?
3. The high cost of medical care and insurance is a growing societal problem. Develop a mind map of this problem. (Advanced: Use Inspiration software.)
4. Individually or in teams, develop a map of a healthcare process or system with which you are familiar. Make sure that your process map has a start and an endpoint, all inputs and outputs are defined, and all key process steps are included. Explain your map to the rest of the class—this may help you to determine if anything is missing. (Advanced: Use Microsoft Visio.)
5. For this exercise, choose a service offered by a healthcare organization and create a service blueprint. You may have to imagine some of the systems and services that take place backstage if you are unfamiliar with them.
6. Think of a problem in your healthcare organization. Perform an RCA of the identified problem using the five whys technique and a fishbone diagram.
7. Pick one solution to the problem identified in exercise 4 and do a force field analysis.
8. Complete the TOC exercise found at: http://webcampus.stthomas.edu/ cob/jmhays/ (Note: this is not a healthcare exercise, but it does help in understanding TOC.)

References

Buzan, T. 1991. *Use Both Sides of Your Brain.* New York: Plume.

Buzan, T., and B. Buzan. 1994. *The Mind Map Book: How to Use Radiant Thinking to Maximize Your Brain's Untapped Potential.* New York: Dutton.

Detsky, A. S., G. M. Naglie, M. D. Krahn, D. M. Naimark, and D. A. Redelmeier. 1997. "Primer on Medical Decision Analysis: Parts 1 to 5." *Medical Decision Making* 17 (2): 123–59.

Goldratt, E. M., and J. Cox. 1986. *The Goal: A Process of Ongoing Improvement*. New York: North River Press.

Institute for Healthcare Improvement. 2005. "Failure Mode and Effects Analysis Tool." [Online information; retrieved 1/1/06.] www.ihi.org/ihi/workspace/tools/fmea/.

Ishikawa, K. 1985. *What Is Total Quality Control?* Translated by D. J. Lu. Englewood Cliffs, NJ: Prentice-Hall Inc.

Joint Commission. 2005a. "Sentinel Event Forms and Tools." [Online information; retrieved 1/1/06.] www.jointcommission.org/SentinelEvents/Forms/.

———. 2005b. "Sentinel Event Policy and Procedures." [Online information; retrieved 1/1/06.] www.jointcommission.org/SentinelEvents/Policyand Procedures/.

———. 2001. "Patient Safety Standards—Hospitals." [Online information; retrieved 1/1/06.] www.jcrinc.com/subscribers/perspectives.asp?durki=2973 &site=10&return=2897.

Kassean, H. K., and Z. B. Jagoo. 2005. "Managing Change in the Nursing Handover from Traditional to Bedside Handover—A Case Study from Mauritius." *BMC Nursing* 4: 1.

Lewin, K. 1951. *Field Theory in Social Science: Selected Theoretical Papers*, edited by D. Cartwright. New York: Harper.

Reid, S. 2000. "Using the 'Theory of Constraints' Methodology to Increase, Improve Services to Patients." *ImpAct* 6 (March/April).

Ruland, C. 2002. "Patient Preferences in Health Care Decision Making." [Online information; retrieved 1/7/06.] www.dbmi.columbia.edu/homepages/cmr7001/sdm/html/methods.htm.

Russo, J. E., and P. J. H. Schoemaker. 1989. *Decision Traps: The Ten Barriers to Brilliant Decision-Making and How to Overcome Them*. New York: Simon & Schuster.

Shostack, G. L. 1984. "Designing Services that Deliver." *Harvard Business Review* 62 (1): 133–39.

Veterans Administration National Center for Patient Safety. 2006. "Healthcare Failure Mode and Effect Analysis (HFMEA)." [Online information; retrieved 1/7/06.] hwww.patientsafety.gov/SafetyTopics.html#HFMEA.

Wolstenholme, E. 1999. "A Patient Flow Perspective of UK Health Services: Exploring the Care for New 'Intermediate Care' Initiatives." *System Dynamics Review* 15 (3): 253–71.

Womack, D., and S. Flowers. 1999. "Improving System Performance: A Case Study in the Application of the Theory of Constraints." *Journal of Healthcare Management* 44 (5): 397–405.

Wysocki, B., Jr. 2004. "To Fix Health Care, Hospitals Take Tips from Factory Floor." *Wall Street Journal*, April 9, A1–A5. [Online information; retrieved 7/1/06.] http://prhi.org/pdfs/ACF28EB.pdf.

USING DATA AND STATISTICAL TOOLS FOR OPERATIONS IMPROVEMENT

CHAPTER OUTLINE

Design of Experiments
Conclusion

Which Technique to Use
Discussion Questions

Chapter Exercises
References

KEY TERMS AND ACRONYMS

additive property of proba-
    bility
α error, see Type I error
analysis of variance
    (ANOVA)
area sample, see cluster sam-
    ple
artificial neural network
    (ANN)
Bayes' theorem
β error, see Type II error
binomial distribution
bounds on probability
census
central limit theorem
central tendency
Chebyshev's rule
chi-square test (χ^2)
cluster sample
coefficient of determination
    (r^2)
coefficient of variation (CV)
conditional probability
confidence interval (CI)
convenience sample, see
    nonrandom sample
correlation coefficient (r)
design of experiments
    (DOE)
dot plot
exponential distribution
F-test

general linear model (GLM)
histogram
hypothesis test
logic of a study
mean absolute deviation
    (MAD)
mean, median, mode
multicollinearity
multiple regression
multiplicative property of
    probability
multivariate analysis of vari-
    ance (MANOVA)
nonrandom sample
normal distribution
normal probability plot
neural network (NN)
observed probability
odds
opinion probability
Pareto chart
Poisson distribution
population mean (μ), see
    mean
population standard devia-
    tion (σ), see standard
    deviation
population variance (σ^2), see
    variance
population
practical significance
precision

probability distribution
proportion
range
reliability
sample
sample size
scatter plot
sequential sample, see sys-
    tematic sample
simple linear regression
simple random sample
standard deviation
standard normal
    distribution, see
    z-distribution
statistical significance
stratified sample
systematic sample
t-distribution
theoretical probability
transformation
tree diagram
triangular distribution
t-test
turnip graph
Type I error
Type II error
uniform distribution
validity
variance
Venn diagram
z-distribution

Operations Management in Action

Who's Counting: Flu Deaths, Iraqi Dead Numbers Skewed

(Reprinted by permission of the author, John Allen Paulos)

Fear of an avian-flu pandemic is widespread and growing. It is, of course, a very serious concern—all the more reason for reports on avian flu to be as clear and informative as possible. On the whole, this standard has been reasonably approximated, but one glaring exception has been the reporting on the mortality rate from H5N1 avian flu.

News story after news story repeats the statistic that out of 140 or so human cases of avian flu reported so far in Southeast Asia, more than half have resulted in death. The reporters then intone that the mortality rate for avian flu is more than 50 percent.

This, of course, is a terrifying figure. But before examining it, let's first look for a bit of perspective. The standard sort of influenza virus, it's believed, infects somewhere between 20 million and 60 million people in this country annually. It kills an average of 35,000, and it thus has a mortality rate that is a minuscule fraction of 1 percent. The swine flu in the 1970s killed a handful of people, more of whom may have died from the vaccine for it than from the disease itself. And the Spanish flu of 1918 to 1919—the deadliest pandemic in modern history and also an avian flu—killed 500,000 to 700,000 people here and an estimated 20 million to 50 million people worldwide. Most assessments of its mortality rate range between 2 percent and 5 percent. If the avian H5N1 virus mutated so that human-to-human transmission was as easy as it is with the normal flu, and if the mortality rate of more than 50 percent held, the U.S. alone would be facing tens of millions of deaths from the avian flu.

Sample Bias

There is one glaring problem with this purported mortality rate of more than 50 percent, however: It is based on those cases that have been reported, and this leads to an almost textbook case of sample bias. You wouldn't estimate the percentage of alcoholics by focusing your research on bar patrons, nor would you estimate the percentage of sports fans by hanging around sports stadiums. Why do something analogous when estimating the avian-flu mortality percentage?

Who goes to hospitals and emergency rooms but people who are very sick? Who doesn't go to hospitals and emergency rooms but people who are not so very sick?

Given how many people in Southeast Asia deal with chickens and other poultry in a hands-on way, some unknown, but likely quite large num-

ber of them have contracted avian H5N1 flu over the past several years. Its symptoms are many times indistinguishable from those of the normal flu. Some no doubt have died of it, but the majority are likely to have recovered. The people who have recovered from the avian flu don't make it into the mortality-rate calculations, which are, as a consequence, likely to be skewed substantially upward.

Little Is Known About Changes and Virulence

The Centers for Disease Control and Prevention cautiously acknowledges on its website that it is quite possible that "the only cases currently being reported are those in the most severely ill people." Random samples—the lifeblood of statistics—are hard to obtain under the best of circumstances, and canvassing poor people in rural Southeast Asia certainly doesn't qualify. The fact is that not only is it almost impossible to estimate how long it might take for the present H5N1 virus to mutate into one easily transmitted between humans, but it's almost impossible as well to estimate the virulence of such a virus. Sample bias, various epidemiological models, and the fact that extremely virulent viruses are less likely to spread—because they kill a high percentage of their hosts—all suggest that a mortality rate of more than 50 percent is much, much too high.

This, of course, does not mean complacency is in order. It does mean that everyone—health professionals, the media, and politicians—should try very hard not to hype risks or minimize them.

Postscript on Iraqi War Dead

Another figure in the news recently has been the number of Iraqis killed in the war. President Bush mentioned last month that in addition to the more than 2,100 American soldiers killed so far in Iraq, that there were approximately 30,000 Iraqis killed. He was likely referring to the approximate figure put out by Iraq Body Count, a group of primarily British researchers who use online Western media reports to compile an extensive list of Iraqi civilians killed. The organization checks the names and associated details of those killed. It necessarily misses all those whose names don't make it into the reports, and it makes no attempt to estimate the number it misses. The group's list contains almost 30,000 names at present.

A study that appeared in the prestigious British medical journal, The Lancet, in October 2004, used statistical sampling techniques to estimate all Iraqis killed because of the war and its myriad direct and indirect effects. The figure researchers came up with at that time—15 months ago—was approximately 100,000 dead, albeit with a large margin of error. The

Lancet study used the same techniques that Les F. Roberts, a researcher at Johns Hopkins and lead author of the study, used to investigate mortality caused by the wars in Bosnia, the Congo, and Rwanda. Although Roberts' work in those locations was unquestioned and widely cited by many, including British Prime Minister Tony Blair and former Secretary of State Colin Powell, The Lancet estimates on Iraq were unfortunately dismissed or ignored in 2004.

These last 15 months have considerably raised the American death toll, the IBC numbers, and any update that may be in the works for The Lancet's staggering 100,000 figure. In fact, if the Lancet estimates rose at a rate proportional to the IBC's numbers since October 2004—from about 17,000 then to about 30,000—the updated figure would be approximately 175,000 Iraqis dead since the war began.

Overview

The focus of this chapter is on data collection and analysis. Knowledge-based management and improvement require that decisions be based on facts rather than on feeling or intuition. Collecting the right data and analyzing them correctly enables fact-based decision making.

Many of the philosophies and tools (e.g., quality, Lean, simulation) discussed in later chapters of this book require a basic knowledge of data collection, probability, and statistical analysis. For those readers with little or no background in statistics or probability, this chapter is meant to provide an introduction to the basic concepts and tools, many of which are an integral part of the continuous improvement philosophy of quality and Lean. For readers with greater understanding of statistics and probability, this chapter is intended to be a review of the important concepts underlying the methodologies covered in later chapters. The major topics covered include:

- Data collection;
- Graphic tools for data presentation and analysis;
- Probability and probability distributions; and
- Mathematic tools for data analysis including hypothesis testing, analysis of variance, and regression.

More in-depth coverage of the topics in this chapter can be found on ache.org/books/OpsManagement.

This chapter gives readers a basic understanding of probability and statistics to enable them to:

- Collect valid data;
- Analyze data using the appropriate graphic or mathematic technique; and
- Ultimately, make decisions based in fact.

Data Collection

To design effective and efficient systems or improve existing systems, knowledge of the system, including both inputs to the system and the desired output, is needed. The goal of data collection is to obtain valid data to better understand and improve the system being studied. Decisions or solutions based on invalid data are doomed to failure. Ensuring that the data obtained are valid is the most important part of any study, and often the most problematic. A valid study has no logic, sampling, or measurement errors.

Logic
The first step in data collection is determining the question(s) that will be asked of the data. Why are the data needed, and what will they be used for? Are the patterns of the past going to be repeated in the future? If there is reason to believe that the future will look different than the past, data from the past will not help to answer the question, and other, nonquantitative methods should be used. This is the logic phase of the data collection process, where the focus is on ensuring that the right question is being asked and that it is possible to answer that question.

Selection or Sampling
Census versus sample
Next, one needs to determine who or which objects are relevant to the question or situation. Here, a determination is made as to whether a sample or a census is appropriate. Typically, a census is used if all of the data are available in an easily accessible format. A sample is used if it would be cost or time prohibitive to obtain all of the data in a usable format. If it is determined that a sample is appropriate, *how* to sample from the population of interest must be determined.

Nonrandom sampling methods
Nonrandom, or convenience, methods are selection procedures where there is no specific probability of selecting any particular unit. They should only be used as a last resort, if random methods are unavailable or would be cost prohibitive, because of the possibility that they will not be representative of the targeted population of interest. Nonrandom methods include self-selected

groups in which the members are volunteers and groups in which the units are most accessible and convenient for the researcher.

Simple random sampling
In simple random sampling, every unit in the population has an equal chance of being chosen.

Stratified sampling
In stratified sampling, the population is first divided into segments, and a random sample is taken from each segment. Stratified sampling is used to force representation by all segments of the population. This type of sampling is typically used where a simple random sample might miss some segments of the population, usually because the population contains few of them.

Systematic sampling
In systematic, or sequential, sampling every 10th or Xth unit is chosen. Although this type of sampling is sometimes easier to administer, caution must be used to ensure that the population is not work misrepresented. For example, if a decision was made to look at every 5th work day and this always falls on Friday, the sample obtained might not be representative of the whole week.

Cluster sampling
In cluster, or area, sampling, units are grouped or clustered, and a simple random or stratified sample is taken from the grouped units. This is typically done when it would be cost or time prohibitive to obtain the data from a simple random sample. For example, if a study was based on face-to-face interviews of patients, and the population of interest was every person who visited an emergency department for heart-related problems in Minnesota, generating a list of all people who visited an emergency department for heart-related problems in Minnesota and then randomly sampling from this list would necessitate extensive travel to reach the subjects. Instead, the hospitals could be clustered by size, a random sample of hospitals within these clusters would be taken, and only patients at the chosen hospitals would be interviewed. This would greatly reduce the interviewers' travel.

Sample size
Sample size is determined by how certain the conclusions of a study are desired to be. Population size is irrelevant; larger populations do not need larger sample sizes. However, variation in the population does affect the needed sample size: As variation increases, larger sample sizes are needed to obtain the same level of certainty. Larger samples (assuming they are valid) enable greater certainty about the conclusions.

Measurement

In the measurement phase of the data collection process, one must determine how to measure the characteristic of interest. Often, direct measures of the characteristic of interest are difficult to obtain, and a proxy for the variable must be identified.

It is useful to distinguish between two broad types of variables: categoric, or qualitative, and numeric, or quantitative. Each is broken down into two subtypes: qualitative data can be ordinal or nominal, and quantitative data can be discrete (often, integer) or continuous. Because qualitative data always have a limited number of alternative values, they are sometimes also described as discrete. All qualitative data are discrete, whereas some numeric data are discrete and some are continuous. For statistical analyses, qualitative data can often be converted into discrete numeric data by counting the number of units in each category.

Measurement errors arise from a lack of precision, accuracy, or reliability.

Precision

The precision of a measurement is its degree of fineness. For example, in a study of patient weight, weight could be measured to the nearest ten pounds, one pound, one ounce, and so forth. The precision of a measurement for a study should be determined on the basis of the study's requirements. Typically, greater precision is more costly or time consuming.

Accuracy

Accuracy is related to whether the measurements are "on target." An accurate measurement is not biased in any way. For example, in a study of patient compliance, the accuracy of the measurement would be poor if the patients did not tell the truth.

Reliability

Reliability is related to repeatability. Will the measurement be the same if it is repeated? If the study was repeated on the same (or a similar) sample, would the outcome be the same? If a patient is tested for diabetes, the test would be reliable if it could be repeated and the same results obtained. A pictorial comparison is shown in Figure 7.1.

Validity

The importance of ensuring that a study is valid cannot be overemphasized. For a study to be valid, it must have no logic, sampling, or measurement errors. Each of these threats to validity should be assessed and eliminated to ensure the validity of the data and study. Conclusions or decisions made based on an invalid study are themselves invalid. Valuable time and effort will

Reliable, but not accurate	Reliable and accurate	Not reliable but, on average, accurate
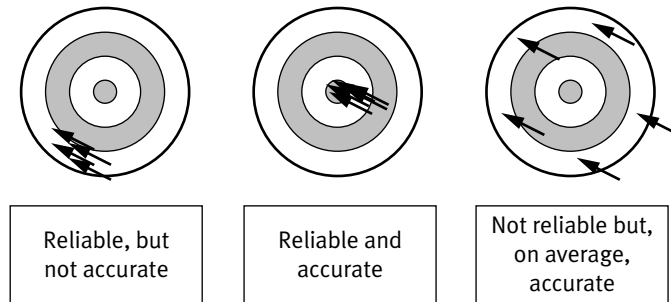
be wasted on data collection if those data do not enable better decisions. Figure 7.2 illustrates the issues and choices involved in data collection.

Ethical and Legal Considerations

Often, ethical and legal considerations are involved in collecting, analyzing, and reporting data. For healthcare organizations in particular, patient confidentiality and privacy may need to be addressed in the design and execution of any study. Ethical considerations and legal compliance should be an integral part of the design of any study undertaken by an organization.

Graphic Tools

Mapping

Graphic tools such as mind mapping can be employed to enable the collection of valid data. A mind map can be used to help frame the problem or question in an attempt to avoid logic errors (Figure 7.2 and Chapter 6).

Visual Representations of Data

Once valid data are collected, those data need to be analyzed to answer the original question or make a decision. The data need to be examined not only to determine their general characteristics, but also to look for interesting or unusual patterns. Subsequent sections of this chapter outline numeric tools that can be employed for this purpose.

Visual representations of the data can be powerful in both answering questions and convincing others of the answers. Tufte (1983, 1990, 1997) provides guidance for visual presentation of data. The following sections present graphic analysis tools. The human mind is powerful and has the ability to discern patterns in data, which numeric methods can then be used to validate. The first step in data analysis is always to graph the data.

FIGURE 7.2
Data Collection Map
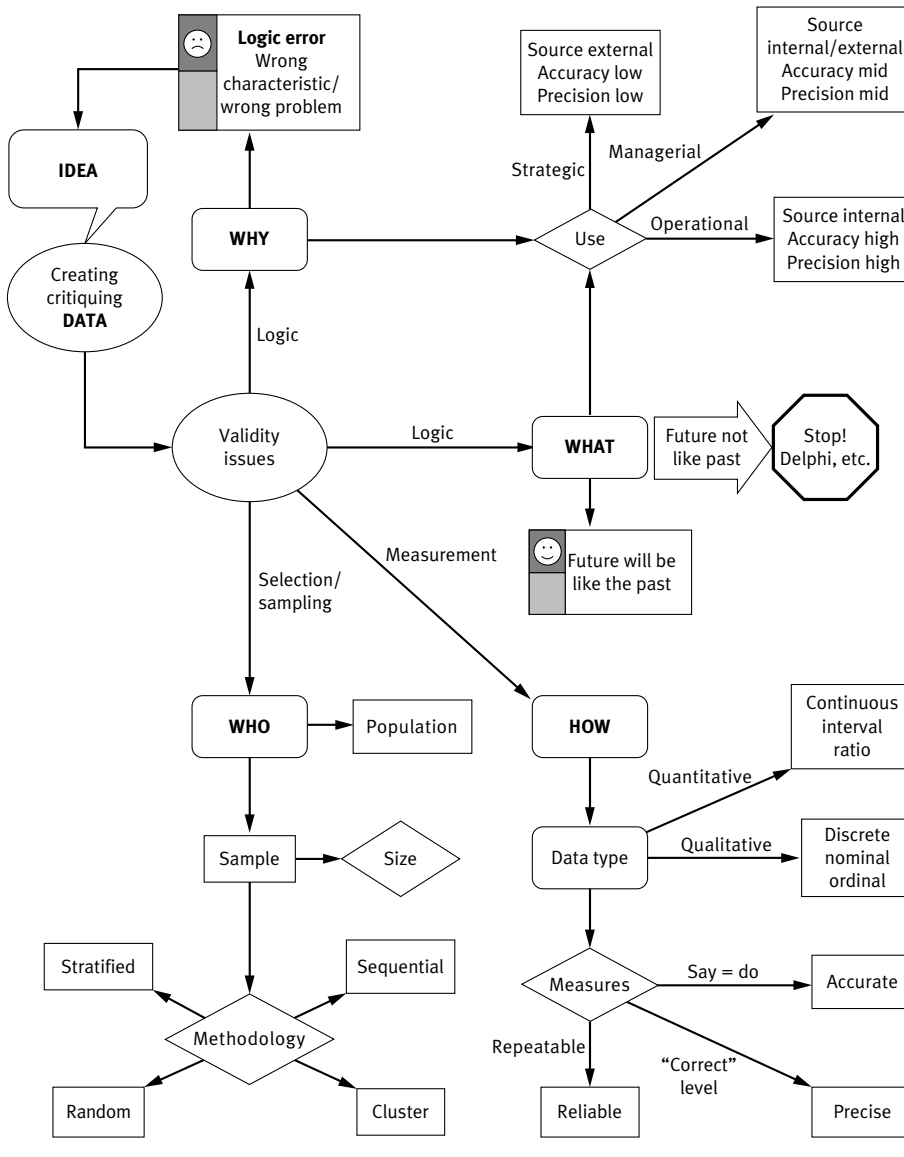
Histograms and Pareto Charts

Histograms and Pareto charts are two of the seven basic quality tools (Chapter 8). A histogram (Figure 7.3) is used to summarize discrete or continuous data. These graphs can be useful for investigating or illustrating important characteristics of the data such as their overall shape, symmetry, location, spread, outliers, clusters, and gaps. However, for some distributions, a particular choice of bin width can distort the features of a data set. (For an example of this problem, see the Old Faithful Histogram applet linked from the companion web site at ache.org/books.OpsManagement.)

FIGURE 7.3
Histogram of
Length of
Hospital Stay
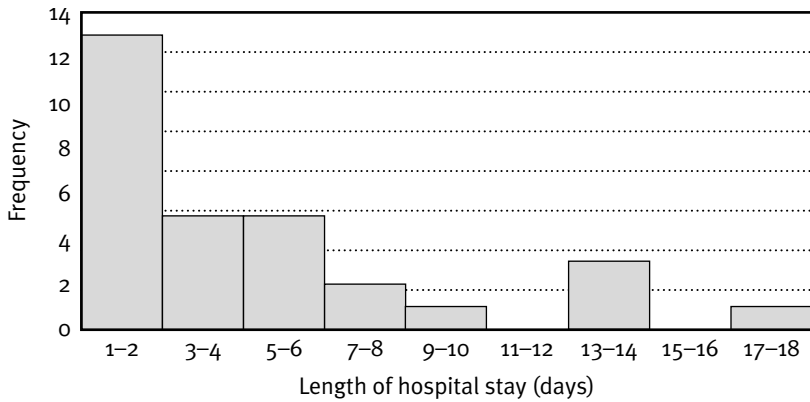
To construct a histogram, the data are divided or grouped into classes. For each group, a rectangle is constructed with its base equal to the range of values in the group and its area proportional to the number of observations falling into the group. If the ranges are the same length, the height of the histogram will also be proportional to the number of observations falling into that group.

For categoric data, a bar chart is typically used, and the data are grouped by category. The height of each bar is proportional to the number of observations. A Pareto diagram (Figure 7.4) is simply a bar chart or histogram sorted by frequency of occurrence.

Dot Plots

A dot plot (Figure 7.5) is similar to a histogram, but the frequency of occurrence is represented by a dot. Dot plots are useful for displaying small data sets with positive values because they are quick and easy to construct by hand.

FIGURE 7.4
Pareto Diagram
of Diagnosis
Category
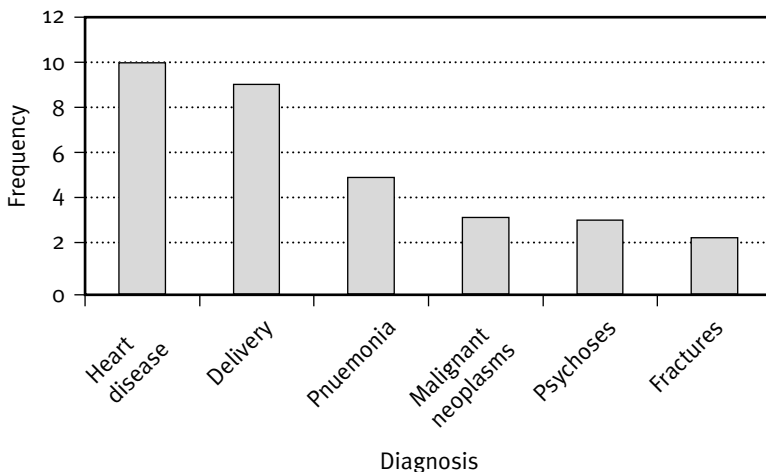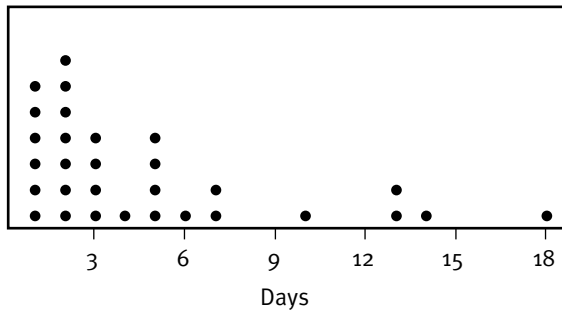
FIGURE 7.5
Dot Plot of Length of Hospital Stay

Turnip Graphs

A turnip graph is similar to a dot plot, but it is centered. Intervals are on the vertical axis of the plot, and symbols (or dots) are placed horizontally on the intervals to represent the frequency of occurrence or number of observations in that interval (Figure 7.6).

Normal Probability Plots

A normal probability plot (Figure 7.7), sometimes called a quantile plot, is a visual display of the normality (or lack of normality) in a given set of data. Many statistical tests and techniques assume or require that the data be nor-
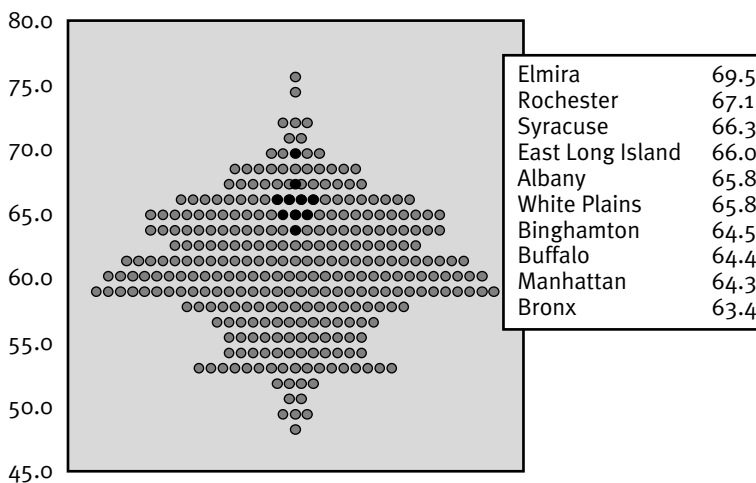
FIGURE 7.6

Turnip Graph: Medicare Enrollees with Diabetes Receiving Eye Exams Among 306 Hospital Referral Regions, 2001

Elmira	69.5
Rochester	67.1
Syracuse	66.3
East Long Island	66.0
Albany	65.8
White Plains	65.8
Binghamton	64.5
Buffalo	64.4
Manhattan	64.3
Bronx	63.4

NOTE: Each dot represents the score of a region on a quality measure for diabetes. The numerator is the number of patients with diabetes who received the medically necessary care, an examination. The denominator is the number of patients with diabetes living in the region.
SOURCE: Wennberg (2005). Data from the Dartmouth Atlas Project, figure copyrighted by the Trustees of Dartmouth College. Used with permission.

FIGURE 7.7
Normal
Probability Plot
of Length of
Hospital Stay
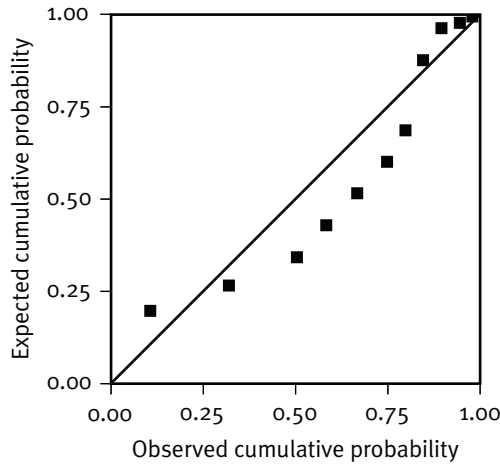
mally distributed. The normal plot can help to determine this. Although other graphic displays can help to determine if the distribution is bell shaped, the normal plot is more useful in determining symmetry, lack of outliers, and weight of the tails.

The normal plot is a scatter plot of the actual data values plotted against the "ideal" values from a normal distribution. If the data are normally distributed, the plotted points will lie close to a diagonal straight line. Systematic deviations from a line indicate a non-normal distribution.

Scatter Plots

Scatter plots are another of the seven basic quality tools (Chapter 8). A scatter plot graphically displays the relationship between a pair of variables and can give initial information on whether two variables are related, how strongly they are related, and the direction of the relationship. For example, is there a relationship between length of hospital stay and weight? Does length of stay increase (decrease) as weight increases? How strong is the relationship between length of stay and weight? A scatter plot can help to answer these questions. Regression, the statistical tool related to scatter plots that gives more detailed, numeric answers to these questions, is discussed later in this chapter.

To construct a scatter plot related to the aforementioned questions, data on length of hospital stay and weight from the population of interest would be collected. Typically, the "cause," or independent variable, is on the horizontal (x) axis and the "effect," or dependent variable, is on the vertical (y) axis. Each pair of variables is plotted on this graph. Some typical scatter plots and their interpretations are shown in Figure 7.8.
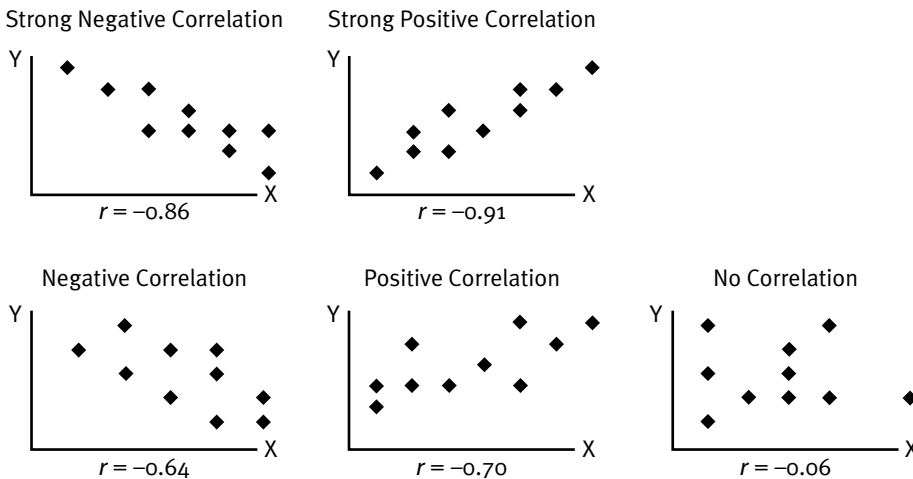
FIGURE 7.8
Typical Scatter Plots and their Interpretations

Mathematic Descriptions

When describing or summarizing data, three characteristics are usually of interest: central tendency, spread or variation, and probability distribution. In this section, the following simple data set is used to illustrate some of these measures: 3, 6, 8, 3, 5.

Measures of Central Tendency
The three common measures of central tendency are mean, median, and mode.

Mean
The mean is the arithmetic average of the population:

$$\text{Population mean} = \mu = \frac{\sum x}{N},$$

where x = individual values and

N = number of values in the population.

The population mean can be estimated from a sample:

$$\text{Sample mean} = \bar{x} = \frac{\sum x}{n},$$

where n = number of values in the sample.

For our simple data set, $\bar{x} = \dfrac{3+6+8+3+5}{5} = 5$

Median

The median is the middle value of the sample or population. If the data are arranged into an array (an ordered data set),

$$3, 3, \underset{\uparrow}{5}, 6, 8,$$

5 would be the middle value or median.

Mode

The mode is the most frequently occurring value. In the previous example, the value 3 occurs more often (two times) than any other value, so 3 would be the mode.

Measures of Variability

Several measures are commonly used to summarize the variability of the data, including variance, standard deviation, mean absolute deviation (MAD), and range.

Range

A simple way to capture the variability or spread in the data is to take the range, the difference between the high and low values. All of the information in the data is not being used with this measure, but it is simple to calculate:

$$\text{Range} = x_{high} - x_{low} = 8 - 3 = 5$$

Mean absolute deviation

Another possible measure of the variability or spread in the data is the average difference from the mean. However, for any data set this will equal zero, because the values above the mean will balance the values below the mean. One way to eliminate this problem is to take the absolute value of the differences from the mean. This measure is called the MAD and is commonly used in forecasting to measure variability. However, absolute values are difficult to work with mathematically:

$$\text{MAD} = \frac{\sum |x - \bar{x}|}{n} = \frac{2 + 1 + 3 + 2 + 0}{5} = \frac{8}{5} = 1.6$$

Variance

The average square difference from the mean—called the variance—provides another measure of the variability in the data. For a population, variance is a

good estimator. However, for a sample it can be proven that variance is a biased estimator and needs to be adjusted; rather than dividing by n, the number of values in the sample, it must be divided by $n{-}1$:

$$\text{Population variance} = \sigma^2 = \frac{\sum (x - \mu)^2}{N} = \frac{4 + 1 + 9 + 4 + 0}{5} = \frac{18}{5} = 3.6$$

$$\text{Sample variance} = s^2 = \frac{\sum (x - \bar{x})^2}{n - 1} = \frac{4 + 1 + 9 + 4 + 0}{5 - 1} = \frac{18}{4} = 4.5$$

Standard deviation

Taking the square root of the variance will result in the units on this measure being the same as the units of the mean, median, and mode. This measure, the standard deviation, is the most commonly used measure of variability.

$$\text{Population standard deviation} = \sqrt{\sigma^2}$$

$$= \sqrt{\frac{\sum (x - \mu)^2}{N}}$$

$$= \sqrt{\frac{4 + 4 + 0 + 1 + 9}{5}} = \sqrt{\frac{18}{5}} = \sqrt{3.6} = 1.9$$

$$\text{Sample standard deviation} = \sqrt{s^2}$$

$$= \sqrt{\frac{\sum (x - \bar{x})^2}{n}}$$

$$= \sqrt{\frac{4 + 4 + 0 + 1 + 9}{5 - 1}} = \sqrt{\frac{18}{4}} = \sqrt{4.5} = 2.1$$

Coefficient of variation

Given another data set (data B) with a standard deviation of 5 and the sample data set (data A) with a standard deviation of 1.9 and a mean of 5, which data are more variable? This question cannot be answered without knowing the mean of data B. If the mean of data B is 5, then data B is more variable. However, if the mean of data B is 25, data B is less variable. The coefficient of variation (CV) is a measure of the relative variation in the data.

$$\text{Coefficient of variation} = \text{CV} = \frac{\sigma}{\mu}$$

or

$$\frac{s}{x} = \frac{1.9}{5} = 0.4$$

Probability and Probability Distributions

Throughout history, people have tried to deal with the uncertainties inherent in the world. Myth, magic, and religion all played a role in explaining the variability of the universe, and inexplicable events were attributed to a higher being, fate, or luck. People have a need to feel in control, or at least a desire to predict how the world will behave.

Two types of models exist to explain what is seen in the world: deterministic and probabilistic. In a deterministic model, the given inputs *determine* the output with certainty. For example, given a person's date of birth and the current date, her age can be determined. The inputs determine the output.

Date of Birth
Current Date $\longrightarrow$ | Age Model | $\longrightarrow$ Person's Age

In a probabilistic model, the given inputs provide only an *estimate* of the output. For example, given a person's age, her remaining life span can only be *estimated*.

Age $\longrightarrow$ | Life Span Model | $\longrightarrow$ Person's Remaining Life Span
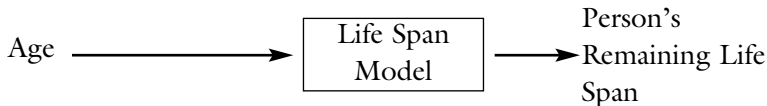
Determination of Probabilities

Probabilities can be determined through observation or experimentation; through applying theory or reason; or subjectively, through opinion.

Observed probability

Observed probability is a summary of the observations or experiments and is referred to as empirical probability or relative frequency. Observed probability is the relative frequency of an event—the number of times the event occurred divided by the total number of trials.

$$P(A) = \frac{\text{Number of times A occurred}}{\text{Total number of observations, trials, or experiments}} = \frac{r}{n}$$

Drug or protocol effectiveness is often determined in this manner:

$$P(\text{Drug is effective}) = \frac{\text{Number of times patients cured}}{\text{Total number of patients given the drug}} = \frac{r}{n}$$

Theoretical probability

The second method of determining probability, the theoretical relative frequency of an event, is based on logic—it is the theoretical number of times an event will occur divided by the total number of possible outcomes.

$$P(A) = \frac{\text{Number of times A could occur}}{\text{Total number of possible outcomes}} = \frac{r}{n}$$

Casino revenues are based on this theoretical determination of probability. If a card is randomly selected from a common deck of 52, the probability that it will be a spade is determined as follows:

$$P(\text{Card is a spade}) = \frac{\text{Number of spades in the deck}}{\text{Total number of cards in the deck}} = \frac{13}{52} = 0.25$$

Opinion probability

The final method for determining probability is based on opinion. Opinion probability is a subjective determination based on an individual's personal judgment about how likely an event is to occur; it is not based on a precise computation but is often a reasonable assessment by a knowledgeable person—it is an opinion about the number of times an event will occur divided by the imaginary total number of possible outcomes or trials.

$$P(A) = \frac{\text{Opinion of number of times an event will occur}}{\text{Theoretical total}} = \frac{r}{n}$$

Handicapping horse races or sporting events is an example of this type of probability determination:

$$P(\text{Secretariat winning the Belmont Stakes}) =$$
$$\frac{\text{Opinion on the number of times Secretariat would win the Belmont}}{\text{Imaginary total number of times the Belmont would be run}} = \frac{r}{n}$$

Odds are sometimes used to refer to this type of probability. In the previous example, if the handicapper believes the odds of Secretariat winning the Belmont Stakes are 20 to 3, this means that if the Belmont is run 23 times under conditions identical to the time in question, Secretariat would win 20 times and lose 3 times.

No matter how they are determined, all probabilities have certain properties.

Properties of Probabilities
Bounds on probability

Probabilities are bounded. The least number of times an event could occur is zero; therefore, probabilities must always be greater than or equal to zero, and an event that cannot occur will have a probability of zero. The largest number of times an event could occur is equal to the total possible number of outcomes—t cannot be any larger; therefore, probabilities must always be less than or equal to one:

$$0 \le P(A) \le 1$$

The sum of the probabilities of all possible outcomes is one. From this property, it follows that:

$$P(A) + P(A') = 1 \text{ and } 1 - P(A') = P(A)$$

where A' is not A. This property can be useful when determining probabilities: Often, it is easier to determine the probability of "not A" than to determine the probability of A.

Multiplicative property

Two events are independent if the outcome of one event does not affect the outcome of the other event. For two independent events, the probability of both A **and** B occurring, or the intersection ($\cap$) of A and B, is the probability of A occurring times the probability of B occurring:

$$P(A \textbf{ and } B \text{ occurring}) = P(A \cap B) = P(A) \times P(B)$$

Combining a coin toss with a die toss, what is the probability of obtaining both heads and a three?

$$P(H \cap 3) = P(H) \times P(3) = \frac{1}{2} \times \frac{1}{6} = \frac{1}{12}$$

A tree diagram (Figure 7.9) or a Venn diagram (Figure 7.10) can be used to illustrate this property. Note that decision trees (Chapter 6) are different from the tree diagrams presented here. Decision trees follow a time progression and analyses of the choices that can be made at particular points in time.

FIGURE 7.9
Tree
Diagram—
Multiplicative
Property

FIGURE 7.10
Venn
Diagram—
Multiplicative
Property

The multiplicative property provides a way to test whether events are independent. If they are not independent,

$$P(A \cap B) \neq P(A) \times P(B).$$

Additive property

For two events, the probability of A **or** B occurring, the union ($\cup$) of A with B, is the probability of A occurring, plus the probability of B occurring, minus the probability of both A and B occurring:

$$P(A \text{ or } B \text{ occurring}) = P(A \cup B) = P(A) + P(B) + P(A \cap B)$$

Combining a coin toss with a die toss, what is the probability of obtaining heads or a 3, but not both?

$$P(H \cup 3) = P(H) + P(3) - P(H \cap 3) = \frac{1}{2} + \frac{1}{6} - \frac{1}{12} = \frac{6}{12} + \frac{2}{12} - \frac{1}{12} = \frac{7}{12}$$

A tree diagram (Figure 7.11) or Venn diagram can be used to illustrate the additive property.

Conditional probability

In some cases, it is possible to revise the estimate of the probability of an event occurring if more information is obtained. For example, suppose a patient usually waits in the emergency department for fewer than 30 minutes before being moved into an exam room. However, on Friday nights, when the department is busy, the wait is longer. Therefore, if it is a Friday night, the probability of waiting for 30 minutes or less is lower. This is the conditional probability of waiting less than 30 minutes given that it is a Friday night.

The conditional probability that A will occur given that B occurred is

$$P(A|B) = \frac{P(A \cap B)}{P(B)}$$

Suppose a study was done of 100 emergency department patients; 50 patients were observed on a Friday night and 50 patients were observed at other times. On Friday night, 20 people waited fewer than 30 minutes, but 30 people waited more than 30 minutes. At other times, 40 people waited fewer than 30 minutes, and only 10 people waited more than 30 minutes. A contingency table (Table 7.1) is used to summarize this information.

Contingency tables are used to examine the relationships between qualitative or categoric variables. A contingency table shows the frequency of one vari-
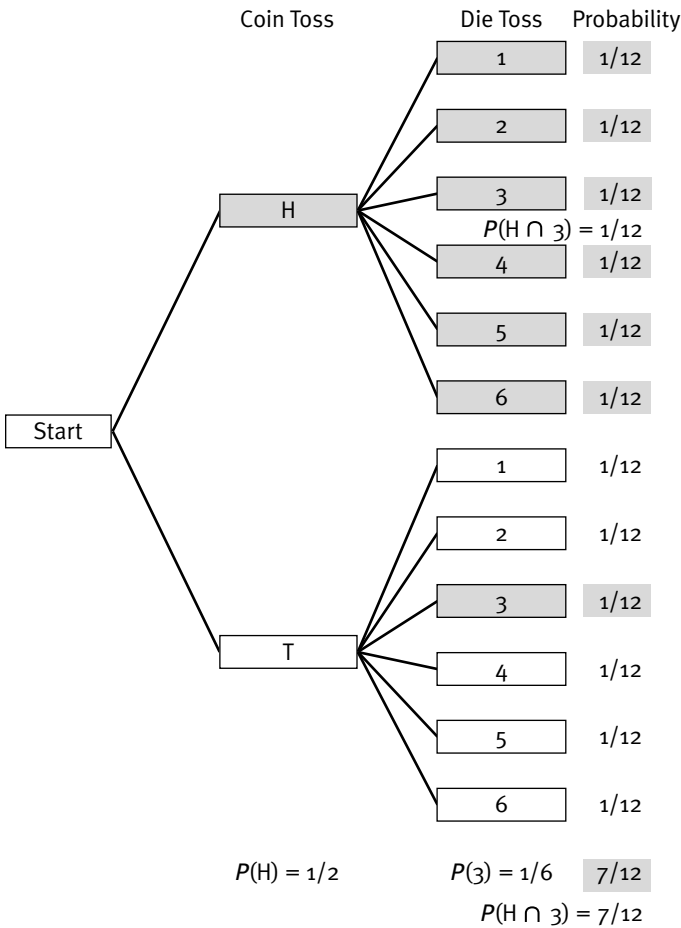
FIGURE 7.11
Tree
Diagram—
Additive
Property

	≤ 30-Minute Wait	> 30-Minute Wait	
Friday night	20	30	50
Other times	40	10	50
Total	60	40	100

TABLE 7.1
Contingency
Table for
Emergency
Department
Wait Times

able as a function of another variable. The column an observation is in (≤ or > 30 minutes) is contingent upon (depends on) the row the subject is in (time of day).

For all patients, the probability of waiting longer than 30 minutes is:

$$P(\text{Wait} > 30 \text{ minutes}) = \frac{\text{Number of patients who wait} > 30 \text{ Minutes}}{\text{Total number of patients}}$$

$$= \frac{40}{100}$$

$$= 0.40$$

Furthermore, the (conditional) probability of waiting more than 30 minutes given that it is Friday night is:

$$P(A|\text{Friday night}) = \frac{P(\text{Wait} > 30 \text{ Minutes and Friday night})}{P(\text{Friday night})}$$

$$\frac{\text{Number of Patients Who Wait} > 30 \text{ Minutes on Friday night}}{\text{Number of Patients on Friday night}}$$

$$= \frac{30}{50}$$

$$= 0.60$$

A tree diagram for this example is shown in Figure 7.12.

Note that $P(A \cap B) = P(A|B) \times P(B) = P(B|A) \times P(A)$, and if one event has no effect on the other event (the events are independent), then $P(A|B) = P(A)$ and $P(A \cap B) = P(A) \times P(B)$. In the coin and dice example, the coin toss and die toss are independent events, so the probability of tossing a 6 is the same no matter the outcome of the coin toss. For the emergency department wait time example, if night and wait time were independent, then the probability of waiting fewer than 30 minutes on a Friday night would be $0.5 \times 0.6 = 0.30$. But this is not true, wait time and night are not independent—they are related. From this simple study, it could not be concluded that Friday night causes wait time.

Bayes' theorem allows the use of new information to update the conditional probability of an event. It is stated as follows:

$$P(A|B) = \frac{P(A \cap B)}{P(B)} = \frac{P(B|A) \times P(A)}{P(B)} = \frac{P(B|A) \times P(A)}{P(B|A) \times P(A) + P(B|A') \times P(A')}$$

Bayes' theorem is often used to evaluate the probability of a false-positive test result. If a test for a particular disease is performed on a patient,

	Night	Wait Time	Probability	Conditional Probability
Start	Friday	≤ 30 minutes	0.2	0.3/0.5 = 0.6
		> 30 minutes	0.3	
	Other	≤ 30 minutes	0.4	
		> 30 minutes	0.1	
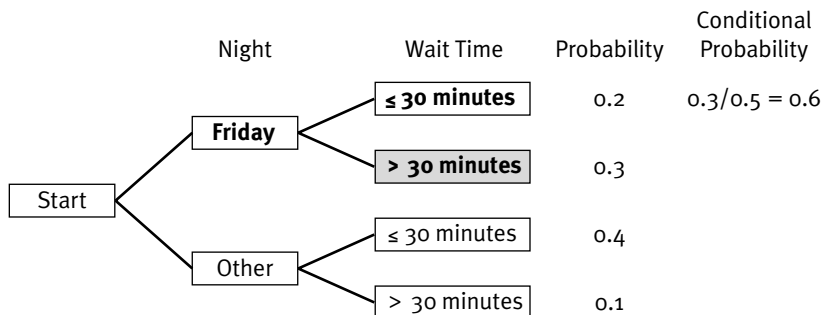
there is a chance that the test will return a positive result even if the patient does not have the disease. Bayes' theorem allows the determination of the probability that a person who tests positive for a disease actually has the disease. For example, if a tested patient has the disease, the test reports that with 99 percent accuracy, and if the patient does not have the disease, the test reports that with 95 percent accuracy; also, suppose that the incidence of the disease is rare—only 0.1 percent of the population has the disease:

$$P(\text{No disease | Test positive}) =$$

$$\frac{P(\text{Test positive | No disease}) \times P(\text{No disease})}{P(\text{Test positive | No disease}) \times P(\text{No disease}) + P(\text{Test positive | Disease}) \times P(\text{Disease})}$$

$$\frac{0.050 \times 0.999}{0.050 \times 0.999 + 0.990 \times 0.001} = 0.981$$

A tree diagram (Figure 7.13) helps to illustrate this problem.

The test results are positive $0.00099 + 0.04995 = 0.05094$ of the time; 0.049955 of that time, the person does not have the disease. Therefore, the probability that a person does not have the disease, although the test for the disease was positive, is:

$$\frac{0.049955}{0.05094} = 0.981, \text{ or } 98.1 \text{ percent}$$

Probability Distributions

A probability distribution is a tabulation or function used to summarize knowledge about the random variable in question. It represents the probability of an event associated with all possible outcomes. Probability distributions can be used to model or simulate a situation and can help to solve
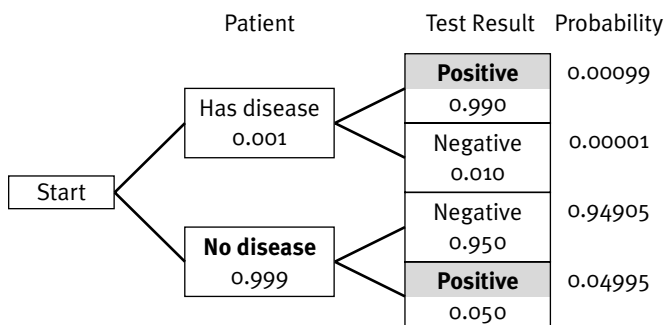
FIGURE 7.13
Tree Diagram—Bayes' Theorem Example

problems and answer questions. See Chapters 10 and 12 for examples of the uses of probability distributions.

Discrete Probability Distributions

Discrete probability distributions are associated with discrete random variables. The variables can be described by an exact (only one) number or description.

Binomial distribution

The binomial distribution describes the number of times that an event will occur in a sequence of events. The event is binary—it will either occur or it will not. The binomial distribution is used to determine whether an event will occur, not the magnitude of the event. For example, in a clinical trial the variable of interest might be whether the patient survives. The binomial distribution describes the probability of survival, not how long the patient survives.

The binomial distribution is specified by the number of observations, n, and the probability of occurrence, p. An example often used to illustrate the binomial distribution is the tossing of a coin. If a coin is tossed three times, the possible outcomes are zero, one, two, or, three heads. The probability of obtaining this result is, respectively, 1/8, 3/8, 3/8, and 1/8. Figure 7.14 illustrates the tree diagram associated with this example, and Figure 7.15 shows the resulting probability distribution.

The binomial distribution function is:

$$P(x) = \frac{n!}{x!(n-x)!} p^x (1-p)^{n-x}$$

FIGURE 7.14
Tree
Diagram—
Binomial
Distribution
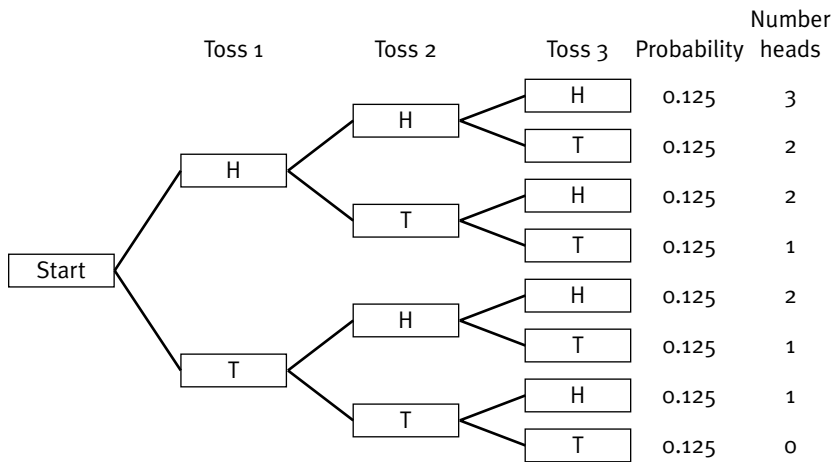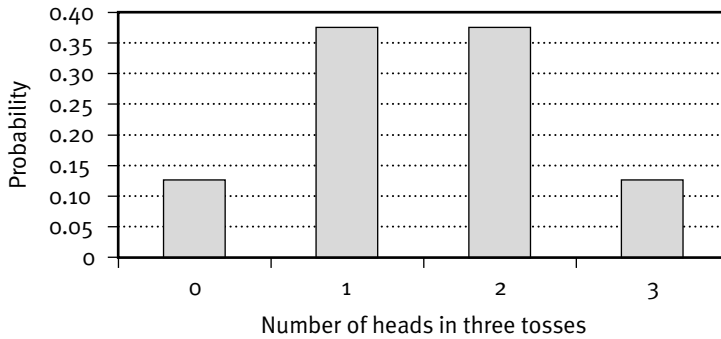
where ! = factorial. Therefore, the probability of obtaining two heads in three tosses can be calculated as:

$$P(2 \text{ heads}) = \frac{3!}{2!(3-2)} 0.5^2 (1-0.5)^{3-2}$$

$$= \frac{3 \times 2 \times 1}{(2 \times 1) \times (1)} 0.5 \times 0.5 \times (0.5)^1$$

$$= 3 \times 0.5^3$$

$$= 0.375$$

Poisson distribution

The Poisson distribution also takes on integer values: $x = 0, 1, 2, 3$, etc. It is used to model the number of events (e.g., number of telephone calls to a triage center, number of patients arriving at an emergency department) in a specific time period.

The Poisson distribution is determined by one parameter, λ, the average number of events in the given interval. The Poisson distribution function is:

$$P(x) = \frac{e^{-\lambda} \lambda^x}{x!}$$

where e = the base of the natural logarithm, 2.72.

If patient arrivals at the emergency department follow a Poisson distribution, and the average number of patients arriving at the department every hour is 3 (mean arrival rate = 3 patients/hour), then the probability of 5 patients arriving would be:

$$P(5) = \frac{e^{-\lambda} \lambda^x}{x!} = \frac{e^{-3} 3^5}{5!} = \frac{0.0498 \times 243}{5 \times 4 \times 3 \times 2 \times 1} = 0.10$$

FIGURE 7.16

Poisson
Distribution
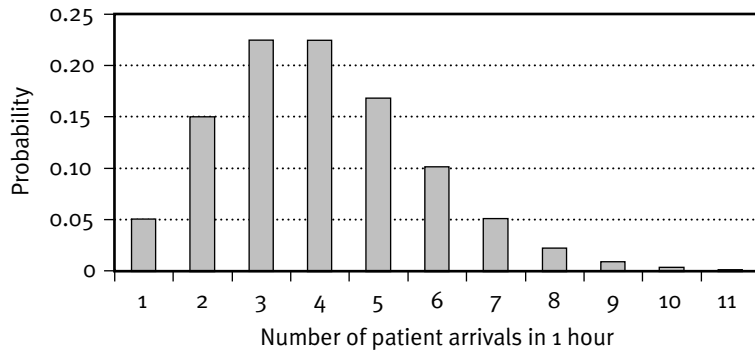
Figure 7.16 illustrates the Poisson distribution when the mean arrival rate is 3 patients/hour.

Continuous Probability Distributions

Continuous probability distributions are associated with continuous random variables, which can theoretically take on an infinite number of possible values. Continuous random variables are usually measurements of some attribute (height, weight, length, etc.). For example, the height of a person could be measured to the nearest meter, centimeter, millimeter, and so on; a person's height could be 2 meters, 2.10 meters, 2.105 meters, etc. Height could be measured to an infinite number of possible values. Continuous probability distributions are modeled by a smooth curve, where the total area under the curve is one ($P(x) \leq 1$), and the area under the curve between two distinct points defines the probability for that interval. In a continuous probability distribution, the probability at a single point is always zero.

Uniform distribution

The uniform distribution is the simplest continuous distribution. The probability of occurrence is the same for all outcomes. This distribution is useful for modeling. The uniform distribution function is:

$$P(x) = \frac{1}{b-a} \text{ for } a \leq x \leq b$$

For the uniform distribution $\mu = \dfrac{b-a}{2} = \text{median}$, and $\sigma = \sqrt{\dfrac{(b-a)^2}{12}}$.

Normal distribution

When people first began observing the occurrence of events and constructing frequency diagrams, a bell-shaped distribution was often observed. This

shape occurred so frequently that people began to expect it and it came to be called the normal distribution. The normal distribution is symmetric and unimodal; the mean is the same as the mode and median.

The normal distribution was commonly observed because many variables are distributed approximately normally. Events that are the aggregation of many smaller but independent and possibly unobservable random events will follow a normal distribution. For example, a person's weight is the result of many random events including such things as genetics, caloric intake, and exercise. The central limit theorem (discussed later in this chapter) is the basic principle underlying the occurrence of the normal distribution. Statistical process control is based in the central limit theorem and normal distribution (Chapter 8).

The normal distribution provides a reasonable approximation of the distribution of many random variables; it is "well-behaved" and mathematically tractable. Additionally, many statistical techniques require that the individual data follow a normal distribution. Fortunately, many of these tests work well even if the distribution is only approximately normal, and some tests work even with significant deviations from normality. Finally, the normal distribution can be described with two parameters: the mean (μ) and the standard deviation (σ). The normal distribution function is:

$$P(x) = \frac{1}{\sqrt{2 \Pi \sigma^2}} e^{-(x-\mu)2/2\sigma^2}$$

where Π = the population proportion.

The normal distribution is indicated by $x \sim N(\mu, \sigma^2)$.

The standard normal distribution, or z distribution, is the normal distribution with a mean of zero and a standard deviation of one. Any normal distribution can be transformed to a standard normal distribution by: $z = (x - \mu)/\sigma$. This is called the z score and represents the number of standard deviations away from the mean for a particular value. For instance, if a person scored 60 on a test with a mean of 50 and a standard deviation of 10, his z-score would be 1, because his score is 1 standard deviation above the mean. Figure 7.17 illustrates some normal distributions.

Probabilities associated with z-scores are widely available in tables or statistical software. Some often-used z-scores and their associated probabilities are shown in Table 7.2. Even if the original distribution is not normal, something is known about the probabilities based on the number of standard deviations from the mean. Chebyshev's rule states that for any distribution, the proportion of values between $\pm k$ standard deviations is at least $(1 - 1/k^2)$.
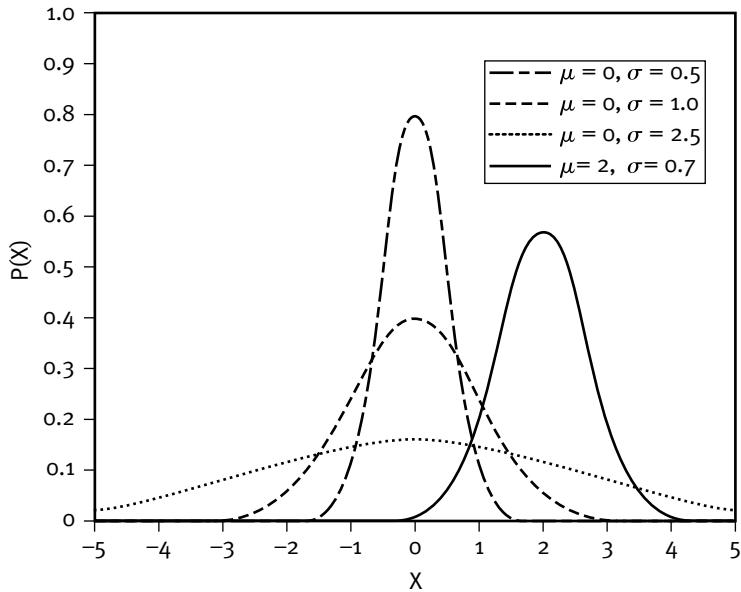
z-Score Limits	Proportion Within the Limits if Distribution Is Normal	Proportion Within the Limits Even if Distribution Is Not Normal
± 1 z	0.680	
± 2 z	0.950	0.750
± 3 z	0.997	0.890

Triangular distribution

The triangular distribution is often used in modeling and simulation because the needed parameters are relatively easy to estimate. The triangular distribution is described by the mode, minimum, and maximum values. It can be difficult for people to estimate the standard deviation of a random variable but relatively easy for them to estimate the minimum and maximum expected values. The triangular distribution function is:

$$P(x) = \begin{cases} \dfrac{2(x-a)}{(b-a)(c-a)} & \text{for } a \le x \le c \\ \dfrac{2(b-x)}{(b-a)(b-c)} & \text{for } c \le x \le b \end{cases}$$
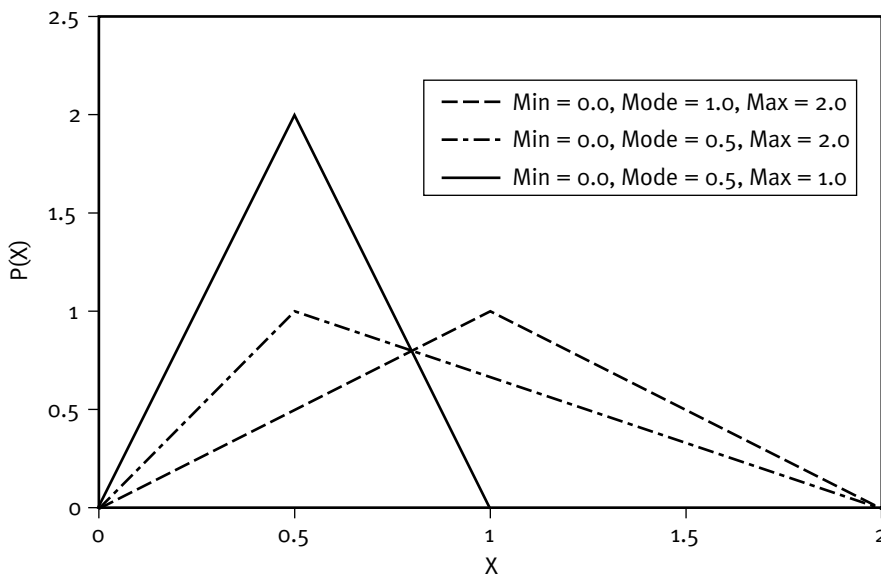
FIGURE 7.18
Triangular
Distribution

As noted, many statistical tests require that the data be normally distributed. The triangular distribution (Figure 7.18) has properties similar to the normal distribution and, therefore, does not violate assumptions of normality to a large degree. For the triangular distribution, where $b - c = c - a$ (symmetric), median = mode and $\mu = c$ = median = mode and $\sigma = \sqrt{\dfrac{(b-c)^2}{6}}$.

Exponential distribution

The exponential distribution is specified by only one parameter and is "memory-less." If an event follows an exponential distribution with parameter l and has not occurred prior to some time, the distribution of the time until it does occur also follows an exponential distribution with the same parameter, l. The exponential distribution is used in simulation to model waiting time. For example, the time until the next patient arrival can be modeled with the exponential distribution. The exponential distribution function is:

$$P(x) = \lambda e^{-\lambda x} \text{ for } x \geq 0$$

where λ is the arrival rate in number/unit of time or distance and $1/\lambda$ is the mean time between arrivals. For the exponential distribution μ = mean = $1/\lambda$, median = $\ln(2)/\lambda$, mode = 0, and $\sigma = 1/\lambda$. Figure 7.19 illustrates this distribution.

FIGURE 7.19
Exponential
Distribution
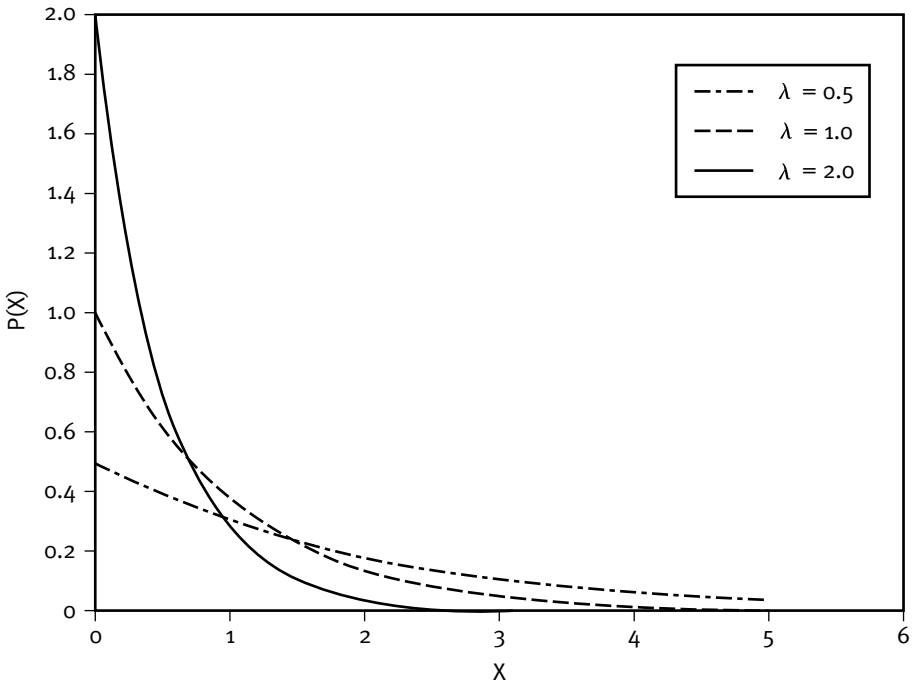
Chi-Square Test

The chi-square test of independence is used to test the relationship between qualitative or categoric variables. For example, to compare staffing levels at various clinics, frequency data would be collected and tabulated (Table 7.3). First, the expected frequency for each cell is computed under the assumption that no difference in staffing exists. The table shows that of the 40 employees, 20 work at Clinic A. If there were no difference in staffing, the expected frequency for the nurse–Clinic A cell would equal the product of the total number of nurses and the proportion of staff at Clinic A, or $22 \times (20/40) = 11$. The expected frequencies are shown in brackets in Table 7.3. The chi-square test for independence is:

$$\chi^2 = \sum \frac{(E-O)^2}{E}$$
$$= \frac{(11-12)^2}{11} + \frac{(9-8)^2}{9} + \frac{(11-10)^2}{11} + \frac{(9-10)^2}{9}$$
$$= 0.40$$

where E = the expected frequency and O = the observed frequency

Higher values of χ^2 provide evidence that differences in staffing exist across clinics. In this case, the chi-square value does not support the contention that there are differences in staffing.

Clinic	Staff Type		Total
	Nurse	Doctor	
A	12 [(20 × 22)/40 = 11]	8 [(20 × 18)/40 = 9]	20
B	10 [(20 × 22)/40 = 11]	10 [(20 × 18)/40 = 9]	20
	22	18	40

TABLE 7.3
Contingency Table for Staffing Level and Clinic

In a table with two rows and two columns, the chi-square test of independence is equivalent to a test of the difference between two sample proportions. In this example, the question is whether the proportion of nurses differs as a function of clinic. Note that the test of the difference between proportions for these data (see Hypothesis Testing, *Proportions*, later in this chapter) results in a *z* of 0.63, which, when squared, equals 0.40, the chi-square value. A chi-square test can also be performed when there are more than two rows or more than two columns (greater number of categories).

Confidence Intervals and Hypothesis Testing

Central Limit Theorem

The central limit theorem states that as the sample size becomes large, the sampling distribution of the mean approaches normality, no matter the distribution of the original variable. Additionally, the mean of the sampling distribution is equal to the mean of the population and the standard deviation of the sampling distribution of the mean approaches $\sigma/\sqrt{n}$, where σ is the standard deviation of the population and n is the sample size. This means that if a sample is taken from *any* distribution, the mean of the sample will follow a normal distribution with mean = μ and standard deviation = $\sigma/\sqrt{n}$, commonly called the standard error of the mean ($\sigma_{\bar{x}}$ or SE).

The central limit theorem can be used to determine a confidence interval (CI) for the true mean of the population. If the standard deviation of the population is known, a CI for the mean would be:

$$\bar{x} - z_{\alpha/2} \times \sigma_{\bar{x}} \leq \mu \leq \bar{x} + z_{\alpha/2} \times \sigma_{\bar{x}}$$

$$\bar{x} - z_{\alpha/2} \times \frac{\sigma}{\sqrt{n}} \leq \mu \leq \bar{x} + z_{\alpha/2} \times \frac{\sigma}{\sqrt{n}}$$

where $z_{a/2}$ is the z value associated with an upper- or lower-tail probability of α. In other words, to obtain a 95 percent CI, the upper- and lower-tail probabilities would be 0.025 (2.5 percent in the upper tail and 2.5 percent in the lower tail, leaving 95 percent in the middle), and the associated z-value is 1.95 (2 is commonly used). Note that increasing the sample size will "tighten" the confidence limits.

If the population standard deviation (σ) is unknown, the sample standard deviation (s) is used to estimate the standard error of the mean:

$$\bar{x} - z_{\alpha/2} \times \sigma_{\bar{x}} \leq \mu \leq \bar{x} + z_{\alpha/2} \times \sigma_{\bar{x}}$$

$$\bar{x} - z_{\alpha/2} \times \frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + z_{\alpha/2} \times \frac{s}{\sqrt{n}}$$

Small samples (generally, $n < 30$) do not follow a z distribution; they follow a t distribution. The t distribution has greater probability in the tails of the distribution than a z distribution and varies according to the degrees of freedom, $n - 1$, where n is the sample size. Therefore, for small samples, the following equation is used:

$$\bar{x} - t_{\alpha/2} \times \frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + t_{\alpha/2} \times \frac{s}{\sqrt{n}}$$

For example, if the waiting time for a random sample of 16 patients was measured and their mean wait time was found to be 10 minutes with a standard deviation of 2 minutes, a 95 percent CI for the true value of wait time would be:

$$\bar{x} - t_{\alpha/2} \times \frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + t_{\alpha/2} \times \frac{s}{\sqrt{n}}$$

$$10 - 2.13 \times \frac{2}{\sqrt{16}} \leq \mu \leq 10 + 2.13 \times \frac{2}{\sqrt{16}}$$

$$10 - 1.06 \leq \mu \leq 10 + 1.06$$

$$8.94 \leq \mu \leq 11.06$$

This means that 19 out of 20 times, if a similar sample is taken, the CI obtained would include the true value of the mean wait time. If a larger sample of 49 patients had been taken and their mean wait time was found to be 10 minutes, with a standard deviation of 1 minute, a 95 percent CI for the true value of the mean would be:

$$\bar{x} - z_{\alpha/2} \times \frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + z_{\alpha/2} \times \frac{s}{\sqrt{n}}$$

$$10 - 2 \times \frac{1}{\sqrt{49}} \leq \mu \leq 10 + 2 \times \frac{1}{\sqrt{49}}$$

$$10 - 0.3 \leq \mu \leq 10 + 0.3$$

$$9.7 \leq \mu \leq 10.3$$

Hypothesis Testing

In the previous section, a range of likely values for the population parameter of interest could be obtained by computing a CI. This interval could be used to determine whether claims about the value were correct by determining whether the CI captured the claimed value. In the wait time example, if it was claimed that wait time for most patients was eight minutes, this claim would be rejected based on the information obtained. However, if it was claimed that the mean wait time was ten minutes, the study would support this claim. Hypothesis testing is a formal way of testing such claims and is closely related to CIs.

In hypothesis testing there is a belief, called the null hypothesis; a competing belief, called the alternate hypothesis; and a decision rule for evaluating the beliefs. In the wait time example, these would be:

Belief, or H_o: μ = 8 minutes

Alternative belief, or H_a: $\mu \neq 8$ minutes

Decision rule: If $t \geq t*$, reject the null hypothesis, where $t = (\bar{x} - \mu)/\sigma_{\bar{x}}$, the number of standard errors away from the mean, and $t*$ is the test statistic based on the desired confidence level and the degrees of freedom. If t is greater than $t*$, it would be unlikely to find a sample mean that is different from the true value of the mean; therefore, the belief about the true value of the mean (H_o) would be rejected. In the wait time example, $t*$ for a 95 percent CI with 15 degrees of freedom (sample size of 16) is 2.13. Therefore, $t = (\bar{x} - \mu)/\sigma_{\bar{x}} = (10 - 8)/0.5$, and $t \geq t*$. The belief (H_o) would be rejected.

More typically, hypothesis testing is used to determine whether an effect exists. For instance, a pharmaceutical company wants to evaluate a new headache remedy by administering it to a collection of subjects. If the new headache remedy appears to relieve headaches, it is important to be able to state with confidence that the effect was really due to the new remedy, not just chance. Most headaches eventually go away on their own, and some headaches (or some peoples' headaches) are difficult to relieve, so the company can make two kinds of mistake: incorrectly concluding that the remedy works when in fact it does not, and failing to notice that an effective remedy

works. The null hypothesis (H_o) is that the remedy does not relieve headaches; the alternative hypothesis (H_a) is that it does.

Type I and Type II errors

A Type I, or α, error occurs if the company concludes that the remedy works when in fact it does not. A Type II, or β, error occurs if the remedy is effective but the company concludes that it is not.

Hypothesis testing is similar to determining of guilt within the U.S. criminal court system. In a trial, it is assumed the defendant is innocent (the null hypothesis) until proven guilty (the alternative hypothesis); evidence is presented (data), and the jury decides whether the defendant is guilty or not guilty based on proof (decision rule) that has to be beyond a reasonable doubt (level of confidence). A jury does not declare the defendant innocent, just not guilty.

If the defendant is really innocent but the jury decides that she is guilty, then it has sent an innocent person to jail (Type I error). If a defendant is really guilty, but the jury finds him not guilty, a criminal is free (Type II error). In the U.S. criminal court system, a Type I error is considered more important than a Type II error, so a Type I error is protected against to the detriment of a Type II error. This is analogous to hypothesis testing (Kenney 1988), as illustrated in Table 7.4.

Usually, the null hypothesis is that something is not present, that a treatment has no effect, or that no difference exists between the effects of different treatments. The alternative hypothesis is that some effect is present, that a treatment has an effect, or that there exists a difference in the effects of different treatments. Assuming the null hypothesis is true should make it possible to compute the probability that the test rejects the null hypothesis, given that it is true (Type I error.) The decision rule is based on the probability of obtaining a sample mean (or other statistic) given the hypothesized mean (or other statistic).

A comparison of wait time at two different clinics, on two different days, or during two different periods would use the following hypothesis test:

$$H_o: \mu_1 = \mu_2$$
$$H_a: \mu_1 \neq \mu_2$$
$$\text{Decision rule: If } t \geq t^*, \text{ reject } H_o$$

(Note that t^* is usually determined with statistical software using the Satherwaite approximation because the two-sample test statistic does not exactly follow a t-distribution.) Table 7.5 illustrates the errors associated with this example.

Assessment or guess	Innocent	Guilty
Innocent	—	Type II error
Guilty	Type I error	—

Reality (spanning header above the table)

Assessment or guess	Wait times at the two clinics are the same ($\mu_1 = \mu_2$)	Wait times at the two clinics are **not** the same ($\mu_1 \neq \mu_2$)
Wait times at the two clinics are the same ($\mu_1 = \mu_2$)		Type II error
Wait times at the two clinics are **not** the same ($\mu_1 \neq \mu_2$)	Type I error	

Equal variance *t*-test

If the wait time at two different clinics were of interest, wait time for a random sample of patients from each clinic might be measured. If wait time for a sample of 10 patients (for explanatory purposes only) from each clinic were measured and it was determined that Clinic A had a mean wait time of 12 minutes, Clinic B had a mean wait time of 10 minutes, and both had a standard deviation of 1.5 minutes, the standard deviations could be pooled and the distribution *would* follow a *t*-distribution with ($n_1 + n_2 - 2$) degrees of freedom. At a 95 percent confidence level,

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad \text{where } s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}} = 1.5$$

$$\frac{(12 - 10) - (0)}{1.5\sqrt{\frac{1}{10} + \frac{1}{10}}} = \frac{2}{0.67} = 2.99 \geq t^* = 2.10$$

Therefore, this test would reject H_o, the belief that the mean wait time at the two clinics is the same.

Alternatively, a 95 percent CI for the difference in the two means could be found:

$$(\bar{x}_1 - \bar{x}_2) \pm t^* \times s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

$$2 - (2.10 \times 0.67) \le \mu_1 - \mu_2 \le 2 + (2.10 \times 0.67)$$

$$0.6 \le \mu_1 - \mu_2 \le 3.4$$

Because the interval does not contain zero, the wait time for the two clinics is not the same.

Statistical software provides the *p*-value of this test. The *p*-value of a statistical significance test represents the probability of obtaining values of the test statistic that are equal to or greater than the observed test statistic. For the wait time example, the *p*-value is 0.015, meaning that H_o would be rejected with a confidence level of up to 98.5 percent, or that zero would not be contained in a 98.5 percent CI for the mean. Smaller *p*-values cause rejection of the null hypothesis. *t*-Tests can also be used to examine the mean difference between paired samples and can be performed when the standard deviations of the means differ. (See the companion website for more information on these types of *t*-tests.)

Proportions

Recall the example in which staffing levels at two clinics were compared.

$$H_o: \pi_1 = \pi_2$$
$$H_a: \pi_1 \ne \pi_2$$

Decision rule: If $z \ge z^*$, reject H_o

The proportion of nurses at Clinic A was $12/20 = 0.60$, and the proportion of nurses at Clinic B was $10/20 = 0.50$. The standard error of the difference in sample proportions is

$$\sqrt{\frac{p(1-p)}{n_1} + \frac{p(1-p)}{n_2}}$$

$$\text{where } p = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2} = \frac{20(0.6) + (20)0.5}{40} = 0.55$$

At a 95 percent confidence level,

$$z = \frac{(p_1 - p_2) - (\pi_1 - \pi_2)}{\sqrt{\dfrac{p(1-p)}{n_1} + \dfrac{p(1-p)}{n_2}}} = \frac{(0.60 - 0.50) - (0)}{\sqrt{\dfrac{(0.55)(0.45)}{20} + \dfrac{(0.55)(0.45)}{20}}}$$

$$= \frac{0.10}{0.157} = 0.64 < t^* = 1.96$$

Therefore, H_o could not be rejected and there could be no difference in the proportion of nurses at each clinic.

A CI for a proportion can be found from the following:

$$p - z_{\alpha/2} \times \sigma_p \leq \pi \leq p + z_{\alpha/2} \times \sigma_p \text{ where } \sigma_{\hat{p}} = \sqrt{\frac{p(1-p)}{n}}$$

$$p - z_{\alpha/2} \times \sqrt{\frac{p(1-p)}{n}} \leq \pi \leq p + z_{\alpha/2} \times \sqrt{\frac{p(1-p)}{n}}$$

A 95 percent CI for the difference in the two proportions of nurses is

$$(p_1 - p_2) \pm z \times \sqrt{\frac{p(1-p)}{n_1} + \frac{p(1-p)}{n_2}}$$

$$0.10 - (1.96 \times 0.157) \leq \pi_1 - \pi_2 \leq 0.10 + (1.96 \times 0.157)$$

$$-0.2 \leq \pi_1 - \pi_2 \leq 0.41$$

Because the interval contains 0, the proportion of nurses at the two clinics may not be different. The p-value for this test is 0.53; therefore, H_o would not be rejected.

Practical versus statistical significance

It is important to distinguish between statistical and practical significance. Statistical significance is related to the ability of the test to reject the null hypothesis, whereas practical significance looks at whether the difference is large enough to be of value in a practical sense. If the sample size is large enough, statistical significance can be found for small differences when there is limited or no practical importance associated with the finding.

For instance, in the clinic wait time example, if the mean wait time at Clinic A was 10.1 minutes, the mean wait time at Clinic B was 10.0 minutes, and the standard deviation for both was 1 minute, the difference would not be significant if the sample size at both clinics was 10; if, however, the sample size was 1,000, the difference would be statistically significant. The Minitab

output for this example is shown in Box 7.1. Tests for statistical significance should not be applied blindly—the practical significance of a difference of 0.1 minute is a judgment call.

BOX 7.1

Statistical
Significance of
Differences—
Minitab
Output for
Clinic Wait
Time Example

TWO-SAMPLE *T*-TEST AND CI

Sample	N	Mean	SD	SEM
1	10	10.10	1.00	0.32
2	10	10.00	1.00	0.32

Difference $= \mu_1 - \mu_2$

Estimate for difference: 0.100000

95% CI for difference: (−0.839561, 1.039561)

T-test of difference $= 0$ (vs not =): *T*-value $= 0.22$

P-value $= 0.826$ df $= 18$

Both use Pooled SD $= 1.0000$

TWO-SAMPLE T-TEST AND CI

Sample	N	Mean	SD	SEM
1	1000	10.10	1.00	0.032
2	1000	10.00	1.00	0.032

Difference $= \mu_1 - \mu_2$

Estimate for difference: 0.100000

95% CI for difference: (0.012295, 0.187705)

T-test of difference $= 0$ (vs not =): *T*-value $= 2.24$

P-value $= 0.025$ df $= 1998$

Both use Pooled SD $= 1.0000$

ANOVA/MANOVA
One-way ANOVA

Analysis of variance (ANOVA) is the most commonly used statistical method for testing hypotheses about three or more means. In the clinic waiting time example, if there were three clinics, days, or time periods of interest (1, 2, and 3), 3 separate *t*-tests (comparing 1 with 2, 1 with 3, and 2 with 3) would be needed. If there were seven clinics, 21 separate *t*-tests would be needed. This would be time consuming but, more important, flawed. In each *t*-test there is a 5 percent chance of the conclusion being wrong (if the confidence level is 95 percent)—of the 21 tests, one would be expected to give a false result.

ANOVA overcomes this problem by enabling the detection of significant differences over more than two "treatments." A single test is used to determine whether differences exist between the means at the chosen significance level. An ANOVA of the means of two groups will give the same results as a *t*-test.

The term "analysis of variance" is often a source of confusion. Despite the name, ANOVA is concerned with differences between means of groups, not differences between variances. Basically, ANOVA determines the variation *within* the groups and compares that to the differences *between* the groups, taking into account how many observations are in each group. If the observed differences are much larger than would be expected by chance, statistical significance exists.

Two-way and higher ANOVA

If the effect of more than one treatment or grouping variable is of interest, the ANOVA technique can be extended. For example, higher-level ANOVAs could be used to investigate differences in waiting times on various days of the week, at various time intervals throughout those days, or at several different clinics.

MANOVA/MANCOVA

Multivariate analysis of variance (MANOVA) is simply an ANOVA with several dependent variables. If the outcomes of interest included patient satisfaction and service time in addition to wait time at different clinics, a MANOVA could be used to evaluate the differences. The MANOVA could be used to test the hypothesis that some of these outcomes are different at different clinics. Instead of a univariate test, a multivariate test would be used. If the overall multivariate test is significant, the conclusion is that the respective effect (e.g., clinic) is significant.

The next question would of course be whether just wait time is different between clinics, just patient satisfaction is different, or both are different. After obtaining a significant multivariate test for a particular main effect or interaction, one would examine the univariate tests for each variable to interpret the respective effect. In other words, one would identify the specific dependent variables that contributed to the significant overall effect.

MANOVA has several advantages over ANOVA when there is interest in several different dependent variables. First, measuring several dependent variables in a single experiment allows a better chance of discovering which factor is truly important. Second, MANOVA can protect against Type I errors that might occur if multiple ANOVAs were conducted independently. Third, it can reveal differences not discovered by ANOVA tests.

Analyis of covariance (ANCOVA) and multivariate analysis of covariance (MANCOVA) are extensions of ANOVA and MANOVA. They are simply

ANOVA or MANOVA in which the categoric dependent variables are "adjusted" for differences in one or more covariates (metric variables). This can reduce error "noise" when error associated with the covariate is removed.

Simple Linear Regression

Regression is a statistical tool used to model the association of a variable with one or more explanatory variables. The variables are typically metric, although there are ways to analyze categoric variables using regression. The relationship(s) can be described using an equation.

Simple linear regression is the simplest type of regression. The equation representing the relationship between two variables is $Y = \beta X + \alpha + \varepsilon$. Most everyone will remember $Y = mX + b$ from elementary school. In statistics, α is used for the intercept (the b from elementary school), β signifies the slope (the m from elementary school; in statistics m or μ represents the mean, so a different variable name is used), and ε is the error.

A simple example will help to illustrate the concept of regression. Assume that the relationship between number of dependents and yearly healthcare expense was of interest and the data in Table 7.6 were collected (for explanatory purposes only, as a larger data set would be needed for a true regression analysis).

First, to visually examine the nature of the relationship between the variables, a scatter plot of the data (Figure 7.20) would be produced. From the scatter plot, it appears that a linear relationship exists—a line could be drawn that best represents the relationship between the two variables. However, many different lines could be drawn to represent the relationship (Figure 7.21).

What is the "best" line? It would be accurate (have no bias) and have the least amount of error. Table 7.7 contains the predicted Y ($\hat{Y}$) and the

TABLE 7.6

Data for Regression Example: Relationship Between Number of Dependents and Yearly Healthcare Expense

Number of Dependents	Annual Healthcare Expense ($1,000)
0	3
1	2
2	6
3	7
4	7
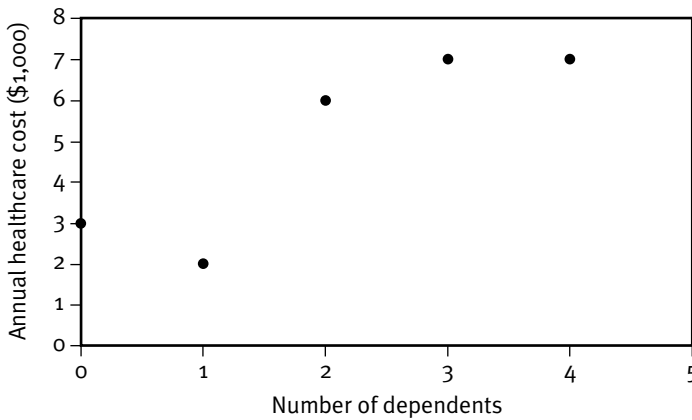
FIGURE 7.20

Scatter Plot—
Number of
Dependents vs.
Annual
Healthcare
Costs

error ($e = Y_{\text{Predicted}} - Y_{\text{Actual}} = \hat{Y} - Y$) for each of the hypothesized lines shown in Figure 7.21. The line $\hat{Y} = 1.2(X) + 2$ is biased—the estimates are high and the sum (Σ) of errors is greater than 0. In a good model, the errors will sum to 0, meaning there is no bias—the estimates are neither high nor low on average.

Although three of the four models' errors sum to zero, which of those is best? Note that the errors sum to zero because some are positive and some are negative. The best model would have the smallest total absolute error. Because absolute values are mathematically intractable, the errors are squared instead. The best-fitting line has a minimum sum of squared error.
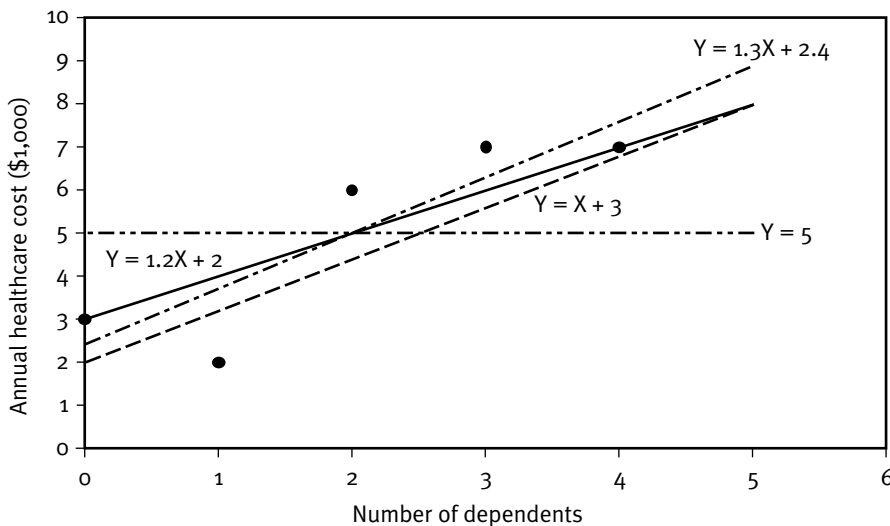
FIGURE 7.21

Scatter Plot
with Possible
Relationship
Lines

TABLE 7.7
Errors Associated with the Various Linear Models

X	Y	$\hat{Y} = 1(X) + 3$	e	$\hat{Y} = 1.2(X) + 2$	e	$\hat{Y} = 1.3(X) + 2$	e	$\hat{Y} = 0(X) + 2$	e
0	3	3	0	2.0	−1.0	2.4	−0.6	5	2
1	2	4	2	3.2	1.2	3.7	1.7	5	3
2	6	5	−1	4.4	−1.6	5.0	−1.0	5	−1
3	7	6	−1	5.6	−1.4	6.3	−0.7	5	−2
4	7	7	0	6.8	−0.2	7.6	0.6	5	−2
Σ			0		−3.0		0		0

TABLE 7.8
Sum of Squared Errors Associated with the Various Linear Models

X	Y	$\hat{Y} = 1(X) + 3$	e^2	$\hat{Y} = 1.3(X) + 3$	e^2	$\hat{Y} = 0(X) + 5$	e^2
0	3	3	0	2.4	0.36	5	4
1	2	4	4	3.7	2.89	5	9
2	6	5	1	5.0	1.00	5	1
3	7	6	1	6.3	0.49	5	4
4	7	7	0	7.6	0.36	5	4
Σ			6		5.10		22

The line $\hat{Y} = 1.3(X) + 2.4$ has the lowest squared error of all the models (Table 7.8). To determine the best-fitting line, or least squared error line, Gauss proved that if $b = \sum (Y - \bar{Y})(X - \bar{X})/\sum (X - \bar{X})^2$ and $a = \bar{Y} - b\bar{X}$, then $\Sigma e = 0$ and Σe^2 is a minimum.

Interpretation

The earlier linear model is interpreted as follows. The slope of the line indicates that with each additional dependent the annual cost of healthcare rises by $1,300; according to the intercept, when there are no dependents the annual cost of healthcare is $2,400. If there were no information, where X = 0 (no data), the intercept would only have mathematic significance.

Coefficient of Determination and Correlation Coefficient

The next question is, "How good is the model?" Is the estimate better when information (X = number of dependents) is used to create knowledge $\hat{Y}$ = 1.3(X) + 2.1? If no information were available, the mean annual healthcare cost could be used as an estimate of every individual's annual healthcare cost. Note that this is $\hat{Y} = 0(X) + 6$, an unbiased estimate (Table 7.9); and the error when using the model could be compared to the error using only the mean.

$$\text{\% Improvement in error} = \frac{\text{Mean error} - \text{Model error}}{\text{Mean error}} = \frac{22 - 5.1}{22} = 77\%$$

There is a 77 percent improvement in error level. Another way to look at this would be to determine whether the error is explained by the model (Figure 7.22):

$$\frac{\text{Explained error}}{\text{Total error}} = \frac{16.9}{22} = 0.77$$

TABLE 7.9 Regression Sums of Squares

X	Y	$\hat{Y}$	e	e^2	$\overline{Y}$	$Y - \overline{Y}$	$(Y - \overline{Y})^2$	$\hat{Y} - \overline{Y}$	$(\hat{Y} - \overline{Y})^2$
0	3	2.4	0.6	0.36	5	−2	4	−2.6	6.76
1	2	3.7	−1.7	2.89	5	−3	9	−1.3	1.69
2	6	5.0	1.0	1.00	5	1	1	0.0	0.00
3	7	6.3	0.7	0.49	5	2	4	1.3	1.69
4	7	7.6	−0.6	0.36	5	2	4	2.6	6.76
S	25	30.0	0.0	5.10	25	0	22	0.0	16.90
				SSE			SSTO		SSR

SSE = Sum of squares error
SSTO = Sum of squares total
SSR = Sum of squares regression
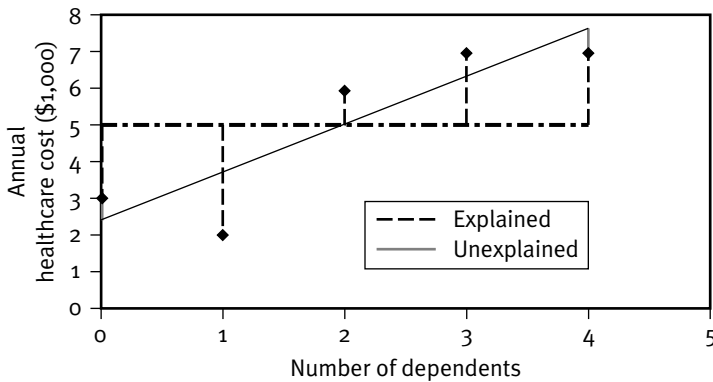
FIGURE 7.22 Explained and Unexplained Error

This measure of how well the model fits the data is called the coefficient of determination (r^2). Note that this is not a statistical test, but rather a measure of the percentage of error explained by the model. The square root of this number is called the correlation coefficient (r). A negative correlation coefficient indicates a negative slope, and a positive correlation coefficient indicates a positive slope. The correlation coefficient is a measure of the linear relationship between two variables, with a value of one indicating perfect correlation and a value of zero indicating no relationship. (Refer to Figure 7.8 for some scatter plots and their correlation coefficients.)

Problems with correlation coefficients

The coefficient of determination and the correlation coefficient are both measures of the *linear relationship* between two variables. A scatter plot of the two variables should always be examined when initially evaluating the appropriateness of a model. Statistical techniques for judging the appropriateness of the model are discussed later in this chapter.

Does a low r^2 mean there is no relationship between two variables? No. Figure 7.23 illustrates two cases (1 and 2) in which r^2 and r are both zero. In case 1, there is no relationship; in case 2, there is a relationship, just not a *linear* relationship. The relationship can be perfectly captured with the equation $Y = \alpha + \beta_1 X + \beta_2 X^2$, a curve or quadratic relationship. Later in the chapter, curve-type relationships are discussed. A low r^2 may also mean that other variables needed to explain the outcome variable are "missing" from the model. Multiple regression might fix this problem.

Does a reasonable or high r^2 mean the model is a good fit to the data? No. Figure 7.23 illustrates several cases in which the model is not a good fit to the data. The r^2 and r can be heavily influenced by outliers, as in cases 4 and 6. In case 5, a better model would be a curve. Always look at the scatter plot of the data.

Does a high r^2 mean that *useful* predictions will be obtained with the model? No. Remember the previous discussion of practical and statistical significance. Finally, does a high r^2 mean that there is a causal relationship between the variables? No—correlation is not causation. The observed correlation between two variables might be due to the action of a third, unobserved variable. For example, Yule (1926) found a high positive correlation between yearly suicides and membership in the Church of England. However, membership in the Church of England did not *cause* suicides.

Statistical Measures of Model Fit

If there is no linear relationship between the two variables, the slope of the best-fitting line will be zero. This idea underlies the statistical tests for the "goodness of fit" of the model.
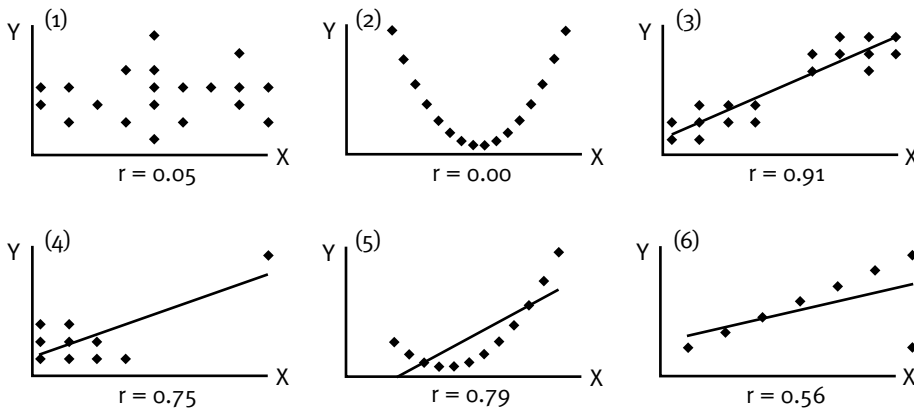
FIGURE 7.23
Low and High
r and r^2
Example Plots

F-test

The *F*-test is a hypothesis test of whether all β values in the model $Y = \alpha + \beta X + \varepsilon$ are equal to zero. In the case of simple linear regression, there is only one β and this is a test of whether β is zero.

H_o: all β values $= 0$
H_a: all β values $\neq 0$
Decision rule: If $F^* \geq F_{(1-\alpha;1;n-2)}$, reject H_o
$$F^* = \frac{\text{Mean square regression}}{\text{Mean square error}} = \frac{MSR}{MSE} = \frac{SSR/1}{SSE/n-2}$$

If the two variables are related, the regression line will explain most of the variance, and *SSR* will be large in comparison to *SSE*. Therefore, large values of F^* imply that there is a relationship and the slope of the line is not equal to zero.

t-Test

For simple linear regression, the *t*-test will give the same answer as the *F*-test; this is not the case for multiple regression. The *t*-test is a hypothesis test of whether a particular $\beta = 0$.

H_o: $\beta = 0$
H_a: $\beta \neq 0$
Decision rule: If $t^* > t_{(1-\alpha; n-2)}$, reject H_o
$t^* = b/s_b$

Alternatively, a CI for β would be:

$$b - t_{(1-\alpha \; ; \; n-2)}s_b \leq \beta \; \leq b - t_{(1-\alpha; \; n-2)}s_b$$

If the interval contains zero, H_o can be rejected.

Statistical software will provide these tests for linear regression as well as r and R^2. Figure 7.24 shows the Microsoft Excel output for the healthcare expense example.

FIGURE 7.24

Regression Output for Healthcare Expense Example

SUMMARY OUTPUT

Regression Statistics

Multiple R	0.8765
R Square	0.7682
Adjusted R Square	0.6909
Standard Error	0.8790
Observations	5

ANOVA

	df	SS	MS	F	Significance F
Regression	1	7.6818	7.6818	9.9412	0.0511
Residual	2	2.3182	0.7727		
Total	3	10.0000			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 90%	Upper 90%
Intercept	−0.9545	1.0162	−0.9393	0.4169	−4.1885	2.2794	−3.3460	1.4369
Y—$1000 Annual Health care Expense	0.5909	0.1874	3.1530	0.0511	−0.0055	1.1873	0.1499	1.0320

RESIDUAL OUTPUT

Observation	Predicted X—Number of Dependents	Residuals	Standard Residuals
1	0.8182	−0.8182	−1.0747
2	0.2273	0.7727	1.0150
3	2.5909	−0.5909	−0.7762
4	3.1818	−0.1818	−0.2388
5	3.1818	0.8182	1.0747

PROBABILITY OUTPUT

Percentile	X—Number of Dependents
10	0
30	1
50	2
70	3
90	4

Y—$1000 Annual Health Care Expense Residual Plot

Normal Probability Plot

Y—$1000 Annual Health Care Expense Line Fit Plot
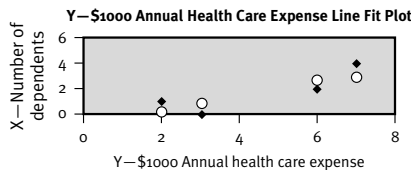
Assumptions of Linear Regression

Linear regression is based on several principal assumptions:

- The dependent and independent variables are linearly related.
- The errors associated with the model are not serially correlated.
- The errors are normally distributed and have constant variance.

If these assumptions are violated, the resulting model will be misleading.

Various plots (and statistical tests) can be used to detect such problems. These plots are usually provided by the software and should be examined for evidence of violations of the assumptions of regression. A scatter plot of the observed versus predicted value should be symmetrically distributed around a diagonal line. A scatter plot of residuals versus predicted value should be symmetrically distributed around a horizontal line. A normal probability plot of the residuals should fall closely around a diagonal line.

If there is evidence that the assumptions of linear regression are being violated, a transformation of the dependent or independent variables may fix the problem. Alternatively, one or two extreme values may be causing the problems. Such values should be scrutinized closely: Are they *genuine* (i.e., not the result of data entry errors), are they *explainable*, are *similar events* likely to occur again in the future, and how *influential* are they in the model-fitting results? If the values are merely errors, or if they can be explained as unique events not likely to be repeated, there may be cause to remove them. In some cases, however, the extreme values in the data may provide the most useful information about values of some of the coefficients or provide the most realistic guide to the magnitudes of prediction errors.

Transformations

If the variables are not linearly related or the assumptions of regression are violated, the variables can be transformed to possibly produce a better model. Transformations are applied to ensure that the model is accurate and reliable. If a person jogged to her doctor's appointment, she would need to wait before having her blood pressure measured if a high reading would result in a diagnosis of hypertension. Blood pressure values obtained immediately after exercising are unsuitable for detecting hypertension; the reason for waiting is not to avoid the diagnosis of hypertension but to ensure that a high reading can be believed. It is the same with transformations.

Deciding which transformation is best is often an exercise in trial and error in which several transformations are tried to see which one provides the best model. Possible transformations include square root, square, cube, log, and inverse. If the data are transformed, this needs to be accounted for when interpreting the findings. For example, imagine that the original variable was measured in days but, to improve the model, an inverse transformation was

applied. Here, it would be important to remember that the lower the value for this transformed variable (1/days), the higher the value of the original variable (days). If the dependent variable is binary (0/1), the assumptions of regression are violated. The logit transformation of the variable, $\ln[p/(1-p)]$, is used in this case.

Multiple Regression

In multiple regression, multiple independent variables are used to predict a single dependent variable. A person might be described as having brown hair. If someone wanted to identify this person, he would have difficulty because this is not a very good description. However, expanding the description to include more characteristics (female, 5'7" tall, 140 pounds, blue eyes, wearing a red shirt) would make it much easier to identify this unknown person.

The same is true of multiple regression: More information can improve the model and allow for a better description of the dependent variable. The equation for multiple regression is:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \varepsilon$$

where there are k independent variables.

In the healthcare expense example, there could be many other possible variables related to healthcare costs in addition to number of dependents; examples include age of dependents, age of insured, and amount of deductible. If these variables were added to the model, a better model might be developed.

The same evaluations of model fit used for simple linear regression are used for multiple regression. Here, the F-test is a test of whether all β values are zero, and individual t-tests can be used to determine whether an individual independent variable in the model is significant. If the overall model is significant but some individual 10.5 pt values are not, these predictors can be removed from the model. A good model will be significant overall, and each individual predictor will also be significant.

One additional issue to be aware of in multiple regression is multicollinearity of the predictor variables. If two predictor variables are highly correlated to each other, the explanatory value of the model will be compromised. A simple example is shown in Table 7.10.

TABLE 7.10 Multicollinearity Example

Y	X_1	X_2
11	1	10
22	2	20

Here, $\Upsilon = X_1 + X_2$. But X_1 and X_2 are perfectly correlated; $X_2 = 10 \times X_1$, so Υ is also $= 10X_1 + 0.10X_2$ and $5X_1 + 0.6X_2$. In the first case, X_1 and X_2 have the same level of effect on Υ. In the other cases, the effects appear different. Multicollinearity will cause this problem.

In multiple regression, predictors are added to or removed from the model until the researcher is satisfied that the model is as good as it can possibly be with the given data. This process can be as much of an art as a science and usually requires expertise and experience.

The General Linear Model

All of the techniques discussed thus far are forms of the general linear model (GLM). It is the most general of all the models and allows for multiple predictor variables, which may be metric, categoric, or both, and for multiple dependent variables, which may also be metric, categoric, or both. A complete discussion of GLM is outside the scope of this text, but it can be used to build complex models.

Additional Techniques

Artificial Neural Networks

Artificial neural networks (ANN) attempt to mimic the processes found in biological systems using the power of the computer. Although a complete treatment of the theory underlying ANNs is beyond the scope of this book, a simple explanation follows.

ANN software takes large amounts of data, transforms and weights the input variables to "learn" from those data, and then predicts an outcome. Traditional models like regression analysis can use limited amounts of data to investigate the nature of relationships in the data. In contrast, ANNs usually require significant amounts of data and do not offer an explanation as to how or why the independent variables affect the dependent variables; they simply predict the outcome given what has happened in the past.

ANNs have been found to offer solutions to problems where traditional models would be extremely complicated and time consuming to build. Today, ANNs are being successfully used in areas such as image recognition (Miller, Blott, and Hames 1992), diagnosis (Dybowski and Gant 2001), and medical decision making (Baxt 1995; Weinstein et al. 1992).

Design of Experiments

Design of experiments (DOE) is a structured approach to the investigation of a system or process. DOE starts with the identification of input variables believed to have an effect on the output variable of interest. Levels of each input variable are chosen such that the relevant range of each input variable

is covered. An experimental plan is developed that determines the level of each input variable for each trial and does not require all possible levels of every input variable. This plan maximizes the information gained while minimizing the number of trials needed to obtain it.

DOE enables the investigation of a number of input variables at the same time and allows the investigator to move from changing one variable at a time and possibly missing or misstating any effects of a combination of input variables. DOE is typically used to find answers to questions of what is causing the problem or how it can be minimized. DOE is employed when the investigators have a reasonably good idea of both the important factors and their relevant ranges, typically after initial investigations have been conducted using the tools outlined previously in this chapter.

Conclusion

An outline for analysis is shown in Table 7.11, with its relationships to the plan-do-check-act (PDCA) process for continuous improvement (Chapters 8 and 9), the define-measure-analyze-improve (DMAIC) process of Six Sigma (Chapter 8), and the key elements of decision making (Chapter 6).

TABLE 7.11
Outline for
Analysis

	PDCA	*DMAIC*	*Key Element*
1. Define the problem/question.	Plan	Define	Frame
2. Determine what data will be needed to address the problem/question.	Plan	Define	Frame
3. Collect the data.	Do	Measure	Gather
4. Graph the data.	Do	Analyze	Gather
5. Analyze the data using the appropriate tool.	Do	Analyze	Conclude
6. Fix the problem.	Do	Improve	Conclude
7. Evaluate the effectiveness of the solution.	Check	Control	Learn
8. Start again.	Plan	Define	Frame

Which Technique to Use

The statistical tool or technique chosen to analyze the data depends on the type of data collected. Table 7.12 provides a guide for choosing the appropriate technique based on data type.

TABLE 7.12
Variable Type and Choice of Technique

Independent Variable		Dependent Variable		Mathematic	Graphic
Categoric	One	Categoric	One	χ^2	
			Many	χ^2 (layered)	
		Metric	One	*t*-Test	Histogram type
			Many	MANOVA	Box plot
	Many	Categoric	One	χ^2	
			Many	χ^2 (layered)	
		Metric	One	ANOVA	Box plot
			Many	MANOVA	
		Both		GLM	
Metric	One	Categoric	One	Logit	
			Many	GLM	
		Metric	One	Simple regression	Scatter plot
			Many	GLM	
		Both		MANCOVA	
	Many	Categoric	One	Logit	
			Many	GLM	
		Metric	One	Multiple regression	
			Many	GLM	
		Both		GLM	
				ANN	
Both		Categoric	One	ANCOVA	
			Many	MANCOVA	
		Metric	One	Simple regression	
			Many	Multiple regression	
		Both		GLM	
				ANN	

Discussion Questions

1. The U.S. presidential elections of 1936, 1948 (Harris Poll Online 2006), and 2000 (Wikipedia 2006) are good examples of flawed studies that led to flawed conclusions. What was the flaw in each of these studies? Discuss a situation from your personal experience in which a study that was not valid (logic, sampling, or measurement errors) led to a flawed decision or conclusion.

2. John Allen Paulos (http://abcnews.go.com/Technology/WhosCounting/) and Jordan Ellenberg (www.slate.com/?id=3944&QueryText=Do+the+Math&Action=DepartmentSrch&GroupBy=Department) both write on numbers, statistics, and probability. Read an article of interest to you and discuss.

3. Discuss how you would redesign a report you receive at work to make it more useful for you. Would a visual presentation of the data be helpful? How would you present the data?

4. Discuss the difference between correlation and causation.

5. Discuss the difference between statistical and practical significance.

6. The balanced scorecard, Six Sigma, Lean, and simulation employ many of the tools, techniques, and tests found in this chapter. Discuss how, where, and why a particular tool would be used for each.

Chapter Exercises

The following problems use data from three data sets available on the companion web site. Each data set contains the raw data as well as reduced or reorganized data for ease of analysis.

1. Think of a question, problem, or issue in your organization. Design a *valid* study to address the issue. Be sure to discuss how you would address all aspects of validity, including logic, sampling, and measurement. Assuming that you can collect valid data, how would you analyze them? How would you present them?

2. Using the data in Health Insurance Coverage.xls, compare insurance coverage in Minnesota to coverage in Texas.
   a. Analyze the validity of the data.
   b. Produce a histogram to compare the two states. Do Minnesota and Texas appear to have similar coverage types?
   c. Produce a Pareto chart for the two states. What does this chart indicate?
   d. What is the probability that a resident of Minnesota or Texas will be uninsured? Insured? Insured by Medicare or Medicaid?
   e. What is the 95 percent CI for the proportion of uninsured in Texas? In Minnesota? What is the 99 percent CI?

    f. What is the 99 percent CI for the difference in the two proportions?

    g. Set up and perform a hypothesis test to determine if the proportion of uninsured differs at a 95 percent confidence level between the two states.

    h. Perform a chi-square test to determine if there are differences in proportions of types of healthcare coverage between Minnesota and Texas.

    i. Comment on the statement, "Living in Texas causes more people to be uninsured." What other information might be helpful here?

3. Use the data in the World Health.xls to analyze worldwide life expectancy. Answer the following questions.

    a. Discuss the validity of the data.

    b. Construct a histogram, stem plot, dot plot, and normal probability plot of CIA life expectancy at birth (years), total for 2006. What do these graphs indicate? Is this random variable normally distributed?

    c. Construct box plots of CIA life expectancy—total, male, and female. What do these graphs show?

    d. Determine the mean, median, mode, range, variance, and standard deviation for CIA life expectancy—total, male, and female. What do these numbers show?

    e. What is the 95 percent CI for mean life expectancy of males and females? The 99 percent CI?

    f. What is the 99 percent CI for the difference in the two means?

    g. Set up and perform a hypothesis test to determine if life expectancy for males and females differs at a 95 percent confidence level.

    h. Perform an ANOVA to determine if life expectancies for males, females, and all are different.

    i. Construct scatter plots of CIA gross domestic product, telephones, televisions, physicians, nurses, pharmacists, hospital beds, and per capita health expenditures versus CIA life expectancy total. What do these graphs indicate?

    j. Construct a correlation matrix for all the data. What does this indicate?

    k. Construct histogram and normal probability plots for CIA gross domestic product, televisions, and hospital beds. (Bonus: Use Best-Fit to determine the best-fitting probability distribution for each of these and total life expectancy.) Are these random variables normally distributed?

    l. Perform three separate simple linear regression analyses for CIA gross domestic product, televisions, and hospital beds with CIA life expectancy total. Interpret your results. (Note: Excel will not perform a regression analysis when data are missing. The workbook "World Health Regression" has eliminated countries for which there are no data on life expectancy. You may need to sort the data and run the analysis only on complete data.)

    m. Discuss the following statement: "World life expectancy could be increased if everyone in the world owned a television."

    n. Look at x-y scatter plots for each pair of variables in l. Do the relationships appear to be linear? Would a transformation of the x variable improve the regression?

    o. Bonus: Build a multiple regression model with the available data to predict life expectancy in countries throughout the world. Be sure to eliminate any outliers and multicollinearity. Transform the data as you deem best.

References

Baxt, W. G. 1995. "Application of Artificial Neural Networks to Clinical Medicine." *Lancet* 346: 1135–38.

Dybowski, R., and V. Gant. 2001. *Clinical Applications of Artificial Neural Networks.* Cambridge, U.K.: Cambridge University Press.

Gould, S. J. 1985. "The Median Isn't the Message." *Discover* 6: 40–42.

Harris Poll Online. 2006. "Two Gigantic Blunders in the History of Election Polling." [Online information; retrieved 8/8/06.] www.harrispollonline.com/uk/history.asp#blunders.

Kenney, J. M. 1988. "Hypothesis Testing: Guilty or Innocent." *Quality Progress* 21 (1): 55–57.

Miller, A., B. Blott, and T. Hames. 1992. "Review of Neural Network Applications in Medical Imaging and Signal Processing." *Medical and Biological Engineering and Computing* 30 (5): 449–64.

Paulos, J. A. 2006. "Who's Counting: Flu Deaths, Iraqi Dead Numbers Skewed." ABCNews.com, January 1. [Online information; retrieved 11/5/07.] http://abcnews.go.com/Technology/WhosCounting/story?id=1432589.

Tufte, E. R. 1997. *Visual Explanations: Images and Quantities, Evidence and Narrative.* Cheshire, CT: Graphics Press.

———. 1990. *Envisioning Information.* Cheshire, CT: Graphics Press.

———. 1983. *The Visual Display of Quantitative Information.* Cheshire, CT: Graphics Press.

Weinstein, J. N., K. W. Kohn, M. R. Grever, V. N. Viswanadhan, L. V. Rubinstein, A. P. Monks, D. A. Scudiero, L. Welch, A. D. Koutsoukos, A. J. Chiausa, K. D. Paull. 1992. "Neural Computing in Cancer Drug Development: Predicting Mechanism of Action." *Science* 258: 447–51.

Wennberg, J. E. 2005. "Variation in Use of Medicare Services Among Regions and Selected Academic Medical Centers: Is More Better?" [Online information; retrieved 6/20/06.] www.ihi.org/IHI/Topics/Improvement/Improvement Methods/Literature/VariationinuseofMedicareservicesamongregionsand selectedacademicmedicalcentersIsmorebetter.htm.

Wikipedia. 2006. "United States Presidential Election, 2000." [Online information; retrieved 8/8/06.] http://en.wikipedia.org/wiki/U.S._presidential_election,_2000.

Yule, G. U. 1926. "Why Do We Sometimes Get Nonsense-Correlations Between Time-Series?—A Study in Sampling and the Nature of Time-Series." *Journal of the Royal Statistical Society* 89 (1): 1–63.

8

QUALITY MANAGEMENT: FOCUS ON SIX SIGMA

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

Baldrige criteria
benchmarking
cause-and-effect diagram, see fish-
    bone diagram
central limit theorem (CLT)
    check sheet
continuous quality improvement
    (CQI)
control limits
cost of quality
count chart (C-chart)
critical to quality (CTQ)
defects per million opportunities
    (DPMO)
define-measure-analyze-improve-
    control (DMAIC)
Design for Six Sigma (DFSS)
failure mode and effects analysis
    (FMEA)
fishbone diagram
flow chart
green belt, black belt, master black
    belt
histogram
house of quality, see quality function
    deployment
Institute of Medicine (IOM)
International Organization for
    Standardization (ISO)
Ishikawa diagram, see fishbone
    diagram
ISO 9000 series

Joint Commission
key process input variables (KPIV)
key process output variables
    (KPOV)
Malcolm Baldrige National Quality
    Award (MBNQA)
mistake proofing, see poka-yoke
Pareto chart
plan-do-check-act (PDCA)
poka-yoke
process capability (C_p, C_{pk})
process map or diagram
proportion chart (P-chart)
Quality Assurance Project (QAP)
quality function deployment (QFD)
radio frequency identification (RFID)
range chart (R-chart)
rolled throughput yield (RTY)
root-cause analysis (RCA)
run chart
sample mean ($\overline{X}$, X-bar)
scatter diagram
seven basic quality tools
sigma, standard deviation
Six Sigma (6σ)
specification limits
statistical process control (SPC)
statistical quality control (SQC), see
    SPC
total quality management (TQM)
voice of the customer (VOC)

Operations Management in Action

In 2001, Heritage Valley Health System (HVHS) began to look beyond traditional healthcare process improvement techniques to offset the issues facing it and many other healthcare organizations. Some of these issues were patient care and satisfaction, finance, staff retention and recruitment, and collaboration with physicians on clinical initiatives. The HVHS operations team ultimately decided to develop a Six Sigma program.

The most critical question facing the organization was, "How can an improvement methodology traditionally linked to manufacturing apply to healthcare?" A related and frequently voiced concern was, "How can we learn from Six Sigma experts who might not understand patient care?"

Because Six Sigma is generally associated with manufacturing, there was concern that the deployment and implementation of the improvement methodology in a healthcare environment wouldn't work. To address this concern, HVHS educated its executive leadership team on Six Sigma and piloted a few projects prior to rolling it out across the system.

One black belt team was charged with evaluating the patient admission process to observation or inpatient status. Within one month, the admissions process improvement team identified multiple sources of lost revenue based on how patients were being classified upon admission. More than $1 million in revenue was captured, and many internal processes were improved as a result of this first project. The effort, from the initial project meeting to final staff education and process change, took seven months.

The second project involved a study of operating room utilization. A team of four, meeting once a week for several months, identified that use of the organization's ambulatory surgery center would improve by transferring typical outpatient surgeries (e.g., for ear, nose, throat; minor orthopedic problems; and cataracts) from HVHS's operating room. The extra capacity generated for the hospital operating room was then filled with inpatient-type surgeries, where the revenue covered overhead cost. An additional outcome from this project included a redesigned urology room, which helped the hospital avoid tandem scheduling of an additional room in case more extensive intervention was required.

The positive results of these short-term projects provided the proof the organization needed to understand that Six Sigma could indeed be applied to healthcare situations.

SOURCE: Beaver, R. 2004. "Six Sigma Success in Health Care." *Quality Digest* March: 31–34. Reprinted with permission.

Overview

Quality management became imperative for the manufacturing sector in the 1970s and 1980s, for service organizations in the 1980s and 1990s and, finally, for the healthcare industry in the 1990s, culminating with a 1999 Institute of Medicine (IOM) report, *To Err Is Human*, that detailed alarming statistics on the number of people actually harmed by the healthcare system and recommended major improvements in quality as related to patient safety. The report recognized the need for systemic changes and called for innovative solutions to ensure improvement in the quality of healthcare.

The healthcare industry is facing increasing pressure to not only increase quality but also to reduce costs. This chapter provides an introduction to quality management tools and techniques that are being successfully used by healthcare organizations. The major topics covered include:

- Defining quality;
- The costs of quality;
- Quality programs, including total quality management (TQM)/continuous quality improvement (CQI), ISO 9000, the Baldrige criteria and Six Sigma (note that Six Sigma programs are different from Six Sigma tools);
- Six Sigma tools and techniques including the define-measure-analyze-improve-control (DMAIC) process, seven basic quality tools, statistical process control (SPC), and process capability; and
- Other quality tools and techniques, including quality function deployment (QFD), Taguchi methods, and poka-yoke.

After completing this chapter, readers should have a basic understanding of quality, quality programs, and quality tools, enabling application of the tools and techniques to begin improving quality in their organizations.

Defining Quality

Although most people would agree that ensuring quality in healthcare is of the utmost importance, many would disagree on exactly what "quality" means. The supplying organization's perspective includes performance (or design) quality and conformance quality. Performance quality includes the features and attributes designed into the product or service. Conformance quality is concerned with how well the product or service conforms to desired goals or specifications.

From the customer's perspective, Garvin (1987) defines eight dimensions of product quality:

1. *Performance:* operating characteristics
2. *Features:* supplements to the basic characteristics of the product
3. *Reliability:* the probability that the product will work over time
4. *Conformance:* product conformance to established standards
5. *Durability:* length of time that the product will continue to operate
6. *Serviceability:* ease of repair
7. *Esthetics:* beauty related to the look or feel of the product
8. *Perceived value:* perceptions of the product

Parasuraman, Zeithaml, and Berry (1988) define five dimensions of service quality:

1. *Tangibles:* physical facilities, equipment, and appearance of personnel
2. *Reliability:* ability to perform promised service dependably and accurately
3. *Responsiveness:* willingness to help customers and provide prompt service
4. *Assurance:* knowledge and courtesy of employees and their ability to inspire trust and confidence
5. *Empathy:* care and individualized attention

The 2001 IOM report *Crossing the Quality Chasm* outlines six dimensions of quality in healthcare: safe, effective, patient-centered, timely, efficient, and equitable. Finally, the Quality Assurance Project (2006) outlines nine dimensions of quality in healthcare: technical performance, access to services, effectiveness of care, efficiency of service delivery, interpersonal relations, continuity of services, safety, physical infrastructure and comfort, and choice.

Obviously, quality and its various dimensions may be viewed in many ways. The dimensions relevant to one organization or project may not be relevant to a different organization. The particular quality dimensions on which to focus, and the relative weight of those dimensions, should be determined taking into account both context and project.

Cost of Quality

The costs of quality—or the costs of poor quality, according to Juran and Godfrey (1998)—are the costs associated with providing a poor-quality product or service. Crosby (1979) says that the cost of quality is "the expense of noncomformance—the cost of doing things wrong."

Quality improvement initiatives and projects cannot be justified simply because "everyone is doing it," but rather must be justified on the basis of financial or societal benefits. However, Cleverley and Harvey (1992) found that lower-quality hospitals have lower levels of profitability, and more

recent research (Midwest Business Group on Health 2003) estimates that 30 percent of all direct healthcare costs in the United States today are the result of poor-quality care. According to the latter study's estimates, $420 billion is spent each year on overuse, misuse, and waste in the healthcare system.

The cost of quality is usually separated into four parts:

1. *External failure:* costs associated with failure after the customer receives the product or service (e.g., bad publicity, liability, customer service)
2. *Internal failure:* costs associated with failure before the customer receives the product or service (e.g., rework, replacement, correction of problems)
3. *Appraisal:* costs associated with inspecting and evaluating the quality of supplies or the final product/service (e.g., audits, accreditation preparation, and review)
4. *Prevention:* costs incurred to eliminate or minimize appraisal and failure costs (e.g., training, investment in systems)

Often, the costs of prevention are seen as expenses while the other, less apparent costs of appraisal and failure are hidden in the system (Suver, Neumann, and Boles 1992). However, it is usually less costly to prevent quality problems than to fix quality failures. Striving for continuous improvement in quality can not only improve quality, but it can also improve an organization's financial situation.

Quality Programs

This book focuses on the Six Sigma methodology because of its popularity and growing utilization, but there are many other, equally valid programs for quality management and continuous improvement. TQM, ISO 9000 certification, the Baldrige criteria, and Lean can all provide a framework for organizational improvement. Although each of these programs or methodologies has a slightly different focus, their underlying principles are basically the same.

Total Quality Management
Total quality management (TQM)—or continuous quality improvement (CQI), as it is sometimes referred to in the healthcare arena (Shortell et al. 1995)—is basically similar to Six Sigma. Based on the philosophies of quality gurus such as Deming and Juran, TQM has been defined as a management philosophy that focuses on meeting customer needs and on continuous improvement. To accomplish this, TQM relies on the active involvement of all functional areas and all employees.

Although there is no one definition of TQM, most experts would agree on the underlying principles that provide its framework (Hackman and Wageman 1995; Powell 1995; Ross and Perry 1999; Samson and Terziovski 1999; Tarí 2005):

- *Focus on the customer.* Quality is based on satisfying, and even delighting, the customer.
- *Top-management leadership and support.* Management is ultimately responsible for quality and must communicate the quality vision to the organization and provide support for it.
- *Employee involvement.* Employees are key to quality. They must buy into the vision and be empowered to reach the goal.
- *Systems thinking.* Everything is related to everything else. Quality will not be achieved without cross-functional involvement.
- *Continuous improvement.* Quality is a moving goal. To achieve it, the organization must continuously improve.
- *Data-based decision making.* The tools and techniques of quality management are needed to ensure quality.

ISO 9000

The International Organization for Standardization (ISO) 9000 series (2006) is primarily concerned with ensuring that organizations maintain consistently high levels of quality. The ISO standards are process oriented and require evidence of outcome achievement. Many organizations require that their vendors be ISO certified, meaning that they have demonstrated to an accredited registrar (a certified third-party organization) compliance with the requirements specified in the standard(s). Organizations seeking certification must implement formal policies, processes, and procedures to ensure that the needs of their customers are being met. To do this, all aspects of their quality systems need to be documented, monitored (or audited), and controlled so that continuous improvements can be made.

ISO 9000:2000 provides a quality management system that takes into account the measures, settings, services, and functions of both clinical and administrative activities within the healthcare industry. ISO 9000-IWA1 provides basic definitions and guidelines that can help healthcare providers select and use the appropriate standard. ISO 9001:2000 standards are system requirements, whereas ISO 9004:2000 is a guideline that goes beyond the other standards to help organizations improve the efficiency of their operations.

The five sections of the ISO 9001:2000 standard are based on quality management principles and define what should be done to consistently provide products and services that meet customer requirements. Organizations must demonstrate appropriate application of the standards through extensive documentation. The five sections of the ISO 9001:2000 standard are:

1. *Quality management system.* The establishment and documentation of a quality management system, including quality policy, quality goals, and a system of control.
2. *Management responsibility.* Management must continually analyze, review, and improve the quality management system.

3. *Resource management.* Employees must be qualified and trained for the job they are doing. Other resources (facilities, equipment, support services) must be sufficient to produce quality products and services.
4. *Measurement, analysis, and improvement.* The organization will carry out inspection, testing, measurement, analysis, and improvement processes.
5. *Product realization.* The processes that produce the organization's product or service must be well controlled.

ISO 9000 provides a methodology and framework for ensuring that an organization has efficiently and effectively defined, organized, integrated, and synchronized its quality management system to optimize performance and ensure customer satisfaction. Dr. Paul M. Schyve (2000), senior vice president of the Joint Commission, believes that accreditation, ISO 9000, and the Baldrige criteria can complement and augment one another as part of a healthcare organization's overall efforts to achieve performance excellence.

Baldrige Criteria

The Malcolm Baldrige National Quality Award was established to recognize U.S. organizations for their achievements in quality. The award has raised awareness about the importance of quality as a competitive priority and helped to disseminate best practices in achieving world-class quality by providing examples of how to achieve quality and performance excellence.

The Baldrige system (Baldrige National Quality Program 2005) focuses on continual improvement of key processes to deliver exceptional customer value. Customers are key to the Baldrige concept; however, employees are the ones who actually deliver that exceptional value to the customer, and the Baldrige system also places significant emphasis on building and retaining a skilled, motivated, and satisfied workforce. Finally, quality is not desired for quality's sake, but rather it is needed to drive business performance; the Baldrige criteria place almost 50 percent of their weight on outcomes. These outcomes include strategies that lead to improved market performance, increased market share, customer retention, and satisfaction. Organizations are encouraged to use financial information such as profit trends to analyze the connections to overall performance.

The Baldrige criteria consist of seven categories of excellence (Figure 8.1) and have been used by thousands of organizations as a self-assessment and improvement tool. Many organizations do not even apply for the award, but still use the framework as an internal assessment and improvement tool. Healthcare organizations that have received the award (Baldrige National Quality Program 2006a) include:

- Bronson Methodist Hospital, Kalamazoo, Michigan (2005);
- Robert Wood Johnson University Hospital Hamilton, Hamilton, New Jersey (2004);
- Baptist Hospital, Inc., and Saint Luke's Hospital of Kansas City (2003); and
- SSM Healthcare, St. Louis (2002).
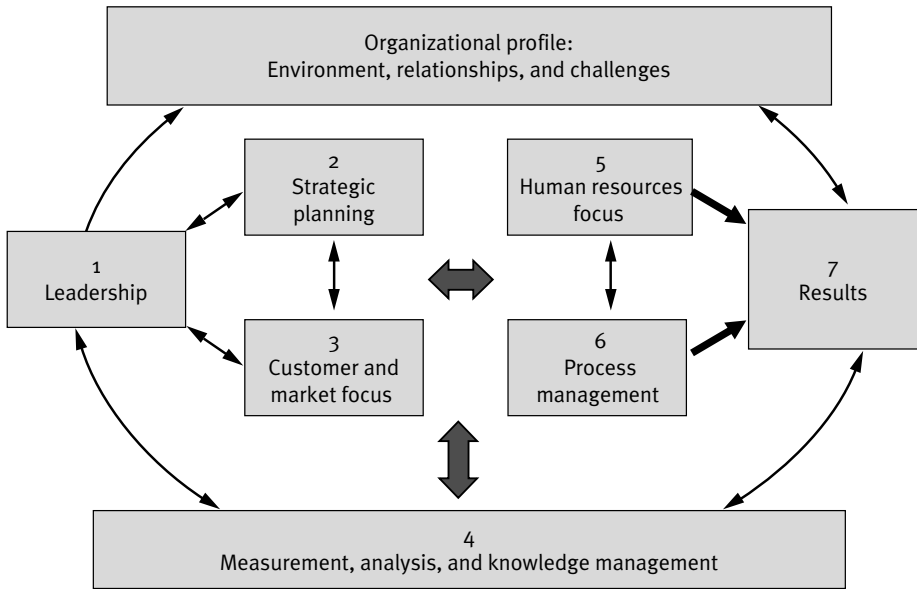
SOURCE: Baldrige National Quality Program (2006b).

Six Sigma

Six Sigma began in the 1980s at Motorola as the organization's in-house quality improvement program. The program has since been adopted by many companies, and training in the Six Sigma methodology is offered by many consultants, including Motorola.

Six Sigma has been defined as a philosophy, methodology, set of tools, and goal. It is seen as a business strategy with a focus on eliminating defects through prevention and process improvement. The Six Sigma philosophy transforms the culture of the organization, and its methodology employs a project team–based approach to process improvement using the define-measure-analyze-improve-control (DMAIC) cycle. Six Sigma is composed of a set of quantitative and qualitative statistically based tools used to provide management with facts to allow improvement of an organization's performance. Finally, Six Sigma also represents a goal of no more than 3.4 defects per million opportunities (DPMOs).

Six Sigma programs can take many forms, depending on the organization, but the successful ones all share some common themes:

- Top management support for Six Sigma as a business strategy;
- Extensive training at all levels of the organization in the methodology and use of tools and techniques;

- Emphasis on the DMAIC approach and use of quantitative measures of project success; and
- Team-based projects for improvement that directly affect the organization's financial well-being.

The Six Sigma methodology has been used successfully to improve quality and business performance in many healthcare organizations, both as a stand-alone program (Barry, Murcko, and Brubaker 2002; Ettinger 2001; Farrell and Simas 2005; Lazarus and Stamps 2002) and as an extension of current CQI or TQM initiatives (Revere and Black 2003).

Culture

Six Sigma, like all successful change initiatives, both requires and supports cultural change within the organization. The culture of the organization can be thought of as its personality, made up of the assumptions, values, norms, and beliefs of the whole of the organization's members. It is evidenced by how tasks are performed, how problems are solved, and how employees interact with one another and the outside world. Leaders and employees of organizations both shape and are shaped by the culture of the organization.

Leadership

Six Sigma focuses on leadership and the need for top management to support and drive the initiative. Without this support, any initiative is doomed to failure. With both financial and ideological support, Six Sigma can transform an organization.

Training

Successful Six Sigma initiatives require a high level of proficiency in the application of the method's qualitative and quantitative tools and techniques. To achieve this, Six Sigma initiatives involve an extensive amount of training at all levels of the organization. As employees receive more training and become more proficient, they are designated as *green belts*, *black belts*, and *master black belts*.

Green belts typically undergo five days of classroom training covering quality management and control, problem solving, data analysis, group facilitation, and project management. To obtain certification, they must usually pass a written exam and successfully complete and defend a Six Sigma project. Green belts continue to perform their usual jobs in addition to Six Sigma projects. Many organizations have a goal of training all their employees to the green-belt level.

Black belts have more Six Sigma project leadership experience than green belts. They have more training in higher-level statistical methods and mentor green belts. Black belts spend a limited amount of time, typically one or two years, working on Six Sigma projects throughout the organization and then return to their usual jobs.

At the highest level are master black belts, qualified to train green belts and black belts and therefore given more extensive training in statistical methods as well as communication and teaching skills. Master black belts provide mentorship and expertise to green and black belts in their organizations.

This training system serves several purposes: It provides the organization with in-house experts; enables everyone in the organization to speak the same language, to understand exactly what Six Sigma and Six Sigma projects are all about; and, by using black belts for a limited amount of time and then returning them to their usual positions within the organization, seeds the organization with Six Sigma disciples.

Define-Measure-Analyze-Improve-Control

DMAIC is the acronym for the five phases of a Six Sigma project: define, measure, analyze, improve, and control. The DMAIC framework, or improvement cycle (Figure 8.2), is used almost universally to guide Six Sigma process improvement projects. DMAIC is based on the plan-do-check-act continuous improvement cycle developed by Shewart and Deming but is much more specific.

There are other improvement and problem-solving frameworks, such as the eight discipline process (Laszlo 2003), but this text focuses on the more popular Six Sigma DMAIC process.

Define

In the definition phase, the Six Sigma team chooses a project based on the strategic objectives of the business and the needs or requirements of the customers of the process. The problem to be solved (or process to be improved) is operationally defined in terms of measurable results. "Good" Six Sigma projects typically have the following attributes:

FIGURE 8.2
DMAIC
Process
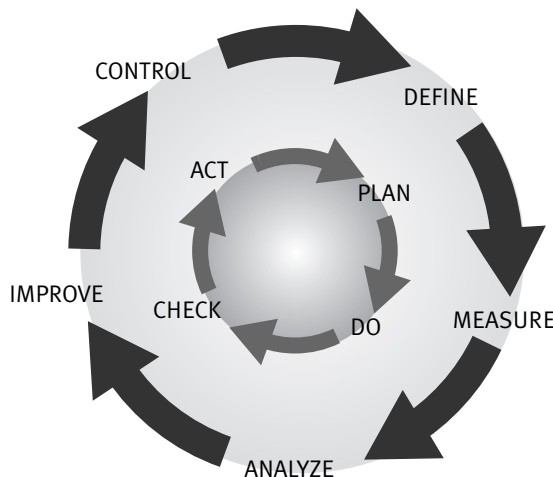
- The project will save or make money for the organization.
- The desired process outcomes are measurable.
- The problem is important to the business, has a clear relationship to organizational strategy, and is (or will be) supported by the organization.

A benchmarking study of project selection (iSixSigma 2005) found that most organizations (89 percent of respondents) prioritize Six Sigma projects on the basis of financial savings. The survey also found that the existence of formal project selection processes, process documentation, and rigorous requirements for project approval were all important to the success of Six Sigma projects.

In the definition phase, internal and external customers of the process are identified and their "critical to quality" (CTQ) characteristics are determined. CTQs are the key measurable characteristics of a product or process for which minimum performance standards desired by the customer can be determined. Often, CTQs must be translated from a qualitative customer statement to a quantitative specification. In this phase, the team also defines project boundaries and maps the process (Chapters 5 and 6).

Measure

In the measurement phase, the team determines the current capability and stability of the process. Key process output variables (KPOVs) are identified, and valid, reliable metrics are determined for them (see Figure 8.3). The inputs to the process are identified and prioritized. Root-cause analysis (RCA) or failure mode and effects analysis (FMEA) is sometimes used here to determine the key process input variables (KPIVs). Valid, reliable metrics are determined for the KPIVs as well. A data collection plan for the process is determined and implemented related to the KPIVs and KPOVs. The purpose of this phase of the project is to establish the current state of the process to evaluate the effect of any changes to it.

Analyze

In the analysis phase, the team analyzes the data that have been collected to determine true root causes, or KPIVs, to decide how best to eliminate variation or failure in the process and improve the outcomes.
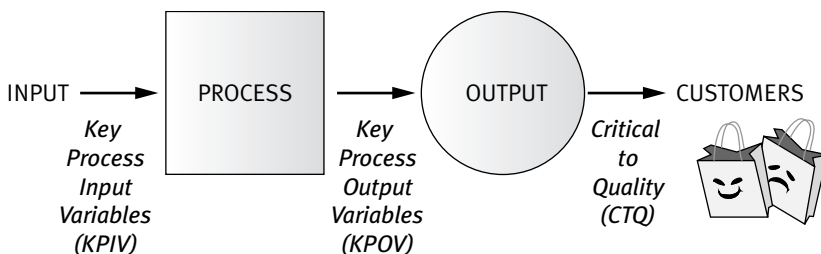
FIGURE 8.3
Six Sigma
Process Metrics

Improve
In the improvement phase, the team identifies, evaluates, and implements the improvement solutions. Possible solutions are identified and evaluated in terms of their probability of successful implementation. A plan for deployment of solutions is developed, and the solutions are implemented. Here, actual results should be measured to quantify the effect of the project.

Control
In the control phase, controls are put in place to ensure that process improvement gains are maintained and the process does not revert to the "old way." The improvements are institutionalized through modification of structures and systems (training, incentives, monitoring, etc.)

Seven Basic Quality Tools
The seven fundamental tools used in quality management and Six Sigma were first popularized by Kauro Ishikawa (1985), who believed that up to 95 percent of quality-related problems could be solved with these fundamental tools (see Figure 8.4):

- *Fishbone diagram:* tool for analyzing and illustrating the root causes of an effect (Chapter 6).
- *Check sheet:* simple form used to collect data. Hatch marks are used to record frequency of occurrence for various categories. Frequently, check sheet data are used to produce histograms and Pareto charts.
- *Histogram:* graph used to show frequency distributions (Chapter 7).
- *Pareto chart:* sorted histogram. Pareto charts are used to separate the vital few from the trivial many, based on the idea that 80 percent of quality problems are due to 20 percent of causes (Chapter 7).
- *Flowchart:* process map (Chapter 6).
- *Scatter plot:* graphical technique to analyze the relationship between two variables (Chapter 7).

FIGURE 8.4
Seven Quality
Tools

Check sheet

Fishbone diagram

Run chart

Pareto chart

Histogram

Flowchart

Scatter diagram
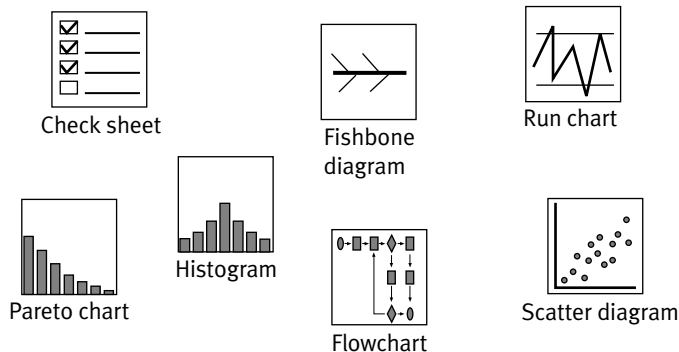
- *Run chart:* plot of a process characteristic, in chronologic sequence, used to examine trends. A control chart, discussed in the next section, is a type of run chart.

Statistical Process Control

Statistical process control (SPC) is a statistics-based methodology for determining when a process is moving out of control. All processes have variation in output, some of it due to factors that can be identified and managed (assignable or special) and some of it inherent in the process (common). SPC is aimed at discovering variation due to assignable causes so that adjustments can be made and "bad" output is not produced.

In SPC, samples of process output are taken over time, measured, and plotted on a control chart. From statistics theory, the sample means will follow a normal distribution. From the central limit theorem, 99.7 percent of sample means will have a sample mean within ±3 standard errors of the overall mean and 0.3 percent will have a sample mean outside those limits. If the process is working as it should, only three times out of 1,000 would a sample mean outside the three standard error limits be obtained. These three standard error limits ($\sigma_{\bar{X}}$) are the control limits on a control chart.

If the sample means fall outside the control limits (or follow statistically unusual patterns), the process is likely experiencing variation due to assignable or special causes and is out of control. The special causes should be found and corrected. After the process is fixed, the sample means should fall within the control limits, and the process should again be "in control."

Some statistically unusual patterns that indicate that a process is out of control are shown in Figure 8.5. A more complete list can be found in Sytsma (1997).

Often, the sample mean ($\bar{X}$, called X-bar) chart is used in conjunction with a range (R) chart. R-charts follow many of the same rules as X-bar charts and can be used as an additional check on the status of a process. There are also C-charts, used when the measured process output is the count of discrete events (e.g., number of occurrences in a day), and p-charts, used when the output is a proportion. There are also more sophisticated types of control charts that can be used in healthcare organizations (Lim 2003).

A control chart could also be set up using individual values rather than sample means. However, this is not often done for two reasons. First, the individual values must be normally distributed. Second, data collection can be expensive. It usually costs less to collect samples of the data than to collect all of the data.

Riverview Clinic SPC

The Riverview Clinic of Vincent Valley Hospital and Health System (VVH) is undertaking a Six Sigma project to reduce its waiting times. In the measurement phase of the project, data were collected on waiting time, and

FIGURE 8.5
Out-of-Control
Patterns

One sample more than ±3 standard errors from mean

Observation

8 or more samples above (or below) mean

Observation

14 or more samples oscillating

Observation

6 or more samples increasing (or decreasing)
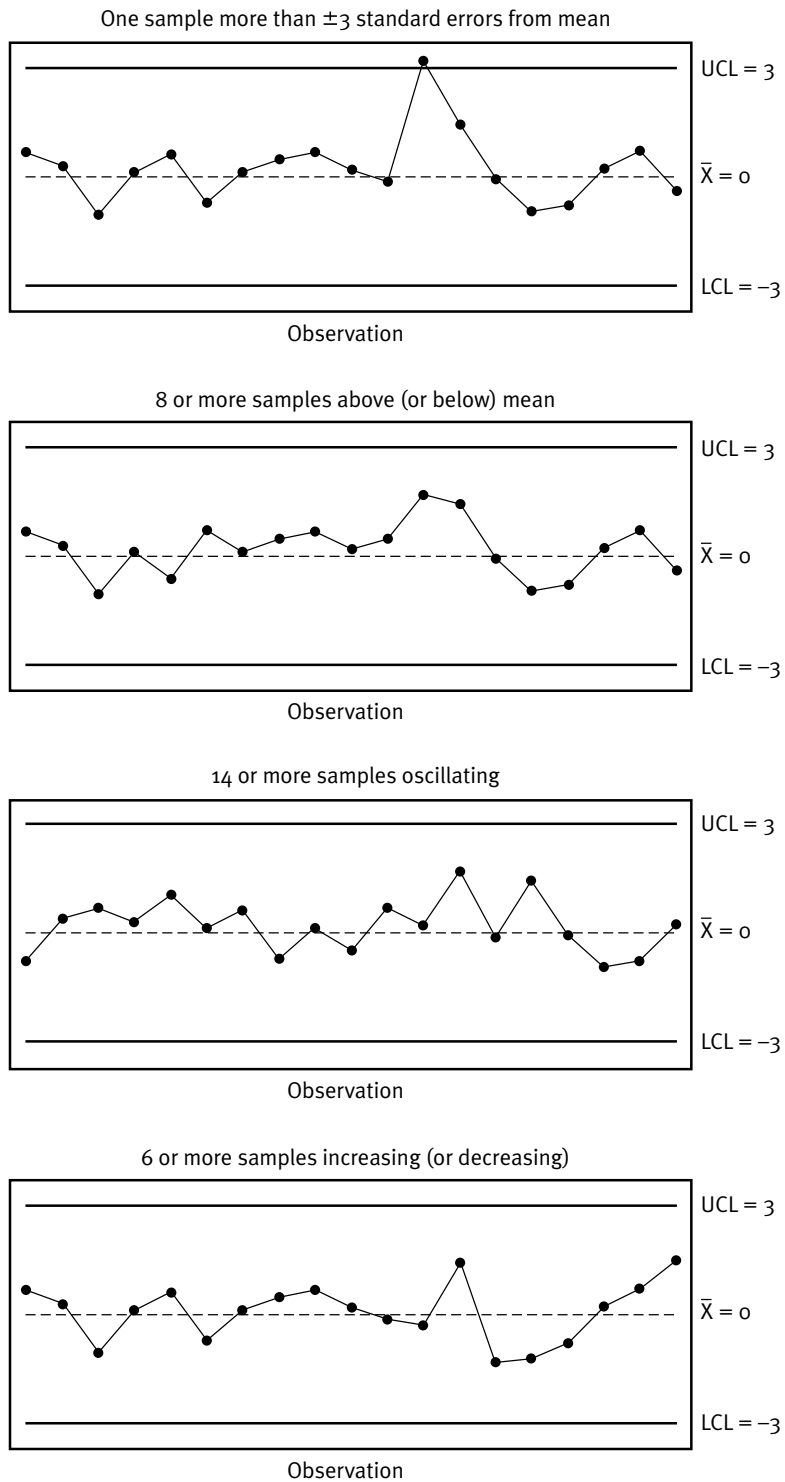
Observation

Riverview decided that a control chart would be helpful for understanding the current situation. Six observations of waiting time were made over 20 days. At randomly chosen times throughout each of 20 days, the next patient to enter the clinic was chosen. The time from when this patient entered the clinic until he exited was recorded (Table 8.1).

Riverview used the standard deviation of all of the observations to estimate the standard deviation of the population. The three-sigma control limits for the X-bar chart are:

$$\bar{x} - z_{\alpha/2} \times \sigma_{\bar{x}} \leq \mu \leq \bar{x} + z_{\alpha/2} \times \sigma_{\bar{x}}$$

$$\bar{x} - z_{\alpha/2} \times \frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + z_{\alpha/2} \times \frac{s}{\sqrt{n}}$$

$$30 - 3 \times \frac{4.4}{\sqrt{6}} \leq \mu \leq 30 + 3 \times \frac{4.4}{\sqrt{6}}$$

$$30 - 5.4 \leq \mu \leq 30 + 5.4$$

$$24.6 \leq \mu \leq 35.4$$

TABLE 8.1

Riverview Clinic Wait Times, in Minutes

Day	Observations of Wait Times (minutes) Observation						Sample Mean	Sample Range
	1	2	3	4	5	6		
1	29	29	22	31	29	31	28.50	9
2	24	29	40	26	36	30	30.83	16
3	28	33	25	26	28	33	28.83	8
4	26	31	38	30	23	28	29.33	15
5	36	29	24	29	26	32	29.33	12
6	26	27	32	25	30	29	28.17	7
7	22	33	30	31	37	34	31.17	15
8	40	29	26	29	32	30	31.00	14
9	32	32	21	34	28	29	29.33	13
10	34	26	35	27	31	26	29.83	9
11	35	30	29	30	31	27	30.33	8
12	31	39	32	32	30	31	32.50	9
13	36	24	30	29	31	26	29.33	12
14	25	23	29	31	25	23	26.00	8
15	38	43	37	35	38	32	37.17	11
16	35	29	30	25	28	30	29.50	10
17	26	29	20	33	30	28	27.67	13
18	22	29	26	30	36	28	28.50	14
19	33	33	34	37	28	30	32.50	9
20	26	26	34	34	25	36	30.17	11

Standard Deviation = 4.42   Overall Mean = 30.00

FIGURE 8.6
Riverview
Clinic Wait
Times: X-Bar
Control Chart
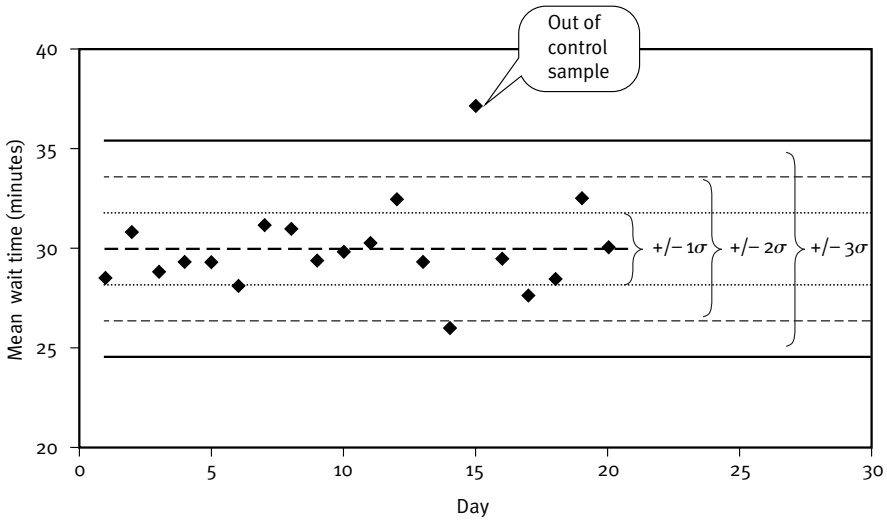
Looking at the control chart (Figure 8.6), it appears that Day 15 was out of control. An investigation found that on Day 15 the clinic was short-staffed because of a school holiday. The control chart cannot be used as is because of the out-of-control point. Riverview could choose to continue to collect data until all points are in control, or it could recalculate the control chart limits, excluding Day 15. Riverview chose to recalculate, and the new three-sigma limits are:

$$\bar{x} - z_{\alpha/2} \times \sigma_{\bar{x}} \le \mu \le \bar{x} + z_{\alpha/2} \times \sigma_{\bar{x}}$$

$$\bar{x} - z_{\alpha/2} \times \frac{s}{\sqrt{n}} \le \mu \le \bar{x} + z_{\alpha/2} \times \frac{s}{\sqrt{n}}$$

$$30 - 3 \times \frac{4.1}{\sqrt{6}} \le \mu \le 30 + 3 \times \frac{4.1}{\sqrt{6}}$$

$$30 - 5.0 \le \mu \le 30 + 5.0$$

$$25.0 \le \mu \le 35.0$$

Unless the system is changed, 50 percent of Riverview patients will experience a wait time longer than 30 minutes (50 percent will experience a wait time of less than 30 minutes), and 10 percent of Riverview patients will experience a wait time of greater than 35.3 minutes (90 percent will experience a wait time of less than 35.3 minutes).

$$\mu \le \bar{x} + z_{\alpha} \times \sigma_{x}$$

$$\mu \le \bar{x} + z\alpha \times s;\ z_{0.9} = 1.3$$

$$\mu \le 30 + (1.3 \times 4.1)$$

$$\mu \le 30 + 5.3$$

$$\mu \le 35.3$$

If Riverview's goal for its Six Sigma project is to ensure that 90 percent of patients experience a wait time of no more than 30 minutes, the clinic needs to improve the system. The Six Sigma team would need to reduce mean wait time to 24.7 minutes if the process variation remains the same (Figure 8.7).

$$\mu \leq \bar{x} + z_\alpha \times \sigma_x$$
$$\mu \leq \bar{x} + z_\alpha \times s; \; z_{0.9} = 1.3$$
$$\mu \leq 30$$
$$\mu \leq 24.7 + 5.3; \bar{x} = 24.7$$

Process Capability and Six Sigma Quality

Process capability is a measure of how well a process can produce output that meets desired standards or specifications. This is done by comparing the natural (or common) variability of an in-control process, the process width, to the specification width. Specifications are determined by outside forces (customers, management, etc.), but process variability is not determined—it is simply a natural part of any process. A capable process is a process that produces few defects, where a defect is defined as an output outside specification limits.

There are two common measures of process capability, C_p and C_{pk}. C_p is used when the process is centered on the specification limits; the mean of the process is the same as the mean of the specification limits. C_{pk} is used when the process is not centered. A capable process will have a C_p or C_{pk} greater than 1. At a C_p of 1, the process will produce about three defects per 1,000.

$$C_p = \frac{USL - LSL}{6\sigma} \text{ and is estimated by } \hat{C}_p = \frac{USL - LSL}{6s}$$
$$C_{pk} = \min\left[\frac{\bar{x} - LSL}{3\sigma} \text{ or } \frac{USL - \bar{x}}{3\sigma}\right]$$
$$\text{and is estimated by } \hat{C}_{pk} = \min\left[\frac{\bar{x} - LSL}{3s} \text{ or } \frac{USL - \bar{x}}{3s}\right]$$

NOTE: USL = upper specified limit and LSL = lower specified limit
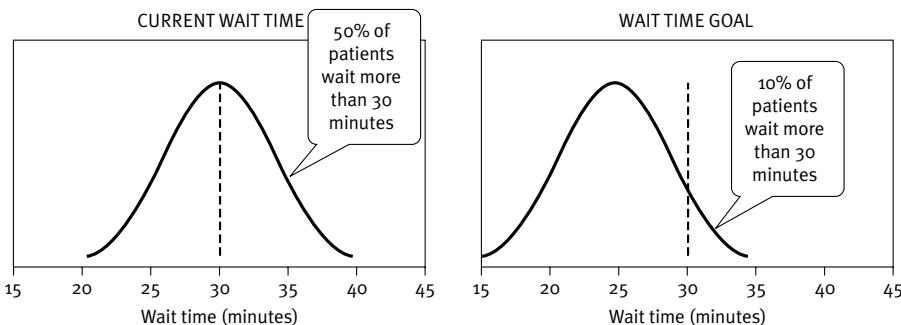
FIGURE 8.7
Riverview
Clinic Wait
Time

Six Sigma quality is defined as fewer than 3.4 defects per million opportunities (DPMO). This definition can be somewhat confusing, as it actually corresponds to the 4.5-sigma one-tail probability limit for the normal distribution. Six Sigma allows for a 1.5-sigma shift in the mean of the process and $C_{pk} = 1.5$ (Figure 8.8).

Riverview Clinic Process Capability

Riverview Clinic management has decided that no patient should wait more than 40 minutes, a waiting time upper specification limit (USL) of 40 minutes. The Six Sigma team wants to determine if the process is capable. Note that because there is no lower specification limit (waiting time less than some lower limit would not be a "defect"), C_{pk} is the correct measure of process capability.

$$\hat{C}_{pk} = \left[\frac{USL - \bar{x}}{3s} \right] = \frac{40 - 30}{3 \times 4.1} = \frac{10}{12.3} = 0.81$$

The C_{pk} is less than 1. Therefore, the process is not capable, and 7,000 DPMOs are expected $[x \sim N(30, 16.8), P(x > 40) = 0.007]$.

The team determines that to ensure Six Sigma quality, the specification limit would need to be 48.8 minutes:

$$\hat{C}_{pk} = 1.5 = \left[\frac{USL - \bar{x}}{3s} \right] = \frac{USL - 30}{12.3} = \frac{48.8 - 30}{12.3} \quad \therefore \quad USL = 48.8$$

FIGURE 8.8

Six Sigma Process Capability Limits
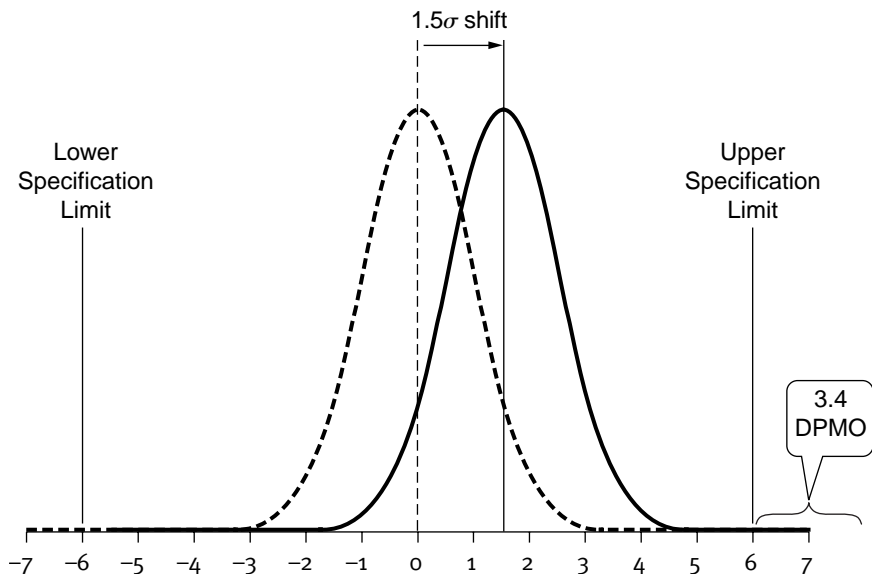
If the Riverview Six Sigma team determined that Six Sigma quality with a specification limit of 40 minutes was a reasonable goal, it could reduce average wait time, reduce the variation in the process, or do some combination of both.

$$\hat{C}_{pk} = \left[\frac{USL - \bar{x}}{3s} \right] = \frac{USL - \bar{x}}{12.3} = \frac{40 - 21}{12.3} \quad \therefore \ \bar{x} = 21$$

$$\hat{C}_{pk} = 1.5 = \left[\frac{USL - \bar{x}}{3s} \right] = \frac{40 - 30}{3s} = \frac{10}{3 \times 2.2} \quad \therefore \ s = 2.2$$

Average wait time would need to be reduced to 21 minutes, or the standard deviation of the process would need to be reduced to 2.2 minutes to reach the goal.

Rolled Throughput Yield

Rolled throughput yield (RTY) is a measure of overall process performance. It is the probability that a unit (of product or service) will pass through all process steps free of defects. For example, consider a process comprising four steps or subprocesses. If each step has a 5 percent probability of producing an error or defect (95 percent probability of an error-free outcome), the RTY of the overall process is 81 percent—considerably lower than that in the individual steps (Figure 8.9).

Additional Quality Tools

In addition to the quality tools and techniques commonly associated with Six Sigma, many other tools can be used in process improvement. Quality function deployment (QFD) and Taguchi methods are often used in the development of new products or processes to ensure quality outcomes. However, they can also be used to improve existing products and processes. Benchmarking is used to help to determine best practices and adapt them to the organization to achieve superior performance. Mistake-proofing, or poka-yoke, is used to minimize the possibility of an error occurring. All of these tools are an essential part of an organization's quality toolbox.
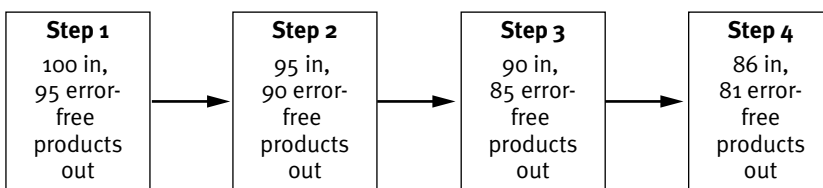
FIGURE 8.9

Rolled Throughput Yield

Step 1	Step 2	Step 3	Step 4
100 in, 95 error-free products out	95 in, 90 error-free products out	90 in, 85 error-free products out	86 in, 81 error-free products out

Quality Function Deployment

QFD is a structured process for identifying customer needs and wants and translating them into a product or process that meets those needs. This tool is most often used in the development phase of a new product or process, but it can also be used to redesign an existing product or process. Typically, QFD is found in a Design for Six Sigma (DFSS) project, where the goal is to design the process to meet Six Sigma goals. The QFD process uses a matrix called the house of quality (Figure 8.10) to organize data in a usable fashion.

The first step in QFD is to determine customer requirements. Customer requirements represent the voice of the customer (VOC) and are often stated in customer terms, not technical terms. There can be many customers for a particular product or service, and the VOC of all must be heard.

Market research tools are used to capture the VOC. The many customer needs found are organized into a few key customer requirements, which are weighted based on their relative importance to the customer. Typically, a scale of one to five is used, with five representing the most important. The customer requirements and their related importance are listed on the left side of the QFD diagram.

A competitive analysis based on the identified customer needs is also performed. The question here is how well competitors meet customer needs. Typically, a scale of one to five is used here as well, with five indicating that the competitor completely meets this need. The competitive analysis is used to focus the development of the service or product to determine where there are oppor-

FIGURE 8.10
House of
Quality
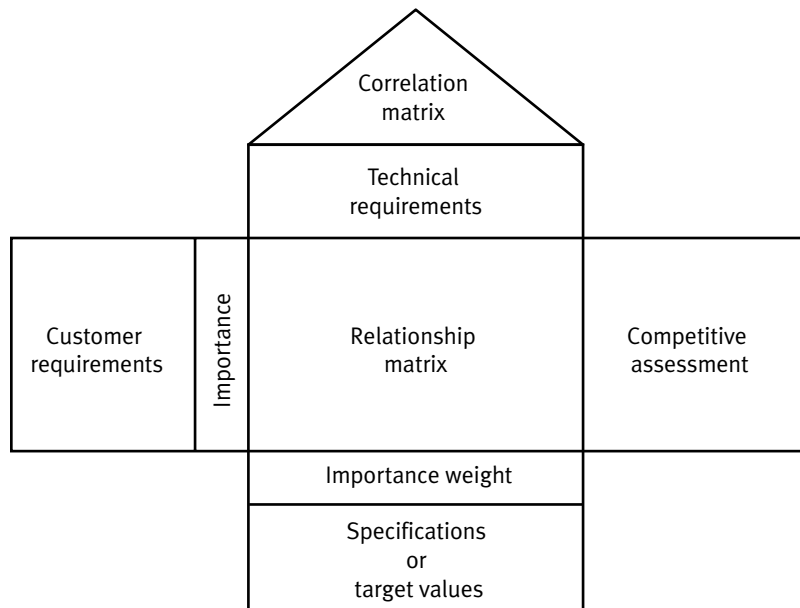
tunities to gain competitive advantage and where the organization is at a competitive disadvantage. This can help the development team to focus on important strategic characteristics of the product or service. The competitors' scores on each of the customer requirements are listed on the right side of the QFD diagram.

Technical requirements of the product or process that relate to customer requirements are determined. For example, if customers want speedy service time, a related technical requirement might be 90 percent of all service times be less than 20 minutes. The technical requirements are listed horizontally across the top of the QFD diagram. The relationship between the customer requirements and technical requirements is evaluated. Usually, the relationships are evaluated as strong, medium, or weak, and symbols are used to represent these relationships in the relationship matrix. Numeric values are assigned to the relative weights (5 = strong, 3 = medium, 1 = weak), and these values are placed in the matrix.

Positive and negative interactions among the technical requirements are evaluated as strongly positive, positive, strongly negative, and negative. Symbols are used to represent these relationships in the "roof," or correlation matrix, of the house of quality. This makes clear the trade-offs involved in product and process design.

Customer importance weights are multiplied by relationship weights and summed for each technical requirement to determine the importance weights. Target values are developed based on the house of quality.

Historically, QFD was a phased process. The aforementioned is the planning phase; for product development, planning is followed by additional houses of quality related to parts, process, and production. For service development and improvement, using only the first house of quality or the first house of quality followed by the process house is often sufficient. For examples of QFD applications in healthcare environments, see Chaplin and Terninko (2000), Mazur, Gibson, and Harries (1995), and Omachonu and Barach (2005).

Riverview Clinic QFD

Many diabetes patients at the Riverview Clinic were not returning for routine preventive exams. The team formed to address this problem decided to use QFD to improve the process and began by soliciting the VOC via focus groups. The team found the following patient needs and wants:

- To know (or be reminded) that they need to schedule a preventive exam;
- To know why an office visit is needed;
- A convenient means to schedule their appointments;
- That their appointments be on time; and
- To know that their appointments will last a certain length of time.

Patient rankings of the importance of these needs and wants was determined via patient surveys.

A competitive analysis of Riverview Clinic's two main competitors was conducted based on the determined needs and wants of Riverview's patients with diabetes. The team developed related technical requirements and evaluated the interactions between them. The house of quality developed is shown in Figure 8.11. On-time appointments have the highest importance ranking because they affect both appointment time and appointment length.

The team then evaluated various process changes and improvements related to the determined technical requirements. To meet these technical requirements, they decided to notify patients via postcard and follow this with e-mail and phone notification if needed. The postcard and e-mail contained information related to the need for an office visit and directed patients to the clinic's web site for more information. Appointment scheduling was made available via the Internet as well as by phone. Staffing levels and appointment times were adjusted to ensure that appointments were on time and approximately the same length. Training was conducted to help physicians and nurses understand the need to maintain constant appointment lengths and provide them with tools to ensure consistent length.

Table 8.2 outlines these process changes and related technical requirements. After the changes were implemented, the team checked to ensure that the technical requirements determined with the house of quality were being met.

FIGURE 8.11

Riverview Clinic House of Quality for Patients with Diabetes

		Initial notification	Subsequent notification	Information on need	Time to schedule	Appointment length range	On-time appointment	*Our service*	*Competitor A*	*Competitor B*
Time knowledge	5	5	3					3	5	3
Why knowledge	3			5				3	5	3
Convenient	4				5			3	3	3
Appointment length	3					5	3	2	3	3
Appointment time	4					3	5	2	4	3
		25	15	15	20	27	29			
		Yes	3	3 channels	8 minutes	8 minutes	90%			

Technical Requirement	Process Change
Initial notification	Postcard mailed
Subsequent notifications	E-mail and/or phone call
Information on need	Web site
Time to schedule	Web site and phone
Appointment length range	Staff levels adjusted
On-time appointment	Staff training

TABLE 8.2
Riverview QFD Technical Requirements and Related Process Changes

Taguchi Methods

Taguchi methods refer to two related ideas first introduced by Genichi Taguchi (Taguchi, Chowdhury and Wu 2004). Rather than the quality of a product or service being good or bad, where good is within some specified tolerance limits and bad is outside those limits, quality is related to the distance from some target value; further from the target is worse. Taguchi developed experimental design techniques (design of experiments, or DOE; Chapter 7) where not only the target value, but also the associated variation, is important. The optimal process design is not necessarily where the target value is maximized but where variation is minimal in relation to the target. In other words, the process is robust and will perform well under less-than-ideal conditions.

Taguchi methods are often used in DFSS where the product or service is designed to be error free while meeting or exceeding the needs of the customer. Rather than "fixing" an existing product or service, the design process of the product or service should ensure quality from the start.

Benchmarking

According to the American Productivity and Quality Center (2005), benchmarking is "the process of identifying, understanding, and adapting outstanding practices and processes from organizations anywhere in the world to help your organization improve its performance." Benchmarking is focused on how to improve any given process by finding, studying, and implementing best practices. These best practices may be found within the organization, in competitor organizations, and even in organizations outside the particular market or industry. Best practices are everywhere—the challenge is to find them and adapt them to the organization.

The benchmarking process consists of deciding what to benchmark, determining how to measure it, gathering information and data, and then implementing the best practice within the organization. Benchmarking can

be an important part of a quality improvement initiative, and many health-care organizations are involved in benchmarking (Bisognano and Caldwell 1995). The journal *Healthcare Benchmarks and Quality Improvement* has information on many of these initiatives.

Poka-Yoke

Poka-yoke (a Japanese phrase meaning to avoid inadvertent errors), or mistake-proofing, is a way to prevent errors from happening. A poka-yoke is a mechanism that either prevents a mistake from being made or makes the mistake immediately obvious so that no adverse outcomes are experienced. For example, all of the instruments required in a surgical procedure are found on an instrument tray with indentations for each instrument. After the procedure is complete, the instruments are replaced in the tray. This provides a quick visual check to ensure that all instruments are removed before closing the patient's incision. Locating the controls for a mammography machine so that the technician cannot start the machine unless she is shielded from radiation via a wall provides another example of mistake-proofing a process. In FMEA, identified fail points are good candidates for poka-yoke.

Technology can often enable poka-yoke. When patient data are input into a system, the software is often programmed to provide an error message if the data are "incorrect." For example, a Social Security number is nine digits long; no more than nine digits can be input into the Social Security field, and an error message appears if fewer than nine digits are entered. In the past, surgical sponges were counted before and after a procedure to ensure that none were left in a patient. Now, the sponges can be radio frequency identification tagged, eliminating the error-prone counting process, and a simple scan can be used to determine if any sponges remain in the patient.

Riverview Clinic Six Sigma Generic Drug Project

Management determined that a strategic objective for Riverview Clinic was meeting pay-for-performance goals related to prescribing generic drugs, and a project team was organized to meet this goal. Benchmarking was done to help the team determine which pay-for-performance measure to focus on and define reasonable goals for the project. The team found that 10 percent of nongeneric prescription drugs could be replaced with generic drugs and that other clinics had successfully met this goal.

Define

In the definition phase, the team articulated the project goals, scope, and business case. This included developing the project charter, determining cus-

tomer requirements, and diagramming a process map. The charter for this project is found in Chapter 5; it defines the project's goals, scope, and business case.

The team identified the health plans and patients as being customers of the process. The outputs of the process were identified as prescriptions and the efficacy of those prescriptions. The process inputs were physician judgment and the information technology (IT) system for drug lists. Additionally, pharmaceutical firms provide input on drug efficacy. The process map developed by the team is shown in Figure 8.12.

Measure

The team determined that the percentage of generic (versus nongeneric) drugs prescribed and the percentage of prescription changes after prescription of a generic drug would be used to quantify the outcomes. Additionally, the team decided that it would need to track and record data on all nongeneric drugs prescribed by each individual clinician for one month.

Analyze

After one month, the team analyzed the data and found that, overall, clinicians prescribed 65 percent generic drugs (Figure 8.13), and prescription changes were needed for 3 percent of all prescriptions. An example of the data collected is shown in Table 8.3. The team generated a Pareto analysis by clinician and drug to determine if particular drugs or clinicians were more problematic. The analysis showed that some drugs were more problematic but that all clinicians were about the same (Figure 8.14).
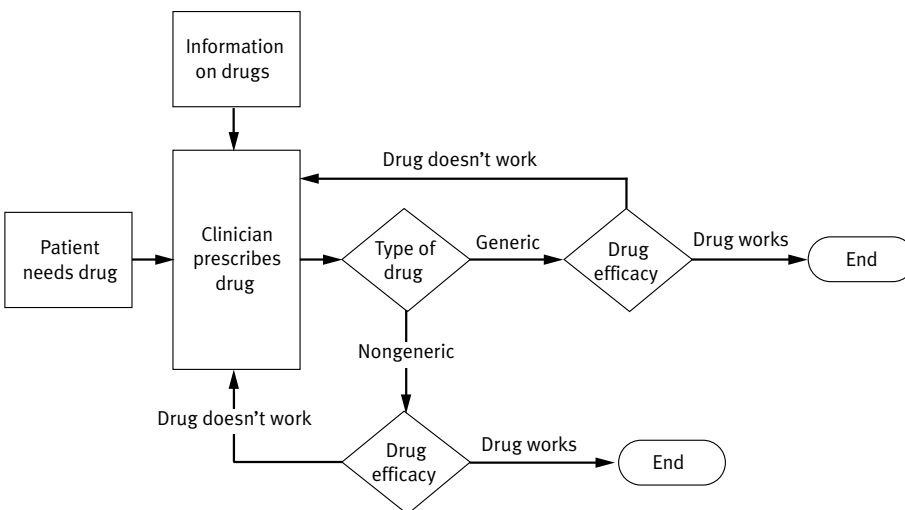
FIGURE 8.12
Riverview Clinic Prescription Process
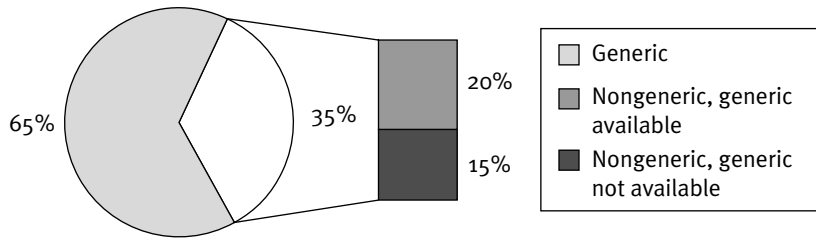
The team reexamined its stated goal of increasing generic drug prescriptions by 4 percent in light of the data collected. If all prescriptions for the top four nongeneric drugs for which a generic drug is available could be changed to generics, Riverview would increase generic prescriptions by 5 percent. Therefore, they decided that the original goal was still reasonable.

TABLE 8.3
Riverview
Clinic Six
Sigma Generic
Drug Project
Example Data

Date	Clinician	Drug	Drug Type	Generic Available	Represcribe
1-Jan	Smith	F	Nongeneric	Yes	No
1-Jan	Davis	G	Generic	Yes	No
1-Jan	Jones	L	Generic	Yes	No
1-Jan	Anderson	F	Nongeneric	No	No
1-Jan	Swanson	R	Generic	Yes	Yes
1-Jan	Smith	S	Nongeneric	Yes	No
1-Jan	Swanson	U	Generic	Yes	No
1-Jan	Jones	P	Generic	Yes	No
1-Jan	Jones	S	Nongeneric	No	No
1-Jan	Swanson	A	Generic	Yes	No
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
31-Jan	Anderson	F	Nongeneric	Yes	No
31-Jan	Anderson	E	Nongeneric	No	No
31-Jan	Davis	T	Generic	Yes	No
31-Jan	Smith	Y	Generic	Yes	No
31-Jan	Jones	D	Generic	Yes	No
31-Jan	Swanson	J	Generic	Yes	No
31-Jan	Swanson	I	Nongeneric	Yes	No
31-Jan	Smith	T	Generic	Yes	No
31-Jan	Davis	G	Generic	Yes	No
31-Jan	Anderson	H	Generic	Yes	No
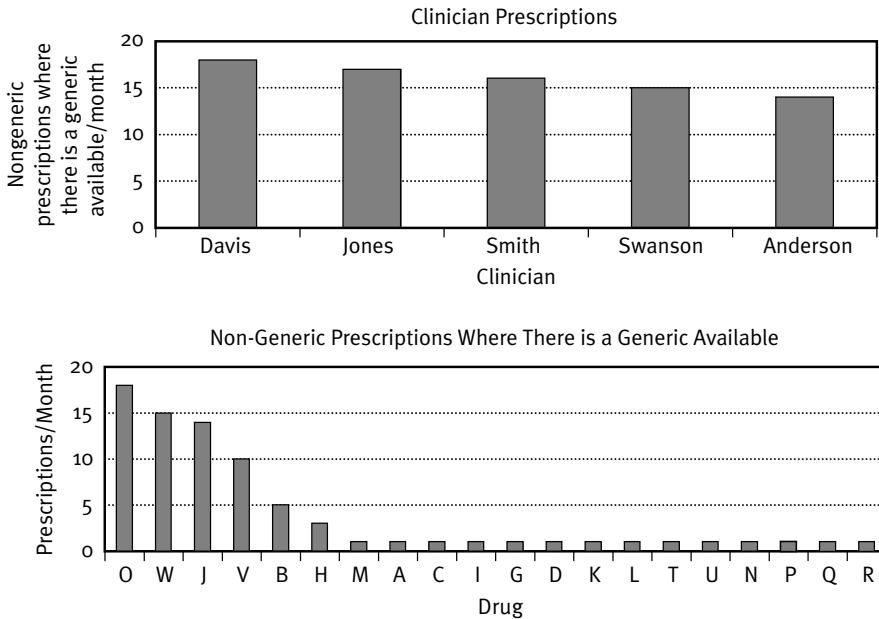
Improve

The team conducted an RCA of the reasons for prescribing nongeneric drugs and determined that the major cause was the clinician's lack of awareness of a generic replacement for the prescribed drug. In addition to the IT system that will identify approved generic drugs, the team decided to publish, based on data from the previous month, a monthly top five list of nongeneric drugs for which an approved generic exists. The team continued to collect and analyze data after these changes were implemented and found that prescriptions for generic drugs had risen by 4.5 percent after 6 months.

Control

To measure progress and ensure continued compliance, the team set up a weekly control chart for generic prescriptions and continued to monitor and publish the top five list. The team conducted an end-of-project evaluation to document the steps taken and results achieved, and to ensure that learning from the project was retained in the organization.

Conclusion

The Six Sigma DMAIC process is a framework for improvement. At any point in the process, it may be necessary to backtrack to ensure improvement. For example, what the team thought was the root cause of the problem may

be found not to be the true root cause. Or, when attempting to analyze the data, it may be that insufficient data, or the wrong data, were taken. In both cases, it may be necessary to go back in the DMAIC process to ensure a successful project.

At each stop in the DMAIC process, various tools could be used. The choice of tool is related to the problem and possible solutions. Table 8.4 outlines suggestions for when to choose a particular tool or technique. This is only a guideline—use whatever tool is most appropriate for the situation.

TABLE 8.4
Quality Tools and Techniques Selector Chart

Tool or Technique	Define	Measure	Analyze	Improve	Control
7 Quality control tools					
Cause-and-effect diagram			x		
Run chart		x	x		
Check sheet					
Histogram		x	x		
Pareto chart		x	x	x	
Scatter plot			x		x
Flowchart	x	x			
Other tools and techniques					
Mind-mapping/ brainstorming	x		x	x	
5 Whys/RCA			x		
FMEA			x	x	
Turnip graph			x		
Pie chart			x		
Hypothesis testing			x		
Regression analysis			x		
Control chart		x		x	x
Process capability		x		x	x
QFD		x	x	x	
DOE/Taguchi methods				x	
Benchmarking	x	x	x	x	
Poka-yoke				x	
Gantt chart				x	
Project planning	x			x	x
Charters	x				
Tree diagram				x	
Simulation			x	x	
Force field analysis				x	x
Balanced scorecard	x	x	x	x	x

Discussion Questions

1. Read the Executive Summary of the IOM report *To Err Is Human* (http://fermat.nap.edu/openbook.php?record_id=9728&page=1) and answer the following questions: Why did this report spur an interest in quality management in the healthcare industry? What does IOM recommend to address these problems? How much has been done since 1999?
2. What does quality in healthcare mean to your organization? To you personally?
3. Discuss a real example of each of the four costs of quality in a healthcare organization.
4. Compare and contrast total quality management/continuous quality improvement, ISO 9000, the Baldrige criteria, and Six Sigma. (More information on each of these programs is linked from the companion web site.) Which would you find most appropriate to your organization? Why?
5. Think of at least three poka-yokes currently used in the healthcare industry. Can you think of a new one for your organization?

Chapter Exercises

1. Clinicians at VVH have been complaining about the turnaround time for blood work. The laboratory manager decides to investigate the problem and collects turnaround time data on five randomly selected requests every day for one month.

	Observation						Observation				
Day	*1*	*2*	*3*	*4*	*5*	*Day*	*1*	*2*	*3*	*4*	*5*
1	44	41	80	51	25	16	14	44	35	52	76
2	28	32	58	42	18	17	52	84	55	63	15
3	54	83	59	50	46	18	28	20	67	76	69
4	57	53	63	15	52	19	25	23	35	21	23
5	30	50	62	68	42	20	46	74	24	10	47
6	42	40	50	49	73	21	33	54	62	40	27
7	26	17	50	47	91	22	64	55	62	14	72
8	54	39	39	82	28	23	53	49	72	49	61
9	46	62	53	64	57	24	15	16	18	35	78
10	49	71	34	42	43	25	64	9	51	47	70
11	53	64	12	35	43	26	36	21	51	40	57
12	75	43	43	50	64	27	24	58	19	88	16
13	74	19	52	55	59	28	75	66	34	27	71
14	91	40	66	15	73	29	60	42	20	59	60
15	59	32	59	49	71	30	52	28	85	39	67

    a. Construct an X-bar chart using the standard deviation of the observations to estimate the population standard deviation. Construct an X-bar chart and R-chart using the range to calculate the control limits. (The Excel template on the companion web site will do this for you.)

    b. Is the process in control? Explain.

    c. If the clinicians feel that any time over 100 minutes is unacceptable, what are the C_p and C_{pk} of this process?

    d. What are the next steps for the laboratory manager?

2. Riverview Clinic has started a customer satisfaction program. In addition to other questions, each patient is asked if he is satisfied with his overall experience at the clinic. Patients can respond "yes," they were satisfied, or "no," they were not satisfied. Typically, 200 patients are seen at the clinic each day. The data collected for two months are shown below.

Day	Proportion of patients who were unsatisfied	Day	Proportion of patients who were unsatisfied	Day	Proportion of patients who were unsatisfied
1	0.17	15	0.15	28	0.18
2	0.13	16	0.14	29	0.19
3	0.15	17	0.13	30	0.14
4	0.22	18	0.15	31	0.19
5	0.16	19	0.15	31	0.10
6	0.13	20	0.22	33	0.17
7	0.17	21	0.19	34	0.15
8	0.17	22	0.15	35	0.17
9	0.11	23	0.12	36	0.15
10	0.16	24	0.16	37	0.15
11	0.15	25	0.18	38	0.15
12	0.17	26	0.14	39	0.14
13	0.17	27	0.17	40	0.19
14	0.12				

    a. Construct a p-chart using the collected data.

    b. Is the process in control?

    c. On average, how many patients are satisfied with Riverview Clinic's service? If Riverview wants 90 percent (on average) of patients to be satisfied, what should the clinic do next?

3. Think of a problem in your organization that Six Sigma could help to solve. Map the process and determine the KPIVs, KPOVs, CTQs, and exactly *how* you could measure them.

4. Use QFD to develop a house of quality for the VVH emergency department (you may need to guess the numbers you do not know). An Excel

template (QFD.xls) available on the companion web site may be helpful for this problem.

References

American Productivity and Quality Center. 2005. "Glossary of Benchmarking Terms." [Online information; retrieved 1/30/06.] www.apqc.org/portal/apqc/ksn/ Glossary%20of%20Benchmarking%20Terms.pdf?paf_gear_id=content gearhome&paf_dm=full&pageselect=contentitem&docid=119519.

Baldrige National Quality Program. 2006a. "1988–2004 Award Recipients' Contacts and Profiles." [Online information; retrieved 1/15/06.] www.quality.nist.gov/ Contacts_Profiles.htm.

———. 2006b. *2006 Criteria for Performance Excellence.* Gaithersburg, MD: National Institute of Standards and Technology.

———. 2005. "Frequently Asked Questions about the Malcolm Baldrige National Quality Award." [Online information; retrieved 1/15/06.] www.nist.gov/ public_affairs/factsheet/baldfaqs.htm.

Barry, R., A. Murcko, and C. E. Brubaker. 2002. *Six Sigma Book for Healthcare: Improving Outcomes by Reducing Errors.* Milwaukee, WI: ASQ Quality Press.

Beaver, R. 2004. "Six Sigma Success in Health Care." *Quality Digest* March: 31–34.

Bisognano, M. A., and C. Caldwell. 1995. "Best Practices in Quality Leadership." *The Quality Letter for Healthcare Leaders* 7 (6): 16–21.

Center for the Study of Healthcare Management. 2002. "Deploying Six Sigma in a Healthcare System." [Online white paper; retrieved 8/13/06.] www.hpm.umn.edu/ research/centerline/8260.pdf.

Chaplin, E. M. D., and J. Terninko. 2000. *Customer Driven Healthcare: QFD for Process Improvement and Cost Reduction.* Milwaukee, WI: American Society for Quality Press.

Cleverley, W. O., and R. K. Harvey. 1992. "Is There a Link Between Hospital Profit and Quality?" *Healthcare Financial Management* 46 (9): 40–44.

Crosby, P. B. 1979. *Quality Is Free: The Art of Making Quality Certain.* Boston: McGraw-Hill.

Ettinger, W. H. 2001. "Six Sigma: Adapting GE's Lessons to Health Care." *Trustee* 54 (8): 10–15.

Farrell, B., and T. Simas. 2005. "Tracking Quality Improvement in Health Care." *Quality Digest* 25 (9). [Online information; retrieved 10/31/07.] www.quality digest.com/sept05/articles/02_article.shtml.

Garvin, D. A. 1987. "Competing on the Eight Dimensions of Quality." *Harvard Business Review* 65 (6): 101–10.

Hackman, J. R., and R. Wageman. 1995. "Total Quality Management: Empirical, Conceptual, and Practical Issues." *Administrative Science Quarterly* 40 (2): 309–42.

Institute of Medicine. 2001. *Crossing the Quality Chasm—A New Health System for the 21st Century*. Washington, D.C.: National Academies Press.

———. 1999. *To Err Is Human: Building a Safer Health System*. Washington, D.C.: National Academies Press.

International Organization for Standardization. 2006. "ISO Homepage." [Online information; retrieved 1/15/06.] www.iso.org/iso/en/ISOOnline.frontpage.

Ishikawa, K. 1985. *What Is Total Quality Control?* Translated by D. J. Lu. Englewood Cliffs, NJ: Prentice-Hall.

iSixSigma. 2005. "Six Sigma Project Selection: How Organizations Choose the Most Important Projects." [Online information; retrieved 1/10/06.] www.isix sigma.com/library/content/dfss.asp.

Juran, J. M., and A. B. Godfrey. 1998. *Juran's Quality Handbook*, 5th ed. New York: McGraw-Hill.

Laszlo, C. 2003. *The Sustainable Company: How to Create Lasting Value Through Social and Environmental Performance*. Washington, D.C.: Island Press.

Lazarus, I. R., and B. Stamps. 2002. "The Promise of Six Sigma (Special Report)." *Managed Healthcare Executive* 12 (1): 27–30.

Lim, T. O. 2003. "Statistical Process Control Tools for Monitoring Clinical Performance." *International Journal for Quality in Health Care* 15 (1): 3–4.

Mazur, G., J. Gibson, and B. Harries. 1995. "QFD Applications in Health Care and Quality of Work Life." Paper presented at the First International Symposium on QFD, Tokyo, Japan, November 11.

Midwest Business Group on Health. 2003. *Reducing the Costs of Poor-Quality Health Care Through Responsible Purchasing Leadership*. Chicago: Midwest Business Group on Health, PPNEW04.

Omachonu, V., and P. Barach. 2005. "QFD in a Managed Care Organization." *Quality Progress* 38 (11): 36–41.

Parasuraman, A., V. A. Zeithaml, and L. L. Berry. 1988. "SERVQUAL: A Multiple-Item Scale for Measuring Consumer Perceptions of Service Quality." *Journal of Retailing* 64 (4): 12–40.

Powell, T. C. 1995. "Total Quality Management as Competitive Advantage: A Review and Empirical Study." *Strategic Management Journal* 16 (1): 15–37.

Quality Assurance Project. 2003. "Dimensions of Quality." [Online information; retrieved 1/15/06.] www.qaproject.org/methods/resdimension.html.

Revere, L., and A. K. Black. 2003. "Integrating Six Sigma with Total Quality Management: A Case Example for Measuring Medication Errors." *Journal of Healthcare Management* 48 (6): 377–91.

Ross, J. E., and S. Perry. 1999. *Total Quality Management: Text, Cases and Readings*. Oxford, UK: CRC Press.

Samson, D., and M. Terziovski. 1999. "The Relationship Between Total Quality Management Practices and Operational Performance." *Journal of Operations Management* 17 (4): 393–409.

Schyve, P. M. 2000. "A Trio for Quality: Accreditation, Baldrige and ISO 9000 Can Play a Role in Reducing Medical Errors." *Quality Progress* 33 (6): 53–55.

Shortell, S. M., J. L. O'Brien, J. M. Carman, R. W. Foster, E. F. Hughes, H. Boerstler, and E. J. O'Connor. 1995. "Assessing the Impact of Continuous Quality Improvement/Total Quality Management: Concept Versus Implementation." *Health Services Research* 30 (2): 377–401.

Suver, J. D., B. R. Neumann, and K. E. Boles. 1992. "Accounting for the Costs of Quality." *Healthcare Financial Management* 46 (9): 28–37.

Sytsma, S. 1997. "Quality and Statistical Process Control." [Online information; retrieved 2/4/06.] www.sytsma.com/tqmtools/ctlchtprinciples.html.

Taguchi, G., S. Chowdhury, and Y. Wu. 2004. *Taguchi's Quality Engineering Handbook.* Hoboken, NJ: Wiley-Interscience.

Tarí, J. J. 2005. "Components of Successful Total Quality Management." *The TQM Magazine* 17 (2): 182–94.

9

THE LEAN ENTERPRISE

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

% value added

advanced access scheduling

andon

care paths

computed tomography (CT)

continuous quality improvement

coronary artery bypass graft
    (CABG)

cycle time

echocardiograph (echo)

five Ss

heijunka

jidoka

Joint Commission

just in time

kaizen blitz, see kaizen event

kaizen event

kaizen philosophy

kanbans

Lean Sigma

muda

necessary activity

non–value added

operating room (OR)

single-minute exchange of die
    (SMED)

Six Sigma

spaghetti diagram

standardized work

takt time

throughput time

total quality management (TQM)

Toyota Production System (TPS)

types of waste

unnecessary activity

value added

value stream mapping

work-in-process (WIP)

Operations Management in Action

The authors of Going Lean in Healthcare *provide the following example of Lean management principles applied in healthcare:*

Virginia Mason Medical Center in Seattle, Washington, has been using lean management principles since 2002. By working to eliminate waste, Virginia Mason created more capacity in existing programs and practices so that planned expansions were scrapped, saving significant capital expenses: $1 million for an additional hyperbaric chamber that was no longer needed; $1 to $3 million for endoscopy suites that no longer needed to be relocated; $6 million for new surgery suites that were no longer necessary.

Despite a no-layoff policy, a key tenet of Lean management, staffing trends at Virginia Mason showed a decrease in 2003 and 2004, after six years of annual increases in the number of full-time equivalents (FTEs). Using Lean principles, staff, providers, and patients have continuously improved or redesigned processes to eliminate waste, requiring fewer staff members and less rework, and resulting in better quality. Consequently, as employees retire or leave for other reasons, improved productivity allows for them not to be replaced.

All 5,000 Virginia Mason employees are required to attend an Introduction to Lean course, and many have participated in Rapid Process Improvement Weeks (RPIW). RPIWs are intensive weeklong sessions in which teams analyze processes and propose, test, and implement improvements. The results from the 175 RPIWs that were conducted from January 2002 through March 2004 are shown in Table 9.1.

SOURCE: Womack et al. (2005).

TABLE 9.1

Results of 175 RPIWs at Virginia Mason Medical Center

Category	2004 Results (After 2 Years of "Lean")	Metric	Change from 2002
Inventory	$1,350,000	Dollars	Down 53%
Productivity	158	FTEs	36% redeployed to other open positions
Floor space	22,324	Sq. Ft.	Down 41%
Lead time	23,082	Hours	Down 65%
People distance	Traveled 267,793	Feet	Down 44%
Product distance	Traveled 272,262	Feet	Down 72%
Setup time	7,744	Hours	Down 82%

SOURCE: Womack et al. (2005). Used with permission.

Overview

Lean tools and techniques have been employed extensively in manufacturing organizations since the 1990s to improve the efficiency and effectiveness of those organizations. More recently, many healthcare organizations have begun to realize the transformative potential of Lean (Panchak 2003; Womack et al. 2005).

The healthcare industry is facing increasing pressure to employ resources in an effective manner to reduce costs and increase patient satisfaction. This chapter provides an introduction to the Lean philosophy as well as the various Lean tools and techniques used by many healthcare organizations today. The major topics covered include:

- The Lean philosophy;
- Defining waste;
- Kaizen;
- Value stream mapping; and
- Other Lean tools, techniques, and ideas, including the five Ss, spaghetti diagrams, kaizen events, takt time, kanbans, single-minute exchange of die, heijunka, jidoka, andon, standardized work, single-piece flow, and pull.

After completing this chapter, readers should have a basic understanding of Lean tools, techniques, and philosophy. This should help them understand how Lean could be used in their organizations and enable them to begin to employ its tools and techniques to facilitate continuous improvement.

What Is Lean?

As described in Chapter 2, Lean production was developed by Taiichi Ohno, Toyota's chief of production after World War II. The Toyota Production System (TPS) was studied by researchers at MIT and documented in the book *The Machine that Changed the World* (Womack, Jones, and Roos 1990). TPS was much more effective and efficient than traditional mass production, and the MIT researchers coined the term *Lean production* to capture this radically different approach. Although Lean production was initially used only in manufacturing operations, it has spread to services and many healthcare organizations (Caldwell, Brexler, and Gillem 2005; Chalice 2005; Spear 2005).

A Lean organization is focused on eliminating all types of waste. Like Six Sigma, Lean has been defined as a philosophy, methodology, and set of tools. The Lean philosophy is to produce only what is needed, when

it is needed, and with no waste. The Lean methodology begins by examining the system or process to determine where in the process value is added and where it is not; steps in the process that do not add value are eliminated, and those that do add value are optimized. Lean tools include value stream mapping, the five Ss, spaghetti diagrams, kaizen events, kanbans, single-minute exchange of die, heijunka, jidoka, and standardized work.

Where Six Sigma and total quality management (TQM)/continuous quality improvement are focused on eliminating defects and reducing variability, Lean is focused on eliminating waste and ensuring swift, even flow through the process or system. However, defects are waste, and variability causes defects. Although the two programs are different, their methodologies, tools, and outcomes are similar. Both programs have Japanese roots, as evidenced by the terminology associated with them, and use many of the same tools and techniques.

Types of Waste

In Lean, waste is called *muda*, which comes from the Japanese term for waste. Many types of waste are found in organizations. Ohno defined seven categories of waste related to manufacturing, and they can be reinterpreted for services and healthcare:

1. *Overproduction:* producing more than is demanded or producing before the product is needed to meet demand. Printing reports, labels, and so forth, and preparing meals when they are not needed are examples of overproduction in healthcare.
2. *Waiting:* time during which value is not being added to the product or service. For services, this includes both customer waiting time and time where the service provider is idle.
3. *Transportation:* unnecessary travel or conveyance of the part being manufactured or the person being provided the service. In healthcare, wasted transportation includes patient travel and equipment movement.
4. *Inventory:* holding or purchasing raw materials, work-in-process (WIP), and finished goods that are not immediately needed. This ties up capital. In healthcare, wasted inventory includes supplies and pharmaceuticals that are not immediately needed.
5. *Motion:* actions of providers or operators that do not add value to the product. This could also include repetitive-type motion that causes injury. In healthcare, wasted motion includes unnecessary travel of the service provider to obtain supplies or information.

6. *Overprocessing:* unnecessary processing or steps and procedures that do not add value to the product or service. There are numerous examples of overprocessing in healthcare related to recordkeeping and documentation.
7. *Defects:* production of a part or service that is scrapped or requires rework. In healthcare, defect waste includes mundane errors, such as misfiling documents, and serious errors resulting in the death of a patient.

Lean focuses on eliminating all waste from the system through continuous improvement.

Kaizen

Kaizen is the Japanese term for change for the better, or continuous improvement. Although kaizen is more typically associated with the Lean philosophy, the quality philosophies (TQM, Six Sigma, etc.) also focus on the need for continuous improvement. The philosophy of kaizen involves all employees in making suggestions for improvement, then implementing those suggestions quickly. Kaizen is based on the assumption that everything can be improved and that many small incremental changes will result in a better system. Prior to adopting a kaizen philosophy organizations used to believe, "If it isn't broken, leave it alone"; with a kaizen philosophy, organizations believe, "Even if it isn't broken, it can be improved." An organization that does not focus on continuous improvement will not be able to compete with other organizations that are continuously improving.

Kaizen is viewed as both a general philosophy of improvement focusing on the entire system or value stream and a specific improvement technique focused on a particular process. The kaizen philosophy of continuous improvement consists of five basic steps:

1. *Specify value:* Identify activities that provide value from the customer's perspective.
2. *Map and improve the value stream:* Determine the sequence of activities or current state of the process and the desired future state. Eliminate non–value-added steps and other waste.
3. *Flow:* Enable the process to flow as smoothly and quickly as possible.
4. *Pull:* Enable the customer to drive products or services.
5. *Perfection:* Repeat the process to ensure a focus on continuous improvement.

The kaizen philosophy is enabled by the various tools and techniques of Lean.

Value Stream Mapping

Value stream mapping is a type of process mapping or flowcharting of the value stream, which includes all of the steps, both the value-adding and the non–value-adding steps, in producing and delivering a product or service. Both information processing and transformational processing steps are included in a value steam map.

The value stream map shows process flow from a systems perspective and can help in determining how to measure and improve the system or process of interest. The value stream map can enable the organization to focus on the entire value stream rather than just a specific step or piece of the stream. Without a view of the entire stream, it is possible, even likely, that individual parts of the system will be optimized according to the needs of those parts, but the resulting system will be suboptimal.

Value stream mapping in healthcare is typically done from the perspective of the patient, where the goal is to optimize her journey through the system. Information, material, and patient flows are captured in the value stream map. Each step in the process is classified as value added or non–value added. Value-added activities are those that change the item being worked on in some way that the customer desires. The key question to ask when determining if an activity is value added is, "Would the customer be willing to pay for this activity?" If the answer is no, the activity is non–value added. In healthcare, an example of a non–value-added activity is waiting time—patients would not pay to wait.

Non–value-added activities can be further classified as necessary or unnecessary. An example of a necessary non–value-added activity that organizations must perform is payroll. Payroll activities do not add value for customers, but employees must be paid. Activities that are classified as non–value added and unnecessary should be eliminated. Activities that are necessary but non–value added should be examined to determine if they can be made unnecessary and eliminated. Value-added and necessary but non–value-added activities are candidates for improvement and waste reduction. The value stream map enables organizations to see all of the activities in a value stream and focus their improvement efforts (Womak and Jones 1999).

A common measurement for the progress of Lean initiatives is percent value added. The total time for the process to be completed is also measured. This can be accomplished by measuring the time a single item, customer, or patient spends to complete the entire process. At each step in the process, the value-added time is measured:

$$\% \text{ Value added} = \frac{\text{Value-added time}}{\text{Total time in system}} \times 100$$

The goal of Lean is to increase percent value added by increasing this ratio. Many processes have a percent value added of 5 percent or less. Once the value stream map has been generated, kaizen activities can be identified that will allow the organization to increase the percent value-added time and employ resources in the most effective manner possible.

Vincent Valley Hospital and Health System Value Stream Mapping

Vincent Valley Hospital and Health System (VVH) identified its birthing center as an area in need of improvement and decided to use Lean tools and techniques to accomplish its objectives. The goals for the Lean initiative were to decrease costs and increase patient satisfaction. Project management tools (Chapter 5) were used to ensure success.

Initially, a team was formed to improve the operations of the birthing center. The team consisted of the manager of the birthing unit (the project manager), two physicians, three nurses (one from triage, one from labor and delivery, and one from postpartum), and the manager of admissions. All team members were trained in Lean tools and techniques and started the project by developing a high-level value stream map over the course of several weeks (Figure 9.1). The team mapped patient and information flows in the birthing center and collected data related to staffing type and level as well as length of time for the various process steps. The high-level value stream map was used to help the team decide where to focus its efforts. The team then developed a plan for the coming year based on the opportunities identified.

Measures and Tools

Takt Time

Takt is a German word meaning rhythm or beat. It is often associated with the rhythm set by a conductor to ensure that the orchestra plays in unison. Takt time determines the speed with which customers must be served to satisfy demand for the service.

$$\text{Takt time} = \frac{\text{Available work time/Day}}{\text{Customer demand/Day}}$$

Cycle time is the actual time to accomplish a task in a system. Cycle time for a system will be equal to the longest task-cycle time in that system. In a Lean system, cycle time and takt time are equal. If cycle time is greater than takt time, demand will not be satisfied and customers or patients will wait. If cycle time is less than takt time in a manufacturing environment, inventory is generated; in a service environment, resources are underutilized. In a Lean system, the rate

FIGURE 9.1 VVH Birthing Center Value Stream Map

Created with eVSM software from GumshoeKI, Inc., a Microsoft Visio add-on.
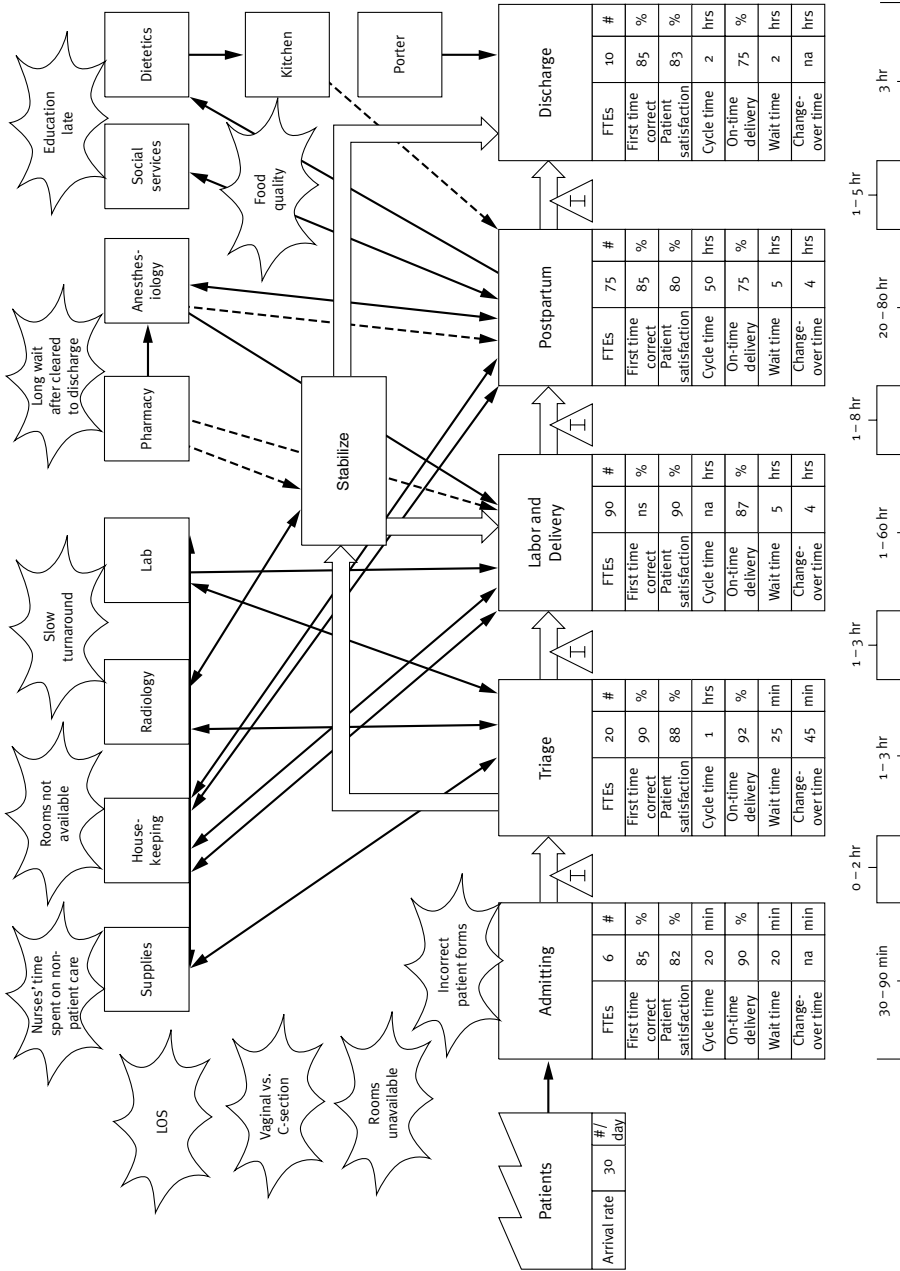
at which a product or service can be produced is set by customer demand, not by the organization's ability (or inability) to supply the product or service.

Throughput Time

Throughput time is the time for an item to complete the entire process. It includes waiting time and transport time as well as actual processing time. In a healthcare clinic, for example, throughput time would be the total time the patient spends at the clinic, starting when he walks through the door and ending when he walks out; this includes not only the time the patient is actually interacting with a clinician, but also time spent waiting in the waiting room and examining room. In a perfectly Lean system, there would be no waiting time and throughput time would be minimized.

Riverview Clinic

VVH's Riverview Clinic collected the data shown in Figure 9.2 for a typical patient visit. Here, the physician exam and consultation has the longest task time, 20 minutes; therefore, the cycle time for this process is 20 minutes. Assuming that physician time is not constrained, every physician could output one patient from this process every 20 minutes. However, the throughput time is equal to the total amount of time a patient spends in the system. Here, it is:

$$3 + 15 + 2 + 15 + 5 + 10 + 20 = 70 \text{ minutes}$$

The available work time per physician day is 5 hours (physicians work 10 hours per day, but only 50 percent of that time is spent with patients), there are 8 physicians, and 100 patients are expected at the clinic every day.
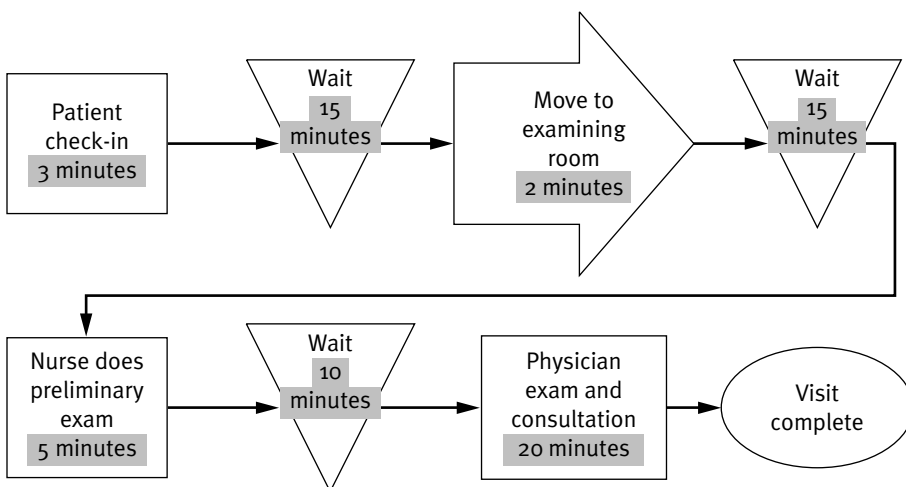
FIGURE 9.2
Riverview
Clinic Cycle,
Throughput,
and Takt Times

NOTE: Created with Microsoft Visio®.

$$\text{Takt Time} = \frac{8 \text{ Physicians} \times 5 \text{ Hours/Day}}{100 \text{ Patients/Day}} = 0.4 \text{ Physician hours/Patient}$$

$$= 24 \text{ Physician minutes/Patient}$$

Therefore, to meet demand, the clinic needs to serve one patient every 24 minutes. Because cycle time is less than takt time, the clinic can meet demand.

Assuming that patient check-in is necessary but non–value added and that both the nurse preliminary exam and the physician exam and consultation are value-added tasks, the value-added time for this process is:

5 Minutes (Nurse preliminary exam)
+ 20 Minutes (Physician exam and consultation) = 25 Minutes

and the percent value-added time is:

25 Minutes/70 Minutes = 36%

A Lean system works toward decreasing throughput time and increasing percent value-added time. The tools discussed in the following sections can aid in achieving these goals.

Five Ss

The five Ss are workplace practices that constitute the foundation of other Lean activities; the Japanese words for these practices all begin with S. The five Ss are essentially ways to ensure a clean and organized workplace. Often, they are seen as obvious and self-evident; a clean and organized workplace will be more efficient. However, without a continuing focus on these five practices, workplaces often become disorganized and inefficient.

The five practices, with their Japanese names and the English terms typically used to describe them, are:

1. *Seiri (sort):* Separate necessary from unnecessary items, including tools, parts, materials, and paperwork, and remove the unnecessary items.
2. *Seiton (straighten):* Arrange the necessary items neatly, providing visual cues to where items should be placed.
3. *Seiso (sweep):* Clean the work area.
4. *Seiketsu (standardize)*: Standardize the first three Ss so that cleanliness is maintained.
5. *Shitsuke (sustain):* Ensure that the first four Ss continue to be performed on a regular basis.

The five Ss are often the first step an organization takes in its Lean journey because so much waste can be eliminated by ensuring an organized and efficient workplace.

Spaghetti Diagram

A spaghetti diagram is a visual representation of the movement or travel of materials, employees, or customers. In healthcare, a spaghetti diagram is often used to document or investigate the movements of caregivers or patients. Typically, the patient or caregiver spends a significant amount of time moving from place to place and often backtracks. A spaghetti diagram (Figure 9.3) can help to find and eliminate wasted movement in the system.

Kaizen Event or Blitz

A kaizen event or blitz is a focused, short-term project aimed at improving a particular process. A kaizen event is usually performed by a cross-functional team of eight to ten people, always including at least one person who actually works with or in the process. The rest of the team should include personnel from other functional areas and even nonemployees with an interest in improving the process. In healthcare organizations, staff, nurses, doctors, and other professionals, as well as management personnel from across departments, should be represented.

Typically, a kaizen event consists of the following steps, based on the plan-do-check-act (PDCA) improvement cycle of Deming and Juran:

- Determine and define the objective(s).
- Determine the current state of the process by mapping and measuring the process. Measurements will be related to the desired objectives but often include such things as cycle time, waiting time, WIP, throughput time, and travel distance.
- Determine the requirements of the process (takt time), develop target goals, and design the future state or ideal state of the process.
- Create a plan for implementation, including who, what, when, and so on.
- Implement the improvements.
- Check the effectiveness of the improvements.
- Document and standardize the improved process.
- Continue the cycle.

The kaizen event is based on the notion that most processes can be quickly (and relatively inexpensively) improved, in which case it makes sense to "just do it" rather than be paralyzed by resistance to change. A kaizen event is typically one week long and begins with training in the tools of Lean, followed by analysis and measurement of the current process and generation of possible ideas for improvement. By midweek, a proposal for changes to improve the process should be ready. The proposal should include the improved process flow

FIGURE 9.3 Spaghetti Diagram: VVH Postpartum Nursing

Notes: 21 position changes
Multiple trips to supply room
Multiple trips to med room
Search time (supplies and paperwork)

and metrics for determining the effects of the changes. The proposed changes are implemented and tested during the remainder of the week. By the following week, the new process should be in place.

A kaizen event can be a powerful way to quickly and inexpensively improve processes. The results are usually a significantly improved process and increased employee pride and satisfaction. Table 9.1 shows the improvements experienced by Virginia Mason Medical Center in Seattle, two years and 175 kaizen events (RPIWs) after beginning their lean journey.

VVH Kaizen Event

The value stream map developed for the VVH birthing center highlighted the fact that nursing staff was spending a significant amount of time on activities not related to actual patient care. This not only resulted in dissatisfied patients, physicians, and nurses, but it also increased staffing costs to the hospital. A kaizen blitz was planned to address this problem in the postpartum area of the birthing center.

The nursing administrator was charged with leading the kaizen event. She put together a team consisting of a physician, a housekeeper, two nurses' assistants, and two nurses. On Monday morning, the team began the kaizen event with four hours of Lean training. On Monday afternoon, they developed a spaghetti diagram for a typical nurse (Figure 9.3) and began collecting data related to the amount of time nursing staff spent on various activities. They also collected historical data on patient load and staffing levels.

On Tuesday morning, the team continued to collect data. On Tuesday afternoon, they analyzed the data and found that nursing staff spent only 50 percent of their time in actual patient care. A significant amount of time— one hour per eight-hour shift—was spent locating equipment, supplies, and information. The team decided that a 50 percent reduction in this time was a reasonable goal for the kaizen event.

On Wednesday morning, the team used root-cause analysis to determine the reasons nursing staff spent so much time locating and moving equipment and supplies. They determined that one of the major causes was general disorder in the supply/equipment room and patient rooms.

On Wednesday afternoon, the team organized the supply/equipment room. They began by determining what supplies and equipment were necessary and removing those that were unnecessary. Next, they organized the supply/equipment room by determining which items were often needed together and locating those items close to one another. All storage areas were labeled, and specific locations for equipment were designated visually. White boards were installed to enable the tracking and location of equipment. The team also developed and posted a map of the room so that the location of equipment and supplies could be easily determined.

On Thursday, the team worked on reorganizing all of the patient rooms, standardizing the layout and location of items in each one. First, the team observed one of the patient rooms and determined the equipment and supply needs of physicians and nurses. All nonessential items were removed, creating more space. Additionally, rooms were stocked with supplies used on a routine basis to reduce trips to the central supply room. A procedure was also established to restock supplies on a daily basis.

On Friday morning, the kaizen team again collected data on the amount of time nursing staff spent on various activities. They found that after implementing the changes, the time nursing staff spent locating and moving

supplies and equipment was reduced to approximately 20 minutes in an eight-hour shift, a 66 percent reduction. Friday afternoon was spent documenting the kaizen event and putting systems in place to ensure that the new procedures and organization would be maintained.

Standardized Work

Standardized work is an essential part of Lean and provides the baseline for continuous improvement. Standardized work is written documentation of the precise way in which every step in a process should be performed. It should not be seen as a rigid system of compliance, but rather as a means of communicating and codifying current best practices within the organization to provide a baseline from which improvements can be made to the process.

All relevant stakeholders of the process should be involved in establishing standard work. Standardizing work in this way assumes that the people most intimately involved with the process have the most knowledge of how to best perform the work. It promotes employee buy-in and ownership of the process and responsibility for improvement. Clear documentation and specific work instructions ensure that variation and waste are minimized. Standardized work should be seen as a step on the road to improvement. As better methods are identified, the work standards are modified to reflect the changes.

In the healthcare industry, examples of standardized work include treatment protocols and the establishment of care paths. (Care paths are also examples of evidence-based medicine, which is explored in more depth in Chapter 3.) Massachusetts General Hospital developed and implemented a care path for coronary artery bypass graft (CABG) surgery that resulted in an average length of stay reduction of 1.5 days; significant cost savings were associated with that reduction (Wheelwright and Weber 2004).

As part of an overall program to improve practices and reduce costs, Massachusetts General identified the establishment of a care path for CABG surgery. A care path is "an optimal sequencing and timing of interventions by physicians, nurses, and other staff for a particular diagnosis or procedure, designed to minimize delays and resource utilization and at the same time maximize the quality of care" (Wheelwright and Weber 2004). A care path defines and documents specifically what should happen to a patient the day before surgery, the day after surgery, and on postsurgical days. The care path was not intended to dictate medical treatment, but to standardize procedures as much as possible to reduce variability and improve the quality of outcomes.

There were 25 participants representing the various areas involved in treatment on the team that developed the care path. The team took more than a year to develop the initial care path, but because of its breadth of

inclusion and applicability, resistance to implementation was minimal. After the successful implementation of the CABG surgical care path, Massachusetts General Hospital developed and implemented more than 50 care paths related to surgical procedures and medical treatments (Wheelwright and Weber 2004).

Standard work processes can be used in clinical, support, and administrative operations of healthcare organizations. The development and documentation of standardized processes and procedures can be a powerful tool for engaging and involving everyone in the organization in continuous improvement.

Jidoka and Andon

In Lean systems, jidoka refers to the ability to stop the process in the event of a problem. The term stems from the weaving loom invented by Sakichi Toyoda, Founder of the Toyota Group. The loom stopped itself if a thread broke, eliminating the possibility that defective cloth would be produced.

Jidoka prevents defects from being passed from one step in the system to the next and enables the swift detection and correction of errors. If the system or process is stopped when a problem is found, everyone in the process works quickly to identify and eliminate the source of the error. In ancient Japan, an andon was a paper lantern used as a signal; in a Lean system, an andon is a visual or audible signaling device used to indicate a problem in the process. Andons are typically used in conjunction with jidoka.

Virginia Mason Medical Center implemented a jidoka-andon system called the Patient Safety Alert System (Womack et al. 2005). If a caregiver believes that something is not right in the care process, she not only can, but must, stop the process. The person who has noticed the problem calls (or alerts, via the Internet) the patient safety department. The appropriate process stakeholders or relevant managers immediately come to determine and correct the root cause of the problem. After two years, the number of alerts per month rose from 3 to 17, enabling Virginia Mason to correct most problems in the process before they become more serious. The alerts are primarily related to systems issues, medication errors, and problems with equipment or facilities.

Kanban

Kanban is a Japanese term meaning signal. A kanban system in a manufacturing organization typically uses containers of a certain size to signal the need for more production. When a container is emptied at a workstation, it is sent upstream to signal to the previous operation that work can begin. Kanbans are the controlling mechanism in a pull production system. The customer indicates that he wants product, a kanban is released to the last operation in the system to signal the customer demand, and that station begins to produce product in

response. As incoming material is consumed at the last workstation, another kanban will be emptied and sent to the previous workstation to signal that production should begin at that station. The empty kanbans go backward through the production system to signal the need to produce in response to customer demand (see Figure 9.4). This ensures that production is only done in response to customer demand, not simply because production capacity exists.

In a healthcare environment, kanbans can be used for supplies or pharmaceuticals to signal the need to order more. For example, a pharmacy would have two kanbans; when the first kanban is emptied, this signals the need to order more and an order is placed. The second kanban is emptied while waiting for the order to arrive. Ideally, the first kanban is received from the supplier at the point that the second kanban is empty and the cycle continues. The size of the kanbans is related to demand for the pharmaceutical during lead time for the order. The number and size of the kanbans determine the amount of inventory in the system.

In a healthcare environment, kanbans could also be used to control the flow of patients, ensuring continuous flow. For example, for patients needing both an echocardiography (echo) procedure and a computed tomography (CT) scan, where the echo procedure is to be performed before the CT scan, the CT scan could pull patients through the process. When a CT is performed, a patient is taken from the pool of patients between CT and echo. A kanban (signal) is sent to the echo station to indicate that another patient should receive an echo (see Figure 9.5). This ensures that a constant pool of patients is kept between the two processes. The patient pool should be large enough to ensure that the CT is busy even when there are disturbances in the echo process. However, this must be balanced with the need to keep patients from waiting for long periods. Eventually, in a Lean system, the pool size would be reduced to one.

FIGURE 9.4

Kanban System
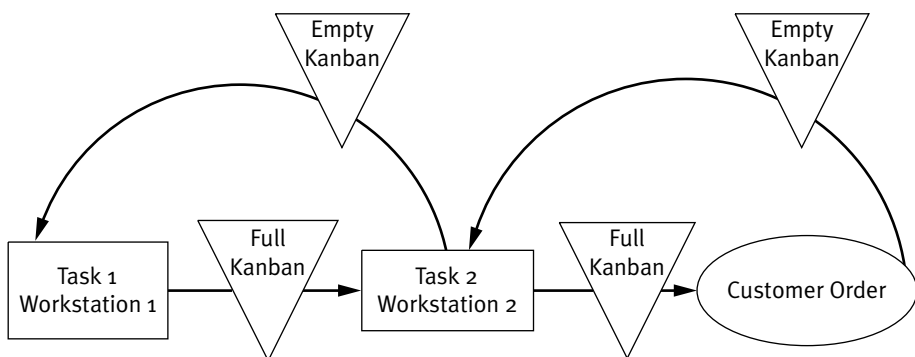
NOTE: Created with Microsoft Visio®.
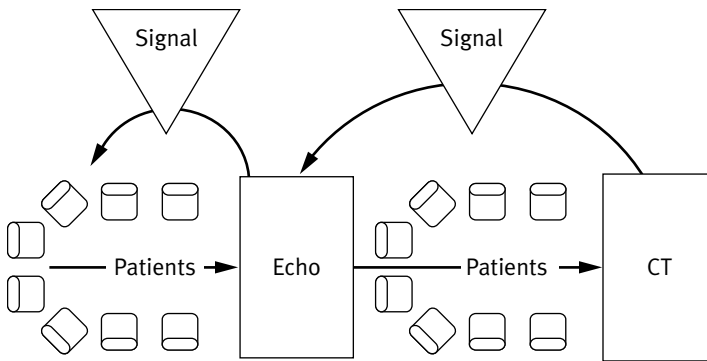
NOTE: Created with Microsoft Visio®.

Single-Minute Exchange of Die

The single-minute exchange of die (SMED) system was developed by Shigeo Shingo (1985) of Toyota. Originally, it was used by manufacturing organizations to reduce changeover or setup time, the time between producing the last good part of one product and the first good part of a different product. Currently, the technique is used to reduce setup time for both manufacturing and services. In healthcare environments, setup is the time needed, or taken, between the completion of one procedure and the start of the next.

The SMED technique consists of three steps:

1. Separating internal activities from external activities;
2. Converting internal setup activities to external activities; and
3. Streamlining all setup activities.

Internal activities are those activities that must be done in the system; they could not be done offline. For example cleaning an operating room (OR) prior to the next surgery is an internal setup activity; it could not be completed outside the OR. However, organizing the surgical instruments for the next surgery is an external setup, as this could be done outside the OR to allow for speedier changeover of the OR.

Setup includes finding and organizing instruments, getting supplies, cleaning rooms, and obtaining paperwork. In the healthcare environment, SMED has been used to streamline the process for changing over from one patient to the next in diagnostic imaging areas, surgical suites, and hospital rooms.

Flow and Pull

Continuous, or single-piece, flow consists of moving items to be worked on (jobs, patients, products) through the steps of the process one at a time without interruptions or waiting. Pull, or just-in-time, production refers to a

system in which products or services are not produced until the downstream customer demands them. A Lean organization continually works toward achieving both of these goals.

Ensuring efficient patient flow has become increasingly important in healthcare. In 2005, the Joint Commission introduced a new standard on managing patient flow: "The leaders develop and implement plans to identify and mitigate impediments to efficient patient flow throughout the hospital." To meet this standard, hospitals need to have policies, processes, and procedures in place to ensure continuous improvement in patient flow. The Institute for Healthcare Improvement (IHI 2006a) has extensive resources available on the Internet to help healthcare organizations improve patient flow; these resources include measures, tools, and case studies. IHI's model for improvement is based on the PDCA cycle and incorporates many Lean tools and techniques.

Heijunka and Advanced Access

Heijunka is a Japanese term meaning "make flat and level." It refers to eliminating variations in volume and variety of production to reduce waste. In healthcare environments, this often means determining how to level patient demand. Producing goods or services at a level rate allows organizations to be more responsive to customers and better use their own resources. In healthcare, advanced access provides a good example of the benefits of heijunka.

Several studies have shown that many people are unable to obtain timely primary care appointments (Murray and Berwick 2003). Advanced access scheduling reduces the time between scheduling an appointment for care and the actual appointment. It is based on the principles of Lean and aims for swift, even patient flow through the system. In clinical settings, reducing the wait time for appointments has been shown to decrease no-show rates (Kennedy and Hsu 2003) and improve both patient and staff satisfaction (Radel et al. 2001). Revenues are increased (O'Hare and Corlett 2004) as a result of higher patient volumes and increased staff and clinician productivity. Additionally, greater continuity of care (Belardi, Weir, and Craig 2004) should increase the quality of care and result in more positive outcomes for patients.

Although the benefits of advanced access are great, implementation can be difficult because the concept challenges established practices and beliefs. However, if the delay between making an appointment and the actual appointment is relatively constant, it should be possible to implement advanced access.

Centra, a multisite primary care clinic located in Chicago, began advanced access scheduling in 2001. The organization was able to reduce access time to 3 days or less, patient satisfaction increased from 72 percent to 85 percent, and continuity of care was significantly increased (75 percent of visits occurred with a patient's primary physician, compared to 40 percent

prior to advanced access). The biggest issue encountered was the greater demand for popular clinicians and the need to address this inequity on an ongoing basis (Murray et al. 2003).

Successful implementation of advanced access requires that supply and demand be balanced. To do this, accurate estimates of both supply and demand are needed, backlog must be reduced or eliminated, and the variety of appointment types needs to be minimized. Once supply and demand are known, demand profiles may need to be adjusted and the availability of bottleneck resources increased (Murray and Berwick 2003). IHI (2006b) offers extensive online resources to aid healthcare organizations in implementing advanced access, and Chapter 12 discusses the concept in more detail.

Conclusion

Recently, organizations have begun combining the philosophies and tools of both Lean and Six Sigma into "Lean Sigma." Although proponents of Lean or Six Sigma might say that these initiatives are very different and champion one or the other, they are actually complementary methods, and combining them can be effective for many organizations.

Lean is focused on eliminating waste and streamlining flow. Six Sigma is focused on eliminating defects and reducing variation. However, both Lean and Six Sigma are ultimately focused on continuous improvement of the system. The kaizen philosophy of Lean begins with determining what customers value, followed by mapping and improving the process to achieve flow and pull. Six Sigma is focused on reducing defects and eliminating variation in the processes. Lean thinking enables identification of the areas causing inefficiencies. However, to truly achieve Lean, variation in the processes must be eliminated—Six Sigma will help to do this. Focusing on the customer and eliminating waste will not only result in increased customer satisfaction, but it will also reduce costs and increase the profitability of the organization. Together, Lean and Six Sigma can provide the philosophies and tools needed to ensure that the organization is continuously improving.

Discussion Questions

1. What are the drivers behind the healthcare industry's "new" focus on employing resources in an effective manner and on patient satisfaction?
2. What are the differences between Lean and Six Sigma? The similarities? Would you like to see both in your organization? Why or why not?
3. From your own experiences, discuss a specific example of each of the seven types of waste.

4. From your own experiences, describe a specific instance in which standardized work, kanban, jidoka and andon, and SMED would enable an organization to become more effective or efficient.
5. Does your primary care clinic have advanced access? Should it? To determine supply and demand and track progress, what measures would you recommend to your clinic?
6. Are there any drawbacks to Lean Sigma? Explain.

Chapter Exercises

1. A simple value stream map for patients requiring a colonoscopy at an endoscopy clinic is shown in Figure 9.6. Assume that patients recover in the same room where the colonoscopy is performed and there are two colonoscopy rooms. What is the cycle time for the process? What is the throughput time? What is the percent value added in this process? If the clinic operates 10 hours a day and demand is 12 patients per day, what is the takt time? If demand is 20 patients per day, what is the takt time? What would you do in the second situation?

FIGURE 9.6

Value Stream Map for Colonoscopies
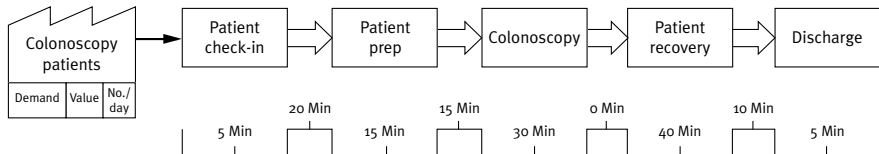
NOTE: Created with eVSM™ software from GumshoeKI, Inc., a Microsoft Visio® add-on.

2. Draw a high-level value stream map for your organization (or a part of your organization). Pick a part of this map and draw a more detailed value stream map for it. On each map, be sure to identify the information you would need to complete the map and exactly how you might obtain it. What are the takt and throughput times of your process? Identify at least three kaizen opportunities on your map. (Advanced: Use eVSM.)
3. For one of your kaizen opportunities described above, describe the kaizen event you would plan if you were the kaizen leader.

References

Belardi, F. G., S. Weir, and F. W. Craig. 2004. "A Controlled Trial of an Advanced Access Appointment System in a Residency Family Medicine Center." *Family Medicine* 36: 341–45.

Caldwell, C., J. Brexler, and T. Gillem. 2005. *Lean-Six Sigma for Healthcare: A Senior Leader Guide to Improving Cost and Throughput.* Milwaukee, WI: ASQ Quality Press.

Chalice, R. 2005. *Stop Rising Healthcare Costs Using Toyota Lean Production Methods: 38 Steps for Improvement.* Milwaukee, WI: ASQ Quality Press.

Institute for Healthcare Improvement. 2006a. "Flow." [Online information; retrieved 7/17/06.] www.ihi.org/IHI/Topics/Flow/.

———. 2006b. "Primary Care Access." [Online information; retrieved 7/17/06.] www.ihi.org/IHI/Topics/OfficePractices/Access/.

Joint Commission on Accreditation of Healthcare Organizations. 2005. "New Standard LD.3.11." [Online information; retrieved 7/17/06.] www.jcrinc.com/subscribers/perspectives.asp?durki=6640&site=10&return=6065.

Kennedy, J. G., and J. T. Hsu. 2003. "Implementation of an Open Access Scheduling System in a Residency Training Program." *Family Medicine* 35: 666–70.

Murray, M., and D. M. Berwick. 2003. "Advanced Access: Reducing Waiting and Delays in Primary Care." *JAMA* 290: 332–34.

Murray, M., T. Bodenheimer, D. Rittenhouse, and K. Grumbach. 2003. "Improving Timely Access to Primary Care: Case Studies in the Advanced Access Model." *JAMA* 289: 1042–46.

O'Hare, C. D., and J. Corlett. 2004. "The Outcomes of Open-Access Scheduling." *Family Practice Management* 11 (2): 35–38.

Panchak, P. 2003. "Lean Health Care? It Works." *Industry Week* 252 (11): 34–38.

Radel, S. J., A. M. Norman, J. C. Notaro, and D. R. Horrigan. 2001. "Redesigning Clinical Office Practices to Improve Performance Levels in an Individual Practice Association Model HMO." *Journal of Healthcare Quality* 23 (2): 11–15.

Shingo, S. 1985. *A Revolution in Manufacturing: The SMED System.* Translated by A. Dillon. New York: Productivity Press.

Spear, S. J. 2005. "Fixing Health Care from the Inside, Today." *Harvard Business Review* 83 (9): 78–91.

Wheelwright, S., and J. Weber. 2004. *Massachusetts General Hospital: CABG Surgery (A).* Harvard Business Review Case 9-696-015. Boston: Harvard Business School Publishing.

Womack, J. P., A. P. Byrne, O. J. Fiume, G. S. Kaplan, and J. Toussaint. 2005. *Going Lean in Health Care.* Cambridge, MA: Institute for Healthcare Improvement. [Online information; retrieved 7/17/06.] www.ihi.org/IHI/Results/WhitePapers/GoingLeaninHealthCare.htm.

Womack, J., and D. Jones. 1999. *Learning to See.* Brookline, MA: The Lean Enterprise Institute.

Womack, J. P., D. T. Jones, and D. Roos. 1990. *The Machine that Changed the World: Based on the Massachusetts Institute of Technology 5-Million Dollar 5-Year Study on the Future of the Automobile.* New York: Rawson Associates.

10

SIMULATION

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

arrival process
bottleneck
capacity utilization (ρ)
cardiopulmonary resuscitation
    (CPR)
community acquired pneumonia
    (CAP)
Decisioneering Crystal Ball
diagnosis-related group (DRG)
discrete event simulation (DES)
entity
event
exponential distribution
first come, first served
flow time, see throughput time
Institute of Medicine (IOM)
interarrival time
Kaizen event
Little's law
M/M/1 queueing system
magnetic resonance imaging (MRI)
mean arrival rate (λ)

mean service rate (μ)
Microsoft Visio
model validation
Monte Carlo simulation
National Academy of Engineering
    (NAE)
Pallisade @Risk
Pallisade BestFit
Poisson distribution
queue
queue discipline
queueing notation
queueing theory
resource or server
shortest processing time
Simul8
state
task cycle time
throughput time
tornado graph
waiting line theory, see queueing
    theory

Operations Management in Action

Surgeons at BC Children's Hospital have a way to shorten wait lists and get their patients through the hospital system more efficiently and with less stress.

Drs. Geoff Blair and Jacques Leblanc, head and assistant head of surgery, respectively, have created a simulation model not unlike those used by airlines and the military during wartime, that allows for the movement of large numbers of people.

Using a branch of mathematical analysis known as the "science of decision making," including game theory and queueing theory, Drs. Blair and Leblanc believed it was possible to simulate and test how changes to patient flow and surgical scheduling would affect throughput, patient waiting times, and budgets, without adversely affecting ongoing operations.

They created a model to simulate the processes from the moment a patient enters BC Children's for surgery to the time they leave. This includes OR prep time, how long each procedure takes per surgeon, how patients are moved from the ICU to the appropriate unit, available bed space and actual recovery times.

Programmers added random factors provided by hospital staff such as unscheduled emergency cases, unplanned fluctuations in staff levels due to illness, equipment breakdowns, and clerical problems. They also came up with a block schedule analysis tool the hospital could use to test various schedule changes, and assess their impact on future wait times, staffing, and costs.

The team used aliases of more than 30,000 actual patient files from the previous three years to ensure confidentially was maintained during the simulation process. They checked the accuracy of the program by running a one-year simulation of patient flow, and the results compared to what actually transpired during that period.

The value of the simulation is that it can effectively get past the "what if?" while staff try to come up with ways to deal with growing wait lists and escalating costs, says Dr. Blair.

"In healthcare, we've been relying on our puny human minds to try to deal with all these systems of queues and decision-making. And the interaction of everything has to be brought to bear to get a kid at Children's Hospital who needs surgery into the operating room, with everybody who needs to be there, with all the equipment that needs to be there, on time, at an appropriate time that reflects the child's medical condition. It's not unlike the same complexity airlines face when faced with ticketing, boarding passes, security, baggage handling, runway availability, 747s unloading their passengers while another 747 is boarding passengers. So why not use the same sort of approach?" he asked.

The model has been a boon for block scheduling, he says. OR times have been set since the hospital opened in 1982, but with the aid of the simulation tool, those surgeries with the longest wait lists can be reallocated without causing a logjam.

"The human tendency is to avoid changing, because we don't know what's going to happen," said Blair. "There's a real inertia in healthcare. And governments are increasingly demanding more proof that we deserve more money, to prove that we are being as efficient as possible. What we can do with this block scheduler [is] simulate what will happen because we have all the data entered in real time—every patient who is waiting is now in the system—and we can then take time away from orthopedics, cardiac surgery and give it to ophthalmology, say, and then we just run it. Within minutes, we can see graphically exactly what will happen to the waiting lists in cardiac surgery, orthopedics, and ophthalmology. It allows us to tweak time in areas that are not in bad shape and not inconvenience anybody; we can predict scientifically, in a valid way, what will happen if we make this change. This removes the fear of change."

The Simulation Tool, as it's called, will also be used to better manage outpatient clinics as well as OR time. It's also going to be applied to better management of beds.

In one striking scenario used by the programmers, Wednesday morning rounds with surgeons and nurses were changed to the afternoon and resulted in an additional 54 surgeries being performed over the course of a year.

"This isn't a cure for cancer," said Blair. "But it could go a long way to 'curing' some of the major problems that affect us every day in our attempts to deliver care to our kids here."

SOURCE: Haley, L. 2005. "Simulation Aims to Speed Patients Through Surgeries." *Medical Post* 41 (1): 2–3. Reprinted with permission.

Overview

Simulation is the process of modeling reality to gain a better understanding of the phenomena or system being studied. Simulation allows the user to ask and answer "what if" questions in an environment that is more cost-effective, less dangerous, faster, or more practical than the real world.

Although the simulation techniques outlined in this chapter are computer-based mathematic models, simulation does not require mathematic models or computer analysis. A fire drill, for example, is a simulation of what would or could happen in the event of a real fire. The drill is run to address

any problems that might arise if there were a real fire, without the danger associated with a real fire. There are many different types of simulations appropriate for many different contexts.

The report *Building a Better Delivery System: A New Engineering/ Health Care Partnership*, a joint effort between the National Academy of Engineering and the Institute of Medicine (2005), identifies engineering tools and technologies that could be employed to help to overcome the current safety, quality, cost, and access crises faced by the healthcare industry. This report specifically cites systems modeling and simulation as tools that have the power to enable healthcare organizations to improve quality, efficiency, and safety.

This chapter provides an introduction to simulation and the theories underlying it. The major topics covered include:

- How, where, and why simulation can be used;
- The simulation process;
- Monte Carlo simulation;
- Queueing theory; and
- Discrete event simulation.

After completing this chapter, readers should have a basic understanding of simulation. This should help them understand how simulation could be used in their organizations to evaluate choices and optimize processes and systems.

Uses of Simulation

Simulation can be used for many different purposes, including performance, proof, discovery, entertainment, training, education, and prediction (Axelrod 2006).

Performance simulation can actually carry out some task for an organization or entity. It is related to artificial intelligence and usually simulates a human behavior. Voice recognition and robotic-assisted surgery are examples of performance simulation.

Simulation can be used to discover new relationships and principles and to provide proof of a theory. For example, Conway's Game of Life (Berlekamp, Conway, and Guy 2003; Poundstone 1985) is used to discover and prove that simple rules can result in complex behavior. Simulations can also be used to entertain, as with virtual reality video games.

Simulation is often used for education and training purposes. Increasingly, simulators are being used to educate healthcare professionals in medical concepts and decision making as well as to train them in therapeutic and diagnostic procedures. For example, the mannequin simulator Resusci-Anne has been used for CPR training since the 1960s (Grenvik and Schaefer

2004). Since then, simulations related to medical training and education have become increasingly sophisticated. Training simulations allow users to practice decisions and techniques in a safe environment where an incorrect decision does not have serious consequences.

Predictive simulation can be used to evaluate the design of new products, systems, or procedures as well as to analyze and improve existing products, systems, or procedures. This chapter focuses on predictive simulation—specifically, Monte Carlo simulation and discrete event simulation.

The Simulation Process

Simulation begins with development of a model. Once the model has been built and validated, the output of the simulation is analyzed to address the original question or problem (Figure 10.1).

Model Development

The first step in model development is to define the problem or question to be answered with the simulation. The usefulness of the simulation will be driven by the accuracy of the problem definition.

The next step in developing a simulation model is defining the conceptual model. Here, the system is described analytically or mathematically; inputs and outputs are determined, and relationships are defined. Because real-world systems are complex and difficult to represent analytically, assumptions about the system must be made. A perfect model of the system is seldom possible, and approximations appropriate for the study must be made. There is usually a trade-off between model validity and model complexity; all things being equal, however, a simpler model is better.

Once the conceptual model has been defined, information required for the simulation must be collected. Data related to the probability distributions of random variables in the system, data defining the relationships in the
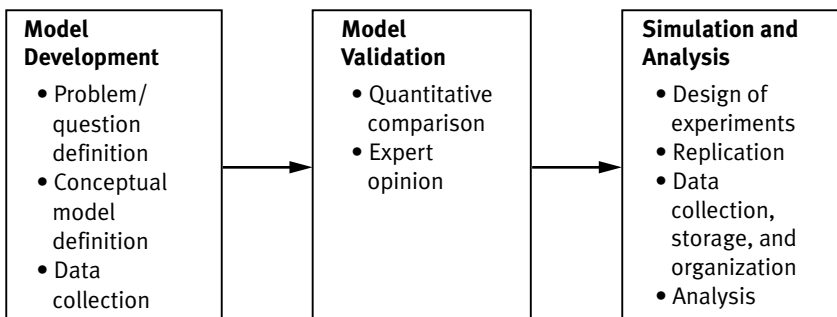
FIGURE 10.1

Simulation Process

Model Development	Model Validation	Simulation and Analysis
• Problem/ question definition • Conceptual model definition • Data collection	• Quantitative comparison • Expert opinion	• Design of experiments • Replication • Data collection, storage, and organization • Analysis

simulation, and data related to the output behavior of existing systems are collected. These data will be used in running and validating the simulation.

The final step in model development is actually building the computer model. In the past, this meant coding the software for the model. Today, many commercially available software packages make this step relatively simple.

Model Validation

The validity of a simulation is related to how closely the simulation mirrors reality and answers the question that was asked. Simulations can be developed that are technically correct but do not accurately reflect reality or do not address the intended question or problem. Therefore, assessing the validity of the simulation is an essential, but often difficult, step.

Ideally, the simulation is run and quantitative output data of the simulation are compared to output data from the real system to determine whether they are similar. Alternatively, experts are asked to determine if the design and output of the simulation make sense to them. If the simulation is not deemed valid, the model must be redeveloped.

Simulation and Output Analysis

Here, the simulation model is actually run and output data are collected. If a number of different variables and variable states are of interest, experimental design can be used to determine the specifications of those variables so that the experiments can be optimally run in a timely, cost-effective manner. Ensuring reliable results may require many replications of the simulation. The results of the simulations must be collected, organized, and stored. Finally, the output data must be analyzed to determine the "answer" to the original question or problem.

Monte Carlo Simulation

Monte Carlo simulation was pioneered by John von Nuemann, Stanislaw Ulam, and Nicholas Metropolis in the 1940s while they were working on the Manhattan Project to develop the first atomic bomb (Metropolis 1987). This group conceived of the idea of modeling the output of a system by using input variables that could not be known exactly but could be represented with probability distributions. Many repetitions of the model were run, and the behavior of the real system could be estimated based on the outcomes of the many replications. This technique came to be known as Monte Carlo simulation because of its use of probability distributions (discussed in Chapter 7) and their relationship to the games of chance found in the famous casino.

The Monte Carlo method consists of defining the relationships in a system mathematically. The random variables in the model (those that are uncertain and have a range of possible values) are not characterized by a single number but by a probability distribution. The probability distribution used to characterize the random variable is chosen based on historical data or expert knowledge of the situation. Many solutions to the model are determined, each one found by sampling from the probability distributions associated with the random variables. The solution is not a single number but a distribution of possible outcomes that can be characterized statistically.

A simple, non–computer-based example of Monte Carlo simulation is provided here to aid in understanding. A clinic wishes to estimate the amount of revenue that will be collected from each patient. Fifty percent of the clinic's patients do not pay for their services, and it is equally likely that they will pay or not pay. The clinic has collected information on charges incurred by the most recent 360 patients (Figure 10.2).

The payment per patient is modeled by:

Probability of payment × Charges/Patient = Payment/Patient

A deterministic solution to this problem would be:

$$0.50 \times \$70/\text{Patient} = \$35 \text{ per Patient}$$

A Monte Carlo simulation of this problem is based on calculating the payment from many individual simulated patients. The probability of payment can be simulated by flipping a coin to represent the probability that a

FIGURE 10.2

Payment Information for Monte Carlo Simulation

Number of patients (frequency)	Charges ($)
10	$ 20
20	$ 30
30	$ 40
40	$ 50
50	$ 60
60	$ 70
50	$ 80
40	$ 90
30	$ 100
20	$ 110
10	$ 120
Total 360	
Average	$ 70

patient will pay, where heads represents payment and equals 1, and tails represents nonpayment and equals 0. The charges incurred can be simulated by rolling two 6-sided dice and multiplying their total by $10. The payment for the simulated patient is calculated as 0 or 1 times the dice total times $10. This process is repeated many times to determine the payment per patient. For example, in the first trial a heads is rolled and the die total is 7. The patient payment is:

$$1 \times 7 \times \$10 = \$70$$

The first ten trials of this simulation are shown in Table 10.1, and a frequency diagram of the output of 100 trials is shown in Figure 10.3.

Although on average each patient pays $35, 50 percent of the patients pay nothing, a small percentage pay as much as $120, and no individual patient pays $35. Using averages or most likely values can mask a significant amount of information. Just as a person can easily drown in a river that is, on average, only three feet deep, decisions based on averages are often flawed (Savage 2002). Monte Carlo simulation can reveal hidden information and is often used in business and economics to gain a clearer understanding of the risks and rewards of a situation or decision.

Flipping coins, rolling dice, and calculating output for thousands of trials would be tedious; however, a computer can accomplish these tasks quickly and easily. There are many commercially available software packages for Monte Carlo simulation; Crystal Ball (Decisioneering Corporation 2006) and @Risk (Pallisade Corporation 2006) are two of the more popular Microsoft Excel–based packages.

TABLE 10.1
Simulation
Trials

Trial No.	Coin Flip	Payment	Die Total	Charges	Patient Payment
1	H	1	7	$70.00	$70.00
2	T	0	10	$100.00	$—
3	H	1	8	$80.00	$80.00
4	T	0	8	$80.00	$—
5	H	1	9	$90.00	$90.00
6	T	0	8	$80.00	$—
7	H	1	7	$70.00	$70.00
8	T	0	10	$100.00	$—
9	H	1	9	$90.00	$90.00
10	T	0	10	$100.00	$—
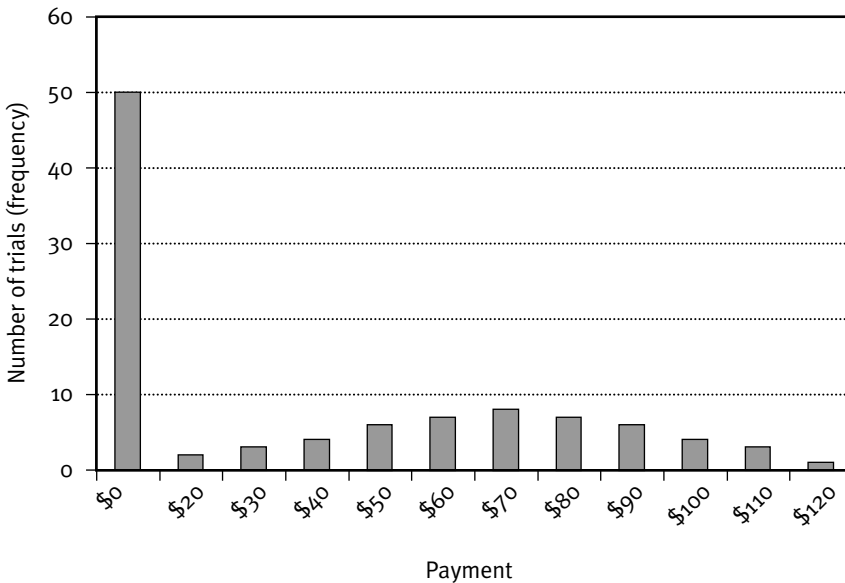
Vincent Valley Hospital and Health System Example

Vincent Valley Hospital and Health System (VVH) is trying to decide if it should participate in a new pay-for-performance (Chapter 3) incentive program offered by the three largest health plans in the area. This program focuses on community-acquired pneumonia (CAP), and hospital performance is evaluated based on composite measures of quality related to this condition. Incentives are based on performance: Hospitals scoring above 0.90 will receive a 2 percent bonus payment on top of the standard diagnosis-related group (DRG) payment, hospitals scoring above 0.85 will receive a 1 percent bonus, hospitals scoring below 0.65 will incur a 2 percent reduction in the standard DRG payment, and hospitals scoring below 0.70 will incur a 1 percent reduction.

VVH has collected payment data related to this condition for the previous 36 months. The organization used BestFit to find the probability distribution that will best represent these data and determined that the data can be represented fairly well by a normal distribution (Figure 10.4) with mean (μ) = \$250,000/month and standard deviation (σ) = \$50,000/month.

Because VVH has no historical data related to the success or cost of a program to increase quality scores related to CAP, expert opinion must be used to estimate them. After discussions with experts, the VVH team believes that reaching a score of greater than 0.90 will cost the organization between \$10,000 and \$50,000, with any cost in the range being equally likely (i.e., a uniform distribution).

FIGURE 10.4
CAP Payment
Data
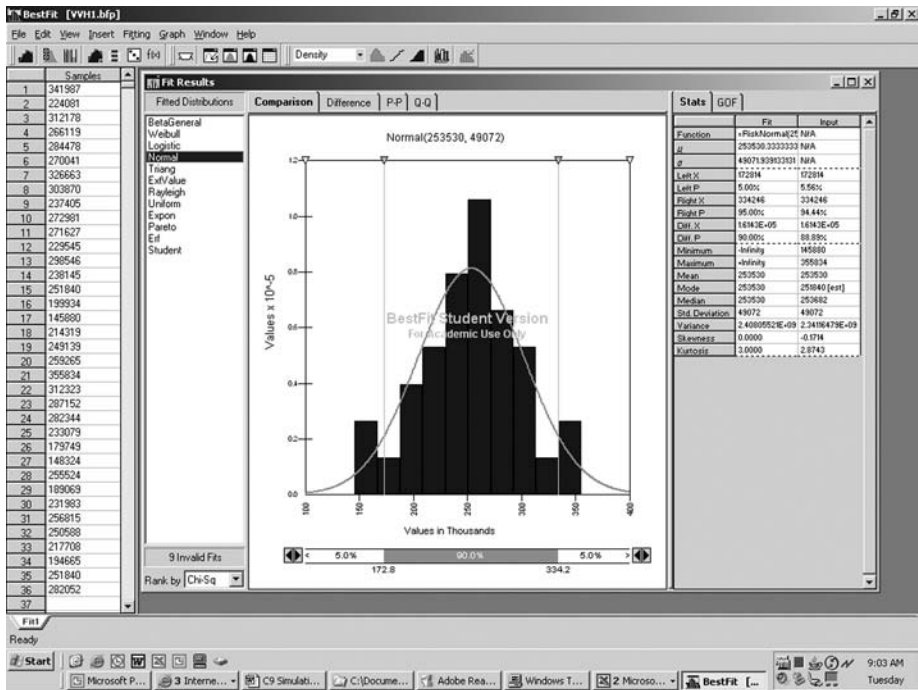
NOTE: Created with BestFit 4.5.

VVH also needs to estimate the probability of receiving various quality scores. A triangular distribution is fairly easy to estimate from expert opinion. All that is needed to define this distribution are high, low, and most likely values. Again, after talking with various internal and external experts, VVH believes that the most likely score it will receive will be 0.88, but that score could be as high as 0.95 or as low as 0.60.

A deterministic evaluation of this situation, using point estimates for all values, results in the following analysis:

$$\text{Profit} = \text{Revenue} - \text{Cost}$$
$$\text{Revenue} = (\text{Revenue/Month} \times 12 \text{ Months/Year}) \times \text{Quality bonus or penalty}$$
$$= (\$250,000/\text{Month} \times 12 \text{ Months/Year}) \times 0.01$$
$$= \$30,000/\text{year}$$
$$\text{Cost} = \$30,000/\text{year}$$
$$\text{Profit} = \$30,000/\text{year} - \$30,000/\text{year} = \$0$$

From this analysis, it appears that there will be no net gain or loss should VVH decide to participate in the pay-for-performance program. However, a Monte Carlo simulation of the situation reveals some additional information.

The Excel spreadsheet for this scenario is shown in Figure 10.5, and the results of the first few simulation trials are shown in Table 10.2.

On the first trial, @Risk randomly selects from a normal distribution with mean of $250,000 and standard deviation of $50,000 and finds that the first month's revenue is $155,687 for CAP-related conditions. @Risk repeats this process for the remaining 11 months and sums those months to obtain a total of $2,699,013 for the year. Random selection from a uniform

FIGURE 10.5

Monte Carlo Simulation of CAP Pay-for-Performance Program

Point Estimate

CAP Quality Score	Pay for Performance Factor
0.00	−0.02
0.65	−0.01
0.70	0.00
0.85	0.01
0.90	0.02

Revenue/ Month	Revenue/ Year	Quality Score	Payment or Penalty	Bonus Payment	Costs/ Year	Profit = Revenue − Costs
$ 250,000.00	$ 3,000,000.00	0.88	0.01	$ 30,000.00	$ 30,000.00	$ -

Simulation Using @Risk

Revenue/ Month	Revenue/ Year	Quality Score	Payment or Penalty Factor	Bonus Payment or Penalty Charge	Costs/ Year	Profit = Revenue − Costs
$ 250,000.00	$ 3,000,000.00	0.81	0.00	0	$ 30,000.00	$ (30,000.00)
"= RiskNormal (250,000, 50,000)"	"= Revenue/ Month * 12"	"= RiskTriang (0.6, 0.88, 0.95)"	"= VLOOKUP (D15,B4:C8,2, TRUE)"	"= Revenue/ Year * Payment or Penalty Factor"	"= RiskUniform (10,000, 50,000)"	"= RiskOutput() Revenue − Cost"

NOTE: Created with @Risk 4.5.

TABLE 10.2

CAP Pay-for-Performance Program Simulation Trials

Output Simulation	Revenue/ Month 1	Revenue/ Year 1	Quality Score 1	Costs/ Year 1	Profit = Revenue − Costs 1
Iteration/Cell	$B$14	$C$14	$D$14	$G$14	$H$14
1	155,687.1563	$2,699,013.25	0.840952277	17,032.68359	$ (17,032.68)
2	244,965.375	$2,903,593.00	0.764673352	15,443.74902	$ (15,443.75)
3	257,408.3125	$2,924,186.25	0.785211325	26,655.60938	$ (26,655.61)
4	335,716.8438	$3,441,799.25	0.652704477	31,370.79883	$ (65,788.80)
5	232,497.8281	$2,857,697.00	0.823849738	46,067.85156	$ (46,067.85)

NOTE: Created with @Risk 4.5.

distribution of costs finds a cost of $17,032, and random selection from a triangular distribution of quality scores determines a score of 0.84. In this trial VVH would not be charged a penalty, nor would it receive a bonus. Therefore, VVH would experience a total loss (negative profit) of $17,032, equal to the cost of the program.

@Risk performs many of these trials, collects output data, and provides statistics and graphs that can be used to analyze this situation. Figure 10.6 shows the distribution of profits for this situation. In contrast to the point estimate obtained in the deterministic analysis, this analysis shows that if VVH chooses to participate in the pay-for-performance program, it will break even or make a profit less than 20 percent of the time. More than 80 percent of the time, VVH will incur a loss that could be as large as $108,000.

A tornado graph showing the correlation between each input and the output can be a useful analytic tool (Figure 10.7). Here, the quality score received has the most important relationship to profit (or loss). In this case,

FIGURE 10.6
Simulated
Distribution of
Profits for CAP
Pay-for-
Performance
Program

NOTE: Created with @Risk 4.5.

REGRESSION SENSITIVITY FOR
PROFIT = REVENUE − COSTS/H14

Quality score/D14 .... 0.815

−0.414 .... Costs/year/G14

Revenue/month 12/T14 .... 0.097

Standard correlation coefficient
(−1 −0.75 −0.5 −0.25 0 0.25 0.5 0.75 1)

NOTE: Created with @Risk 4.5.

it highlights the importance of VVH's investment resulting in the achieve-ment of a high quality score. If VVH believes that a $30,000 investment will result in the quality scores indicated, it may not want to participate in the pay-for-performance program. Alternatively, if VVH decides to participate, it is imperative that the investment results in high quality scores. The VVH team may want to evaluate different types of programs or strategies to increase the probability of achieving a high quality score.

Monte Carlo analyses are particularly useful in enabling organizations to evaluate the probable outcomes of decisions, evaluate the risks involved with those decisions, and hopefully develop strategies to mitigate those risks.

Discrete Event Simulation

Like Monte Carlo simulation, discrete event simulation (DES) is based on using probability distributions to represent random variables. DES, however, has its roots in queueing, or waiting line, theory.

Queueing (Waiting Line) Theory
Although most people are familiar with waiting in line, few are familiar, or even aware of, queueing theory or the theory of waiting line. Most people's experience with waiting lines is when they are actually part of those lines, for example, when waiting to check out in a retail environment. In a manufac-

turing environment, items wait in line to be worked on. In a service environment, customers wait for a service to be performed.

Queues, or lines, form because the resources needed to serve them (servers) are limited—it is economically unfeasible to have unlimited resources. Queueing theory is used to study systems to determine the best balance between service to customers (short or no waiting lines, implying many resources or servers) and economic considerations (few servers, implying long lines). A simple queuing system is illustrated in Figure 10.8.

Customers (often referred to as entities) arrive and are either served (if there is no line) or enter the queue (if others are waiting to be served). Once they are served, customers exit the system. Some important characteristics of this system are discussed below.

The customer population, or input source, can be either finite or infinite. If the source is effectively infinite, the analysis of the system is easier because simplifying assumptions can be made.

The arrival process is characterized by the arrival pattern, the rate at which customers arrive (number of customers/unit of time), or interarrival time (time between arrivals) and the distribution in time of those arrivals. The distribution of arrivals can be constant or variable. A constant arrival distribution would have a fixed interarrival time. A variable, or random, arrival pattern is described by a probability distribution. Often, the Poisson distribution (Chapter 7) is used to model arrivals, and λ is the mean arrival rate.

The queue discipline is the method by which customers are selected from the queue to be served. Often, customers are served in the order in which they arrived—first come, first served. However, many other queue disciplines are possible, and choice of a particular discipline can greatly affect system performance. For example, choosing the customer whose service can be completed most quickly (shortest processing time) usually minimizes the average time customers spend waiting in line. This is one reason urgent care centers are often located near an emergency department—urgent issues can usually be handled more quickly than true emergencies.

The service process is characterized by the number of servers and service time. Like arrivals, the distribution of service times can be constant or

FIGURE 10.8
Simple
Queueing
System
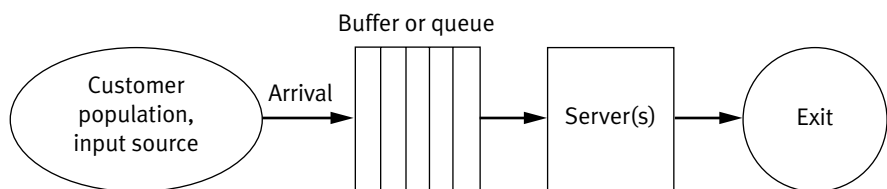
variable. Often, the exponential distribution (Chapter 7) is used to model variable service times, and μ is the mean service rate.

Queueing notation

The type of queueing system is identified with specific notation of the form A/B/c/D/E. The A represents the interarrival time distribution, and B represents the service time distribution. For example, A and B are represented with an M (for Markovian) when the arrival distribution is Poisson exponential interarrival distribution (see Chapter 7 for a complete description of these probability distributions) and the service time distribution is exponential; A and B would be represented with a D for deterministic, or constant, rates. The c represents the number of servers, D represents the maximum queue size, and E is the size of the input population. When both queue and input population are assumed to be infinite, D and E are typically omitted. An M/M/1 queueing system, therefore, has a Poisson arrival distribution, exponential service time distribution, single server, infinite possible queue length, and infinite input population, and it is assumed that only one queue exists.

Queueing solutions

Analytic solutions for some simple queueing systems at equilibrium, or steady state (after the system has been running for some time and is unchanging, often referred to as a stable system), have been determined. The derivation of these results is outside the scope of this text; see Cooper (1981) for a complete derivation and results for many other types of queuing systems.

Here, the results for an M/M/1 queuing system with $\lambda < \mu$ —the arrival rate less than the service rate—are presented. Note that if $\lambda \geq \mu$ (customers arrive faster than they are served), the queue will become infinitely long, the number of customers in the system will become infinite, waiting time will become infinite, and the server will experience 100 percent capacity utilization. The following formulas can be used to determine some characteristics of the queuing system at steady state.

Capacity utilization = Percentage of time the server is busy =

$$\rho = \frac{\lambda}{\mu} = \frac{\text{Mean arrival rate}}{\text{Mean service rate}} = \frac{1/\text{Mean time between arrivals}}{1/\text{Mean service time}}$$

$$= \frac{\text{Mean service time}}{\text{Mean time between arrivals}}$$

Average waiting time in queue = $W_q = \dfrac{\lambda}{\mu(\mu - \lambda)}$

Average time in the system =
Average waiting time in queue + average service time =

$$W_s = W_q + \frac{1}{\mu} = \frac{1}{\mu - \lambda}$$

Average length of queue (or Average number in queue) =

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \left(\frac{\lambda}{\mu}\right)\left(\frac{\lambda}{\mu - \lambda}\right)$$

Average total number of customers in the system =

$$L_s = \frac{\lambda}{\mu - \lambda} = \lambda W_s = \text{Arrival rate} \times \text{Time in the system}$$

This last result is called Little's law and applies to all types of queueing systems and subsystems. To summarize this result in plain language, in a stable system or process, the number of things in the system is equal to the rate at which things arrive to the system multiplied by the time they spend in the system. In a stable system, the average rate at which things arrive to the system is equal to the average rate at which things leave the system. If this were not true, the system would not be stable.

Little's law can also be restated using other terminology:

Inventory (Things in the system)
= Arrival rate (or Departure rate) × Throughput time (Flow time)
and
Throughput time = Inventory/Arrival rate

Knowledge of two of the variables in Little's law allows calculation of the third variable. Consider a clinic that services 200 patients in an eight-hour day, or an average of 25 patients an hour (λ). The average number of patients in the clinic (waiting room, exams rooms, etc.) is 15 (I). Therefore, the average throughput time is:

$$T = I/\lambda$$
$$= \frac{15 \text{ Patients}}{25 \text{ Patients/Hour}}$$
$$= 0.6 \text{ hour}$$

Hence, each patient spends an average of 36 minutes in the clinic.

Little's law has important implications for process improvement and can be seen as the basis of many improvement techniques. Throughput time can be decreased by decreasing inventory or increasing departure rate. Lean initiatives often focus on decreasing throughput time (or increasing through-put rate) by decreasing inventory. The theory of constraints (Chapter 6) focuses on identifying and eliminating system bottlenecks. The departure rate in any system will be equal to 1/task cycle time of the slowest task in the system or process (the bottleneck). Decreasing the amount of time an object spends at the bottleneck task therefore increases the departure rate of the system and decreases throughput time.

VVH M/M/1 queue

VVH had been receiving complaints from patients related to crowded conditions in the waiting area for magnetic resonance imaging (MRI) procedures. VVH wanted an average of only one patient waiting in line for the MRI. The organization collected data on arrival and service rates and found that for MRI the mean service rate (μ) was four patients per hour, exponentially distributed. VVH also found that arrivals followed a Poisson distribution and that mean arrival rate was three patients per hour (λ).

Capacity utilization of MRI = Percentage of time the MRI is busy =

$$\rho = \frac{\lambda}{\mu} = \frac{3}{4} = 75\% \text{ or } \rho = \frac{1/\mu}{1/\lambda} = \frac{15 \text{ Minutes}}{20 \text{ Minutes}} = 75\%$$

If one customer arrives every 20 minutes, and it takes 15 minutes to perform the MRI, the MRI will be busy 75 percent of the time.

Average time waiting in line =

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{3}{4(4 - 3)} = \frac{3}{4} = 0.75 \text{ Hour}$$

Average time in the system =

$$W_s = \frac{1}{\mu - \lambda} = \frac{1}{4 - 3} = 1 \text{ Hour}$$

Average total number of patients in the system =

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{3}{4 - 3} = 3 \text{ Patients or}$$

$$L_s = \lambda W_s = \text{Arrival rate} \times \text{Time in the system} =$$
$$3 \text{ Patients/Hour} \times 1 \text{ Hour} = 3 \text{ Patients}$$

Average number of patients in waiting line =

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \left(\frac{\lambda}{\mu}\right)\left(\frac{\lambda}{\mu - \lambda}\right) = \left(\frac{3}{4}\right)\left(\frac{3}{4 - 3}\right)$$

$$= \frac{3^2}{4(4 - 3)} = \frac{9}{4} = 2.25 \text{ patients}$$

To decrease the average number of patients waiting, VVH needs to decrease the utilization, $\rho = \lambda/\mu$, of the MRI process. In other words, the service rate must be increased or the arrival rate decreased. VVH could increase the service rate by making the MRI process more efficient so that the average time to perform the procedure is decreased, and MRIs can be performed on a greater number of patients in an hour. Alternatively, VVH could decrease the arrival rate by scheduling fewer patients per hour.

To achieve its goal (assuming that the service rate is not increased), VVH needs to decrease the arrival rate to:

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{\lambda^2}{4(4 - \lambda)} = 1$$
$$\lambda^2 = 4 \times (4 - \lambda) = 16 - 4\lambda$$
$$\lambda^2 + 4\lambda - 16 = 0$$
$$\lambda = 2.47$$

Alternatively (assuming that the arrival rate is not decreased), VVH could increase the service rate to:

$$L_q = \frac{3^2}{\mu(\mu - 3)} = \frac{3^2}{\mu(\mu - 3)} = 1$$
$$\mu(\mu - 3) = \mu^2 - 3\mu = 3^2 = 9$$
$$\mu^2 - 3\mu - 9 = 0$$
$$\mu = 4.85$$

VVH could also implement some combination of decreasing arrival rate and increasing service rate. In all cases, utilization of the MRI would be reduced to $\rho = \lambda/\mu = 2.47/4.00$, or $3.00/4.85 = 0.62$.

Real systems are seldom as simple as an M/M/1 queueing system and rarely reach equilibrium; often, simulation is needed to study these more complicated systems.

Discrete Event Simulation Details

DES is typically performed using commercially available software packages. Like Monte Carlo simulation, it is possible to perform DES simulation by hand; however, this would be tedious. Two of the more popular software packages are Arena (Rockwell Automation 2006) and Simul8 (Simul8 Corporation 2006). This text focuses on Arena (an academic version of the software is available on the CD accompanying this text), but this should not limit students, as most DES software packages use the same type of logic as Arena.

The terminology and logic of DES are based on queueing theory. A basic simulation model consists of entities, queues, and resources, all of which can have various attributes. Entities are the objects that flow through the system; in the healthcare arena entities would typically be patients, but they could be any object on which some service or task will be performed. For example, blood samples in the hematology lab could also be entities. Queues are the waiting lines that hold the entities while they are waiting for service. Resources (referred to as servers previously) could be people, equipment, or space for which entities compete.

The logic of a simulation model is based on states (variables that describe the system at a point in time) and events (variables that change the state of the system). Events are controlled by the simulation executive, and data are collected on the state of the system as events occur. The simulation jumps through time from event to event.

A simple example based on the VVH M/M/1 MRI queueing discussion will help to show the logic behind DES software. Table 10.3 contains a list of the events as they happen in the simulation. The arrival rate is three patients per hour, and the service rate is four patients per hour. Random interrarrival times are generated using an exponential distribution with a mean of 0.33 hour. Random service times are generated using an exponential distribution with a mean of 0.25 hour (shown at the bottom of Table 10.3).

The simulation starts at time 0.00. The first event is the arrival of the first patient (entity); there is no line (queue), so this patient enters service. Upcoming events are the arrival of the next patient at 0.17 hours (the interarrival between Patients 1 and 2 is 0.17 hour) and the completion of the first patient's service at 0.21 hours.

The next event is the arrival of Patient 2 at 0.17 hours. Because the MRI on Patient 1 is not complete, Patient 2 enters the queue. The MRI has been busy since the start of the simulation, so the utilization of the MRI is 100 percent. Upcoming events are the completion of the first patient's service at 0.21 hours and the arrival of Patient 3 at 0.54 hours (the interarrival between Patients 2 and 3 is 0.37 hour, and Patient 2 arrived at 0.17 hours).

TABLE 10.3 Simulation Event List

Just Finished			Variables		Attributes		Statistics				Upcoming Events		
Entity #	Time	Event Type	Length of Queue	Server Busy	Arrival Time in Queue	Arrival Time in Service	Number Complete Waits in Queue	Total Wait Time in Queue	Average Queue Length	Utilization	Entity #	Time	Event
1	0.00	Arr	0	1	0.00	0.00	0	0	0	0	2	0.17	Arr
											1	0.21	Dep
2	0.17	Arr	1	1	0.17		0	0	0	1.00	1	0.21	Dep
											3	0.54	Arr
1	0.21	Dep	0	1		0.00	1	0.04	0.19	1.00	3	0.54	Arr
											2	0.77	Dep
3	0.54	Arr	1	1	0.54		1	0.04	0.07	1.00	2	0.77	Dep
											4	0.90	Arr
2	0.77	Dep	0	1	0.17	0.21	2	0.27	0.35	1.00	3	0.79	Dep
											4	0.90	Arr
3	0.79	Dep	0	0		0.77	3	0.27	0.34	1.00	4	0.90	Arr
											4	1.27	Dep
4	0.90	Arr	0	1		0.90	3	0.27	0.30	0.88	4	1.27	Dep
											5	1.49	Arr

			1	2	3	4	5	6	7	8
Interarrival time	Expon (0.33)		0.17	0.37	0.36	0.59	0.14	0.17	0.24	0.06
Time of arrival		0.00	0.17	0.54	0.90	1.49	1.63	1.80	2.04	2.10
Service time	Expon (0.25)	0.21	0.56	0.02	0.37	0.34	0.11	1.02	0.01	0.20

Arr = Arrival; Dep = Departure; Expon = Exponenet.

The first patient's MRI is completed at 0.21 hours. There is no one in the queue at this point because once Patient 1 has completed service, Patient 2 can enter service. The total waiting time in the queue for all patients is 0.04 hour (the difference between when Patient 2 entered the queue and entered service). The average queue length is 0.19 patient. There were no people in line for 0.17 hour and one person in line for 0.04 hour.

$$\frac{0 \text{ People} \times 0.17 \text{ Hours} + 1 \text{ Person} \times 0.04 \text{ Hours}}{0.21 \text{ Hours}} = 0.19 \text{ People}$$

Upcoming events are the arrival of Patient 3 at 0.54 hours and the departure of Patient 2 at 0.77 hours (Patient 2 entered service at 0.21 hours, and service takes 0.56 hour).

Patient 3 arrives at 0.54 hours and joins the queue because the MRI is still busy with Patient 2. The average queue length has decreased from the previous event because more time has passed with no one in the queue—there has still only been one person in the queue for 0.04 hour, but total time in the simulation is 0.54 hour. Upcoming events are the departure of Patient 2 at 0.77 hours and the arrival of Patient 4 at 0.90 hours.

Patient 2 departs at 0.77 hours. There is no one in the queue at this point because Patient 3 has entered service. A total of two people have departed the system. The total wait time in the queue for all patients is 0.04 hour for Patient 2 plus 0.17 hour for Patient 3 (0.77 hour – 0.54 hour), a total of 0.21 hour. The average queue length is:

$$\frac{0 \text{ People} \times 0.50 \text{ Hour} + 1 \text{ Person} \times 0.21 \text{ Hours}}{0.77 \text{ Hours}} = 0.35 \text{ People}$$

The MRI utilization is still 100 percent because the MRI has been busy constantly since the start of the simulation. Upcoming events are the departure of Patient 3 at 0.79 hours (Patient 3 arrived at 0.77 hours, and service takes 0.02 hour) and the arrival of Patient 4 at 0.90 hours.

Patient 3 departs at 0.79 hours. Because no patients are waiting for the MRI, it becomes idle. Upcoming events are the arrival of Patient 4 at 0.90 hours and the departure of Patient 4 at 1.27 hours.

Patient 4 arrives at 0.90 hours and enters service. The utilization of the MRI has decreased to 88 percent because it was idle for 0.11 hour of the 0.90 hour the simulation has run. Upcoming events are the departure of Patient 4 at 1.27 hours and the arrival of Patient 5 at 1.49 hours. The simulation continues in this manner until the desired stop time is reached.

Even for this simple model, performing these calculations by hand would obviously take a long time. Additionally, one of the advantages of simulation is that it uses process mapping; many simulation software package such as Arena are able to import and use Microsoft Visio process and value stream maps. Using DES software makes it possible to build, run, and analyze simple models in limited time. Therefore, Arena was used to build and simulate the present model (Figure 10.9). (Step-by-step instructions for building and running this model are available on the companion web site at ache.org/books/OpsManagement.)

As before, the arrival rate is three patients per hour, the service rate is four patients per hour, and both are exponentially distributed. Averages over time for queue length, wait time, and utilization for a single replication are shown in the plots in Figure 10.9. Each replication of the simulation is run for 200 hours, and there are 30 replications. Replications are needed to determine confidence intervals for the reported values. Some of the output from this simulation is shown in Figure 10.10. The sample mean ± the half-width gives the 95 percent confidence interval for the mean. Increasing the number of replications will reduce the half-width.

FIGURE 10.9

Arena Simulation of VVH MRI M/M/1 Queueing Example
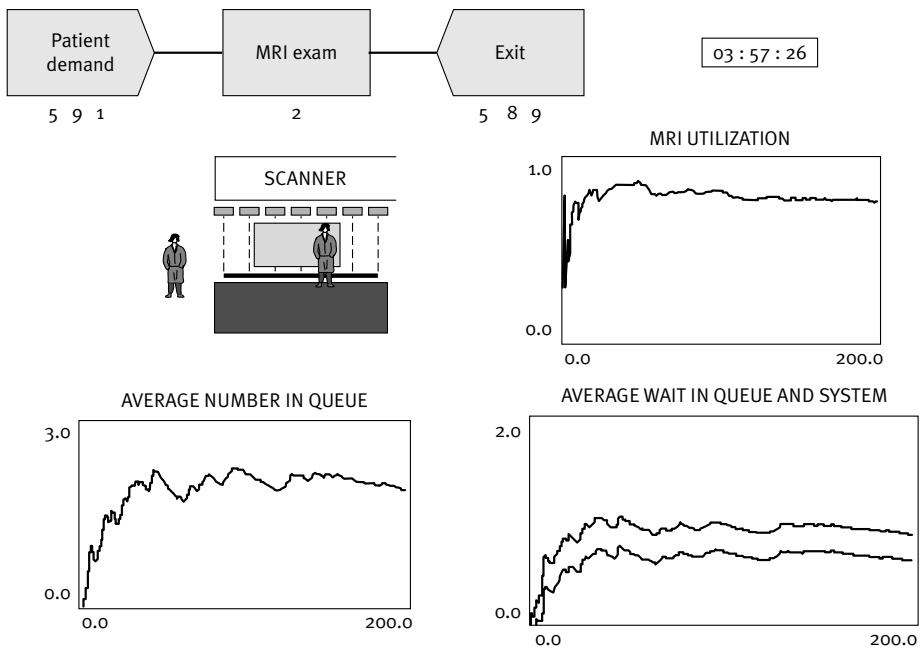
NOTE: Figure created in Arena®, Rockwell Automation.
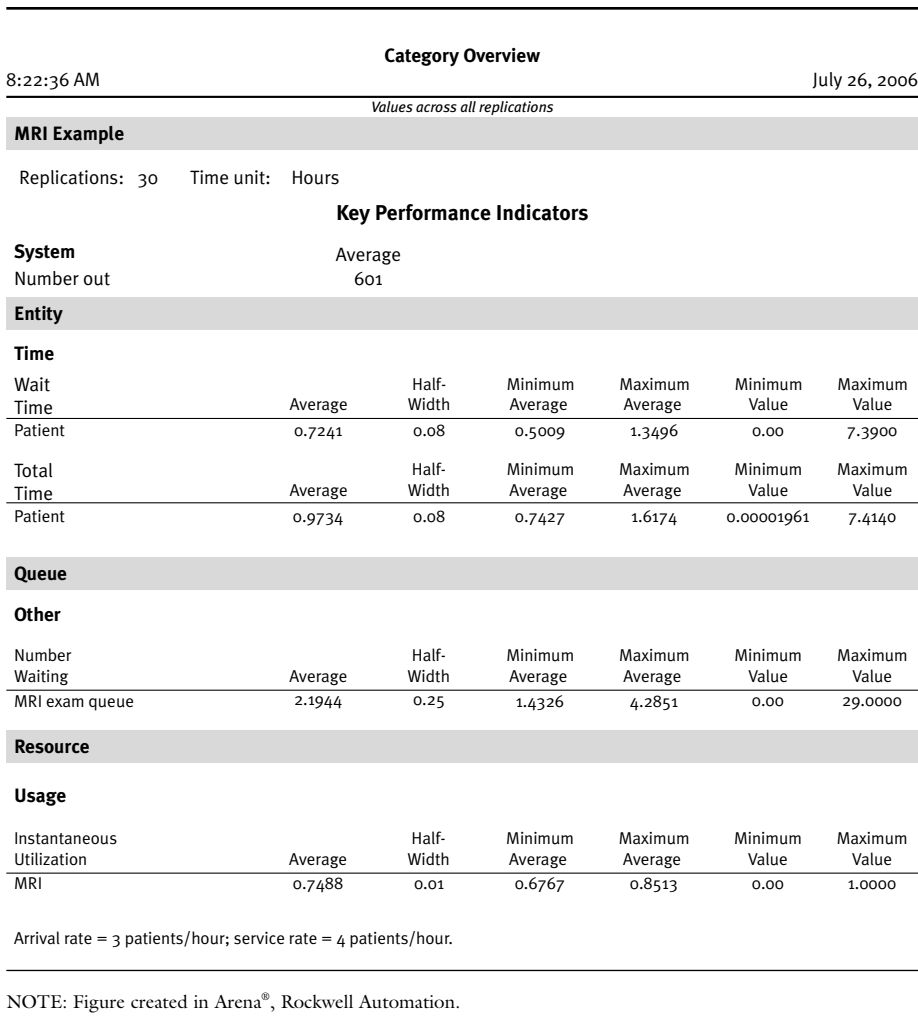
FIGURE 10.10

Arena Output
for VVH MRI
M/M/1
Queueing
Example: 200
Hours

Category Overview

8:22:36 AM   July 26, 2006

Values across all replications

MRI Example

Replications: 30   Time unit: Hours

Key Performance Indicators

System   Average
Number out   601

Entity

Time

Wait Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.7241	0.08	0.5009	1.3496	0.00	7.3900

Total Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.9734	0.08	0.7427	1.6174	0.00001961	7.4140

Queue

Other

Number Waiting	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
MRI exam queue	2.1944	0.25	1.4326	4.2851	0.00	29.0000

Resource

Usage

Instantaneous Utilization	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
MRI	0.7488	0.01	0.6767	0.8513	0.00	1.0000

Arrival rate = 3 patients/hour; service rate = 4 patients/hour.

NOTE: Figure created in Arena®, Rockwell Automation.

The results of this simulation agree fairly closely with the calculated steady-state results because the process was assumed to run continuously for a significant period, 200 hours. A more realistic assumption might be that MRI procedures are only done for 10 hours every day. The Arena simulation was rerun with this assumption, and the results are shown in Figure 10.11. The average wait times, queue length, and utilization are lower than the steady-state values.

VVH M/M/1 Queue

VVH determined that a steady-state analysis was not appropriate for its situation because MRIs are only offered 10 hours a day. The team decided to analyze this situation using simulation. Once the model was built and run, the model and simulation results were compared with actual data and eval-

Category Overview

12:19:03 PM   July 26, 2006

Values across all replications

MRI Example

Replications: 30   Time unit: Hours

Key Performance Indicators

System   Average
Number out   28

Entity

Time

Wait Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.4778	0.15	0.02803444	1.4312	0.00	2.9818

Total Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.7304	0.16	0.2407	1.7611	0.00082680	3.3129

Queue

Other

Number Waiting	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
MRI exam queue	1.5265	0.46	0.2219	4.5799	0.00	10.0000

Resource

Usage

Instantaneous Utilization	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
MRI	0.7167	0.05	0.4088	0.9780	0.00	1.0000

Arrival rate = 3 patients/hour; service rate = 4 patients/hour.

NOTE: Figure created in Arena®, Rockwell Automation.

uated by relevant staff to ensure that the model accurately reflected reality. All staff agreed that the model was valid and could be used to determine what needed to be done to achieve the stated goal. If the model had not been thought to be valid, the team would have needed to build and validate a new model.

The results of the simulation (Figure 10.11) indicate that VVH has an average of 1.5 patients in the queue. To reach the desired goal of an average of only one patient waiting, VVH needs to decrease the arrival rate or increase the service rate. Using trial and error in the simulation, the organization found that decreasing the arrival rate to 2.7 or increasing the service rate to 4.4 would allow the goal to be achieved.

Even using the improvement tools in this text, the team believed that it would only be possible to increase the service rate of the MRI to 4.2 patients per hour. Therefore, to reach the goal the arrival rate must also be decreased. Again using the simulation, VVH found that it would need to decrease the arrival rate to 2.8 patients per hour. Figure 10.12 shows the results of this simulation.

The team recommended that a kaizen event be held for the MRI process to increase service rate and that appointments for the MRI be reduced to decrease the arrival rate. However, the team also noted that implementing these changes would reduce the average number of patients served from 28 to 26 and reduce the utilization of the MRI from 0.72 to 0.69. More positively, however, average patient wait time would be reduced from 0.48 hour to 0.35 hour.

FIGURE 10.12

Arena Output for VVH MRI M/M/1 Queuing Example: Decreased Arrival Rate, Increased Service Rate

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Category Overview

8:24:44 AM					July 26, 2006

Values across all replications

MRI Example

Replications: 30   Time unit: Hours

Key Performance Indicators

System   Average
Number out   26

Entity

Wait Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.3507	0.12	0.02449931	1.4202	0.00	3.4973

Total Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.6008	0.14	0.1899	1.7825	0.00097591	4.2210

Queue

Other

Number Waiting	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
MRI exam queue	1.0342	0.36	0.0928	4.2272	0.00	9.0000

Resource

Usage

Instantaneous Utilization	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
MRI	0.6682	0.06	0.3314	0.9456	0.00	1.0000

Arrival rate = 2.8 patients/hour; service rate = 4.2 patients/hour; 10 hours simulated.

NOTE: Figure created in Arena®, Rockwell Automation.

VVH was able to increase the service rate to 4.2 patients per hour and decrease the arrival rate to 2.8 patients per hour, and the results were as predicted by the simulation. The team also began to look at other solutions that would enable VVH to increase MRI utilization while maintaining wait times and queue length.

Advanced DES

DES is typically used to model more complex situations, processes, and systems than the simple M/M/1 queueing system analyzed previously. The aim of this text is to present an introduction to the modeling process and underlying theory to enable a basic understanding of simulation. More advanced treatments of Monte Carlo simulation can be found in *Practical Management Science: Spreadsheet Modeling and Applications* (Winston and Albright 2005); more advanced discussion of DES can be found in *Simulation with Arena* (Kelton, Sadowski, and Sturrock 2004).

Conclusion

Simulation is a powerful tool for modeling processes and systems to evaluate choices and opportunities. As is true of all of the tools and techniques presented in this text, simulation can be used in conjunction with other initiatives such as Lean or Six Sigma to enable continuous improvement of systems and processes.

Discussion Questions

1. Think of at least three simulations that you personally have used or been a part of. Why was simulation used? What questions did the simulation help you to answer?
2. Why is simulation not used more extensively in healthcare organizations?
3. What are the advantages of simulation? What are its limitations?
4. Explain the "flaw of averages" and provide a specific example where this flaw adversely affected your organization.
5. Discuss at least three opportunities in your organization in which simulation might be useful in analyzing and improving the situation.
6. Describe several places or times in your organization where people or objects (paperwork, tests, etc.) wait in line. How do the characteristics of each example differ?

Chapter Exercises

1. VVH is considering a pharmacy-managed medication assistance program. This program would help patients who are unable to afford pharmaceuticals obtain free drugs from pharmaceutical manufacturers. VVH would save the cost of the drugs but incur costs to manage the program, and the organization would like to know if the program would be cost beneficial. VVH believes that between 60 and 120 patients will use this program, with equal probability over this range (a uniform distribution); the average value of a patient's drugs obtained per year will most likely be $200, but could be as low as $0 or as high as $1,000 (a triangular distribution). The time to administer the program is expected to follow a normal distribution, with a mean of four hours per week and a standard deviation of 0.5 hour per week (but never less than zero hours). VVH also believes that there is an 80 percent probability the program could be administered by pharmacy research fellows who receive wages and benefits of $30 per hour, but hospital pharmacists may need to administer the program ($60 per hour wages and benefits). Analyze this situation using @Risk. What should VVH do? Why?

2. The hematology lab manager has been receiving complaints that the turnaround time for blood tests is too long. Data from the past month show that the arrival rate of blood samples to one technician in the lab is five per hour and the service rate is six per hour. Use queueing theory and assume that both rates are exponentially distributed and that the lab is at steady state to answer the following questions. What is the capacity utilization of the lab? Average number of blood samples in the lab? Average time that a sample waits in the queue? Average number of blood samples waiting for testing? Average time that a blood sample spends in the lab?

3. Use Arena to analyze the above situation. Assume that the lab operates 7 days a week, 24 hours a day; that arrivals are exponentially distributed; and that service rate follows a triangular distribution, with 10 minutes being the most likely time to complete a blood test (but the test could require as few as 5 minutes or as long as 20 minutes). Are the complaints justified? What should the lab manager do?

4. Develop a more realistic model for exercise 3. Assume that the lab is open 10 hours a day. Assume that blood samples arrive at a rate of 25 per hour and that five technicians are available to run the blood tests.

5. Applying one of the previous examples to your organization, develop a model of the process. What data would you need to collect to build a simulation?

References

Axelrod, R. 2006. "Advancing the Art of Simulation in the Social Sciences." In *Handbook of Research on Nature Inspired Computing for Economics and Management*, edited by J. Rennard. Hershey, PA: Idea Group Reference.

Berlekamp, E. R., J. H. Conway, and R. K. Guy. 2003. *Winning Ways (for Your Mathematical Plays),* 2nd ed., Vol. 2. Wellesley, MA: AK Peters.

Cooper, R. B. 1981. *Introduction to Queueing Theory,* 2nd ed. New York: North-Holland. [Online information; retrieved 7/17/06.] www.cse.fau.edu/%7Ebob/publications/IntroToQueueingTheory_Cooper.pdf.

Decisioneering Corporation. 2006. "Crystal Ball." [Online information; retrieved 5/25/06.] www.decisioneering.com/.

Grenvik, A., and J. Schaefer. 2004. "From Resusci-Anne to Sim-Man: The Evolution of Simulators in Medicine." *Critical Care Medicine* 32 (2 Suppl.): S56–S57.

Haley, L. 2005. "Simulation Aims to Speed Patients Through Surgeries." *Medical Post* 41 (1): 2–3.

Kelton, W. D., R. P. Sadowski, and D. T. Sturrock. 2004. *Simulation with Arena,* 3rd ed. Burr Ridge, IL: McGraw-Hill Higher Education.

Metropolis, N. C. 1987. "The Beginning of the Monte Carlo Method." *Los Alamos Science* 15 (Special Issue): 125–30.

National Academy of Engineering and Institute of Medicine. 2005. *Building a Better Delivery System: A New Engineering/Health Care Partnership*, edited by P. P. Reid, W. D. Compton, J. H. Grossman, and G. Fanjiang. Washington, D.C.: National Academies Press. [Online information; retrieved 7/28/06.] www.nap.edu/catalog/11378.html.

Pallisade Corporation. 2006. "@Risk 4.5." [Online information; retrieved 5/25/06.] www.palisade.com/risk/.

Poundstone, W. 1985. *The Recursive Universe*. Chicago: Contemporary Books.

Rockwell Automation. 2006. "Arena." [Online information; retrieved 6/6/06.] www.arenasimulation.com/products/basic_edition.asp.

Savage, S. 2002. "The Flaw of Averages." *Harvard Business Review* 80 (11): 20–21.

Simul8 Corporation. 2006. "Simul8." [Online information; retrieved 6/6/06.] www.simul8.com/index.htm.

Winston, W. L., and S. C. Albright. 2005. *Practical Management Science: Spreadsheet Modeling and Applications* (with CD-ROM Update), 2nd ed. Belmont, CA: Duxbury.

APPLICATIONS TO CONTEMPORARY HEALTHCARE OPERATIONS ISSUES

11

PROCESS IMPROVEMENT AND PATIENT FLOW

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

activity and role lane map

capacity utilization

control loop

discrete event simulation

electronic medical record (EMR)

Emergency Department (ED)

entity

heijunka

idle or wait time

Little's law

load balancing, leveling

non–value-added time

number of defects or errors

patient flow

patients-in-process (PIP)

plan-do-check-act (PDCA)

process mapping

quality at the source

queue

route

service or cycle time

setup time

simulation

station

subprocesses

systems

tasks

theory of constraints

things-in-process (TIP)

throughput

work-in-process (WIP)

Operations Management in Action

The staff of Carondelet St. Mary's Hospital in Tucson, Arizona, undertook an improvement effort aimed at emergency center operations. A number of operational changes were implemented to achieve improvements in patient flow. The hospital:

- *Created a culture for in-house nursing units using "pull system" versus "push system" as a concept to promote patient flow out of the emergency center.*
- *Developed a centralized admitting process with an electronic tracking board.*
- *Implemented a bed-control nurse position.*
- *Developed a mobile admission team to perform bedside admissions.*
- *Developed and implemented a process for direct admit admission labs to improve turnaround time.*
- *Developed and implemented a protocol to bypass the emergency center triage when a bed is available.*
- *Adjusted triage staffing to volume peaks.*
- *Adjusted emergency center staffing to meet volume demand.*
- *Developed physician-driven triage protocols.*
- *Implemented bedside registration in the emergency center when patients bypass triage or arrive by ambulance.*
- *Refocused the inpatient unit charge nurse position to frontline operations with responsibility for unit flow and throughput.*
- *Used the express admission unit as a discharge lounge to open beds and improve patient flow when census is high.*
- *Standardized the channels of communication for follow-up with primary care providers whose patients are cared for by the hospitalist through information systems interfacing.*
- *Provided portal access for physicians to readily obtain patient information.*
- *Opened a fast-track patient care area in the new emergency center to improve flow of low-acuity patients.*
- *Developed a focus team to decrease external and internal transportation delays.*
- *Standardized surgical admission and preadmission testing processes.*
- *Implemented processes to reduce operating room turnover time.*
- *Standardized the recovery process between inpatients and outpatients.*
- *Developed balancing measures to ensure that changes made to improve patient flow did not adversely affect quality indicators.*

These process improvements resulted in the following changes:

- *Reduced the emergency center length of stay by 7 percent;*
- *Increased the emergency center's monthly volume by 5 percent;*
- *Increased the inpatient daily census by 20 percent; and*
- *Improved the hospital's net operating margin by 1.3 percent above budget.*

SOURCE: Schmidt and Messer (2005). Reprinted with permission.

Overview

At the core of all organizations are their operating systems. Excellent organizations continuously measure, study, and make improvements to these systems. This chapter provides a methodology for measuring and improving systems using a selected set of the tools contained in the preceding chapters.

The terminology associated with process improvement can be confusing. Typically, tasks combine to form subprocesses, subprocesses combine to form processes, and processes combine to form a system. The boundaries of a particular system are defined by what is of interest. For example, the boundaries of a supply chain system would be more encompassing than a hospital system that is part of that supply chain. The term "process improvement" refers to improvement at any of these levels, from the task level to the systems level. This chapter focuses on process and systems improvement.

Process improvement follows the classic plan-do-check-act (PDCA) cycle (Chapters 8 and 9), with the following, more specific key steps:

- *Plan:* Define the entire process to be improved using process mapping. Collect and analyze appropriate data for each element of the process.
- *Do:* Use process improvement tool(s) to improve the process.
- *Check:* Measure the results of the process improvement.
- *Act to hold the gains:* If the process improvement results are satisfactory, hold the gains (Chapter 14). If the results are not satisfactory, repeat the PDCA cycle.

This chapter discusses the types of problems or issues being faced by healthcare organizations, reviews many of the operations tools discussed in earlier chapters, and illustrates how these tools can be applied to process improvement. The relevant tools include:

- Basic process improvement tools;
- Six Sigma and Lean tools; and
- Simulation with Arena.

Problem Types

Continuous process improvement is essential for organizations to meet the challenges of today's healthcare environment. The theory of swift, even flow (Schmenner 2001, 2004; Schmenner and Swink 1998) asserts that a process is more productive as the stream of materials (customers or information) flows more swiftly and evenly. Productivity rises as the speed of flow through the process increases and the variability associated with that process decreases.

It should be noted that these phenomena are not independent. Often, decreasing system variability will increase flow, and increasing flow will decrease variability. For example, advanced access scheduling increases flow by decreasing the elapsed time between when a patient schedules an appointment and when she has completed her visit to the provider. This can also decrease variability by decreasing the number of patient no-shows.

Solutions to many of the problems facing healthcare organizations can be found in increasing flow or decreasing variability. For example, a key operating challenge in most healthcare environments is the efficient movement of patients within a hospital or clinic, commonly called "patient flow." Various approaches to process improvement will be illustrated with the patient flow problem. Optimizing patient flow through emergency departments has become a top priority of many hospitals; therefore, the Vincent Valley Hospital and Health System (VVH) example at the end of this chapter will focus on improving patient flow through that organization's emergency department.

Another key issue facing healthcare organizations is the need to increase the level of quality and eliminate errors in systems and processes. In other words, variation must be decreased. Finally, increasing cost pressures result in the need for healthcare organizations to not only improve processes but also to improve processes while reducing costs.

The tools and techniques presented in this book are aimed at enabling cost-effective process improvement. Although this chapter focuses on patient flow and elimination of errors related to patient outcomes, the discussion would be equally applicable to other types of flow problems (e.g., information, paperwork) and other types of errors (e.g., billing). Some tools are more applicable to increasing flow and others to decreasing variation, eliminating errors, or improving quality, but all of the tools can be used for process improvement.

Patient Flow

Efficient patient movement in healthcare facilities can significantly improve the quality of care that patients receive and substantially improve financial performance. A patient receiving timely diagnosis and treatment has a higher likelihood of obtaining a desired clinical outcome. Because most current

payment systems are based on fixed payments per episode of treatment, a patient moving more quickly through a system will generate lower costs and, therefore, higher margins.

Increased interest in patient flow in hospitals has been stimulated by overcrowding in emergency departments and ambulance diversions caused by hospitals being "full." In the United States, the average waiting time for nonurgent visits to emergency departments increased by 33 percent between 1997 and 2000. More than 75 million Americans reside in areas where ambulances are routinely diverted from their primary destinations because hospitals do not have available beds (Institute for Healthcare Improvement 2003).

The cause of emergency department crowding goes deeper than the department itself and involves patient flow issues throughout the hospital. If an operating room is backed up because of scheduled-surgery delays, an emergency patient needing surgery may have to wait. If a lab result is delayed, a patient may wait in the emergency department much longer than is needed for optimal care.

Patient flow optimization opportunities occur in many healthcare settings. Examples include operating suites, imaging departments, urgent care centers, and immunization clinics. Advanced access (same-day scheduling) is a special case of patient flow and is examined in depth in Chapter 12.

There are many causes of poor patient flow, but a culprit discovered by many investigators is variability of scheduled demand. For example, if an operating room is scheduled for a surgery but the procedure does not take place at the scheduled time, or takes longer than it was scheduled to take, the rest of the surgery schedule becomes delayed. These delays ripple through the entire hospital, including the emergency department.

As explained by Dr. Eugene Litvak (Institute for Healthcare Improvement 2006),

> You have two patient flows competing for hospital beds—ICU or patient floor beds. The first flow is scheduled admissions. Most of them are surgical. The second flow is medical, usually patients through the emergency department. So when you have a peak in elective surgical demand, all of a sudden your resources are being consumed by those patients. You don't have enough beds to accommodate medical demand.

If scheduled surgical demand varies unpredictably, the likelihood of inpatient overcrowding, emergency department backlogs, and ambulance diversions increases dramatically. Even when patients are admitted into a bed, they may not be receiving a value-added service. A British study (Walley, Silvester, and Steyn 2006) found that, although National Health Service hospitals were running at an occupancy rate of 90 percent, only "60 to 70 percent of the patients occupying those beds were receiving active treatment and the rest are either waiting for initial visits by doctors, stuck in the system because of delays, or not ill but have

not left the hospital for some reason." Clearly, significant opportunities to improve capacity and reduce cost by improving patient flow exist.

A number of management solutions have been introduced to improve patient flow. Separating low-acuity patients into a unique treatment stream can reduce time in the emergency department and improve patient satisfaction (Rodi, Grau, and Orsini 2006). Once a patient is admitted to the hospital, other tools have been employed to improve flow, especially around the discharge process. These include creating a uniform discharge time (e.g., 11 a.m.), writing discharge orders the night before, communicating discharge plans early in the patient's care, centralizing oversight of census and patient movement, changing physician rounding times, alerting ancillary departments when their testing procedures are critical to a patient's discharge, and improving discharge coordination with social services (Clark 2005).

However, for patient flow to be carefully managed and improved, the formal methods of process improvement outlined below need to be widely employed.

Quality

Ensuring quality of care is becoming an increasingly important problem for the healthcare industry. It was estimated that in 1999 more than 98,000 individuals died in hospitals because of errors made by healthcare professionals (Institute of Medicine 1999). Both consumers and healthcare providers have begun to recognize that errors in patient care need to be reduced or eliminated.

Because the administration and delivery of healthcare involves the interaction of providers and patients, this is a more difficult problem than is encountered in most environments. Human involvement in the "production process" and the intangibility of the resulting product make it difficult to standardize and control healthcare. As noted in *To Err Is Human* (Institute of Medicine 1999), healthcare differs from a systematic production process "mostly because of huge variability in patients and circumstances, the need to adapt processes quickly, the rapidly changing knowledge base, and the importance of highly trained professionals who must use expert judgment in dynamic settings." However, because the consequences of failure—patient injury or death—are so great, the need to reduce or eliminate failures is even more important in healthcare than in manufacturing or other service industries.

Again, to ensure quality and reduce or eliminate errors, the formal methods of process improvement outlined below need to be widely employed.

Process Improvement Approaches

Process improvement projects can use a variety of approaches and tools. Typically, they begin with process mapping and measurement. Some simple tools

can be initially applied to identify opportunities for improvements. Identifying and eliminating or alleviating bottlenecks in a system (theory of constraints) can quickly improve overall system performance. In addition, the Six Sigma tools described in Chapter 8 can be used to reduce variability in process output, and the Lean tools discussed in Chapter 9 can be used to identify and eliminate waste. Finally, simulation (Chapter 10) provides a powerful tool to understand and optimize flow in a system.

All major process improvement projects should use the formal project management methodology outlined in Chapter 5. An important first step is to identify a system's owner: For a system to be managed effectively over time it must have an owner, someone who monitors the system as it operates, collects performance data, and leads teams to improve the system.

Many systems in healthcare do not have an owner and, therefore, operate inefficiently. For example, a patient may enter an emergency department, see the triage nurse, move to the admitting department, take a chair in the waiting area, be moved to an exam room, be seen by a nurse, have his blood drawn, and finally be examined by a physician. From the patient's point of view this is one system, but many hospital departments may be operating autonomously. System ownership problems can be remedied by multidepartment teams with one individual designated as the overall system or process owner.

Problem Definition and Process Mapping

The first step in improving a system is process description and mapping. However, the team should first ensure that the correct problem is being addressed. Mind mapping or root-cause analysis should be employed to ensure that the problem is identified and framed correctly; much time and money can be wasted finding an optimal solution to something that is not a problem.

For example, suppose that a project team was given the task of improving customer satisfaction with the emergency department. If the team assumes that customer satisfaction is low because of high throughput time, they might proceed to optimize patient flow in the emergency department. However, if an analysis of customer satisfaction showed that customers were dissatisfied because of a lack of parking, the solution to the problem would follow a different path. The problem must be clearly understood and defined to determine what process to map.

Processes can be described in a number of ways. The most common is the written procedure or protocol, typically constructed in the "directions" style, which is sufficient for simple procedures—for example, "Turn right at Elm Street, go two blocks, and turn left at Vine Avenue." Clearly written procedures are an important part of defining standard work, as described in Chapter 9.

However, when processes are linked to form systems they become more complex. These linked processes benefit from process mapping because process maps:

- Provide a visual representation that offers an opportunity for process improvement through inspection;
- Allow for branching in a process;
- Provide the ability to assign and measure the resources in each task in a process; and
- Are the basis for modeling the process via computer simulation software.

Chapter 6 provides an introduction to process mapping. To review, the steps in process mapping are:

1. Assemble and train the team.
2. Determine the boundaries of the process (where does it start and end?) and the level of detail desired.
3. Brainstorm the major process tasks and list them in order. (Sticky notes are often helpful here.)
4. Once an initial process map (also called a flowchart) has been generated, the chart can be formally drawn using standard symbols for process mapping.
5. The formal flowchart should be checked for accuracy by all relevant personnel.
6. Depending on the purpose of the flowchart, data may need to be collected or more information added.

Process Mapping: VVH Emergency Department

A basic process map illustrating patient flow in the VVH emergency department is displayed in Figure 11.1.

In this basic process map, the patient arrives at the emergency department and is examined by the triage nurse. If the patient is very ill (high complexity level), she is immediately sent to the intensive care section of the emergency department. If not, she is sent to admitting and then to the routine care section of the emergency department. The simple process map shown here ends with this step. In actuality, other processes would now begin, such as admission into an inpatient bed or a discharge from the emergency department to home with a scheduled clinical follow-up. The VVH emergency department process improvement project is detailed at the end of this chapter.

Process Measurements

Once a process map is developed, relevant data should be collected and analyzed. The situation will dictate which specific data and measures should be employed. Important measures and data for possible collection and analysis include:
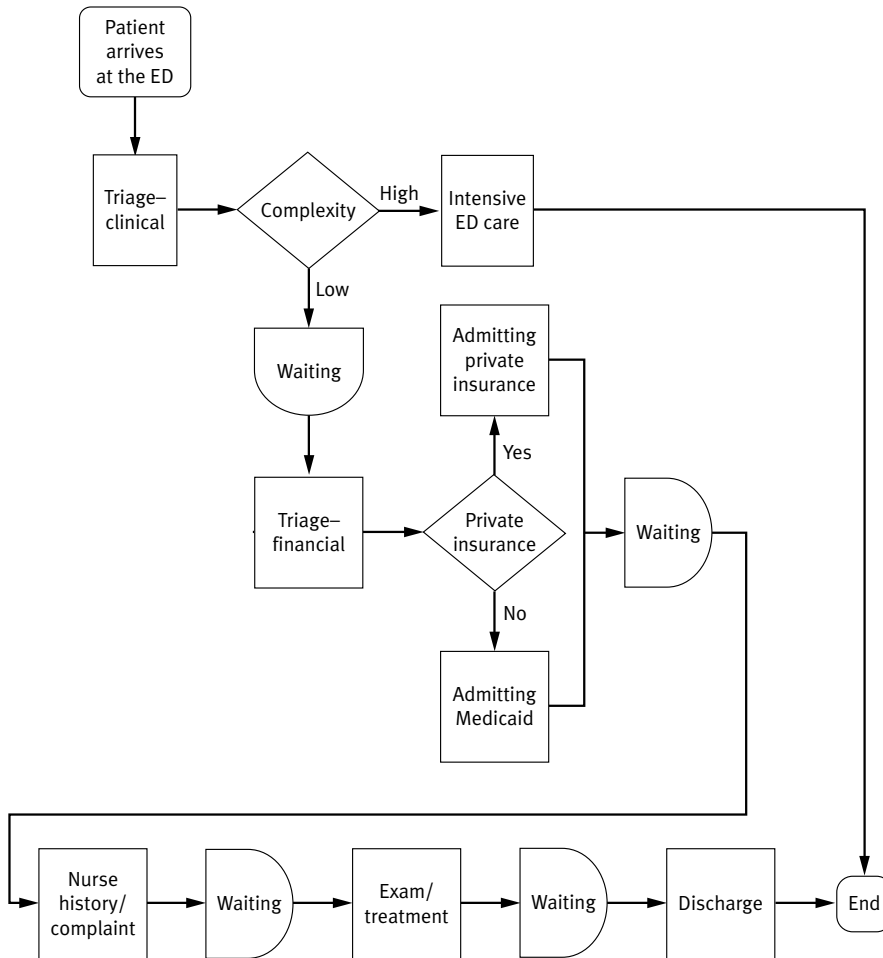
FIGURE 11.1
VVH
Emergency
Department
(ED) Patient
Flow Process
Map

- *Capacity of a process* is the maximum possible amount of output (goods or services) that a process or resource can produce or transform. Capacity measures can be based on outputs or on the availability of inputs. The capacity of a series of tasks is determined by the lowest-capacity task in the series.
- *Capacity utilization* is the proportion of capacity actually being used. It is measured as actual output/maximum possible output.
- *Throughput time* is the average time a unit spends in the process. Throughput time includes both processing time and waiting time and is determined by the critical (longest) path through the process.
- *Throughput rate,* sometimes referred to as drip rate, is the average number of units that can be processed per unit of time.

- *Service time or cycle time* is the time to process one unit. The cycle time of a process is equal to the longest task cycle time in that process. The probability distribution of service times may also be of interest.
- *Idle or wait time* is the time a unit spends waiting to be processed.
- *Arrival rate* is the rate at which units arrive to the process. The probability distribution of arrival rates may also be of interest.
- *Work-in-process, things-in-process, patients-in-process, or inventory* describe the total number of units in the process.
- *Setup time* is the amount of time spent getting ready to process the next unit.
- *Value-added time* is the time a unit spends in the process where value is actually being added to the unit.
- *Non–value-added time* is the time a unit spends in the process where no value is being added. Wait time is non–value-added time.
- *Number of defects or errors.*

The art in process mapping is to provide enough detail to be able to measure overall system performance, determine areas for improvement, and measure the effect of these changes.

Tools for Process Improvement

Once a system has been mapped, a number of techniques can be used to improve the process. These improvements will result in a reduction in the duration, cost, or waste in a system.

Eliminate non–value-added activities

The first step after a system has been mapped is to evaluate every element to ascertain whether each one is truly necessary and provides value (to the customer or patient). If a system has been in place for a long period and has not been evaluated through a formal process improvement project, a number of elements of the system can likely be easily eliminated. This step is sometimes termed "harvesting the low-hanging fruit."

Eliminate duplicate activities

Many processes in systems have been added on top of existing systems without formally evaluating the total system, frequently resulting in duplicate activities. The most infamous redundant process step in healthcare is asking patients repeatedly for their contact information. Duplicate activities increase both time and cost in a system and should be eliminated whenever possible.

Combine related activities

Process improvement teams should examine both the process map and the activity and role lane map. If a patient moves back and forth between depart-

ments, the movement should be reduced by combining these activities so he only needs to be in each department once.

Process in parallel

Although a patient can only be in one place at one time, other aspects of her care can be completed simultaneously. For example, medication preparation, physician review of tests, and chart documentation could all be done at the same time. As more tasks are executed simultaneously, the total time a patient spends in the process will be reduced. Similar to a chef who has a number of dishes on the stove synchronized to be completed at the same time, much of the patient care process can be completed at the same time.

Another element of parallel processing is the relationship of subprocesses to the main flow. For example, a lab result may need to be obtained before a patient enters the operating suite. Many of these subprocesses can be synchronized through the analysis and use of takt time (Chapter 9). This synchronization will enable efficient process flow and help optimize the process.

Load balancing

If similar workers perform the same task, a well-tuned system can be designed to balance the work among them. For example, a mass-immunization clinic would want to develop its system so that all immunization stations are active at all times. This could be accomplished by using a single queue with multiple immunization stations.

Load balancing (or load leveling, heijunka) is difficult when employees can only perform a limited set of specific tasks (an unfortunate consequence of the super-specialization of the healthcare professions). When cross-training of employees can be accomplished, load balancing is easier.

Alternative process flow paths and contingency plans

The number and placement of decision points in the process should be evaluated and optimized. A system with few decision points has few alternative paths and, therefore, does not respond well to unexpected events. Alternative paths (or contingency plans) should be developed for these types of events. For example, a standard clinic patient rooming system should have alternative paths if an emergency occurs, a patient is late, a provider is delayed, or medical records are absent.

Critical path

For complex pathways in a system, it is sometimes helpful to identify the critical pathway using tools described in Chapter 5. If a critical path can be identified, execution of processes on the pathway can be improved (e.g., reduce average service time). In some cases, the process can be moved off the criti-

cal path and be processed in parallel to it. Either technique will decrease the total time on the critical pathway. In the case of patient flow, this will decrease the patient's total time in the system.

Information feedback and real-time control

Some systems have a high level of variability in their operations because of variability in the arrival of jobs or customers (patients) into the process and variability of the cycle time of each process in the system. High variability in the system can lead to poor performance. One tool to reduce variability is the control loop (Chapter 1). Information can be obtained from one process and used to drive change in another. For example, the number of patients in the emergency department waiting area can be continuously monitored and if the number reaches a certain level, contingency plans such as floating in additional staff from other portions of the hospital can be initiated.

Quality at the source

Many systems contain multiple reviews, approvals, and inspections. A system in which the task is done right the first time should not require these redundancies. Deming first identified this problem in the process design of manufacturing lines that had inspectors throughout the assembly process (Deming 1998). This expensive and ineffective system was one of the factors that gave rise to the quality movement in Japan and, later, in the United States.

To eliminate inspections, it is important to design systems that embed quality at the source or beginning of a system. For example, a billing system that requires a clerk to inspect a bill before it is released does not have quality built into the process. A system that has many inspection steps and does not have quality at the source should be redesigned.

Let the patient do the work

The Internet and other advanced information technologies have allowed for more self-service in service industries. Individuals are now comfortable booking their own airline reservations, buying goods online, and checking themselves out at retailers. This trend can be exploited in healthcare with tools that enable patients to be part of the process. For example, online tools are now available that allow patients to make their own clinic appointments. Letting the patient do the work reduces the work of staff and provides an opportunity for quality at the source—if the patients input the data, they are more likely to be correct.

Theory of constraints

Chapter 6 discussed the underlying principles and applications of the theory of constraints, which can be used as a powerful process improvement tool. First, the bottleneck in a system is identified, often through the observation

of queues forming in front of it. Once a bottleneck is identified, it should be exploited and everything else in the system subordinated to it. This means that other non-bottleneck resources (or steps in the process) should be synchronized to match the output of the constraint. Idleness at a non-bottleneck resource costs nothing and non-bottlenecks should never produce more than can be consumed by the bottleneck resource. Often, this will cause the bottleneck to shift—a new bottleneck will be identified. However, if the original bottleneck remains, the possibility of elevating the bottleneck needs to be evaluated. Elevating bottlenecks requires additional resources (e.g., staff, equipment), so a comprehensive outcomes and financial analysis needs to be undertaken to determine the trade-offs among process improvement, quality, and costs.

Process Improvement in Practice

Six Sigma

If the primary goal of a process improvement project is to improve quality (reduce the variability in outcomes), the Six Sigma approach and tools described in Chapter 8 will yield the best results. As discussed previously, Six Sigma uses seven basic tools: fishbone diagrams, check sheets, histograms, Pareto charts, flow charts, scatter plots, and run charts. It also includes statistical process control to provide an ongoing measurement of process output characteristics to ensure quality and enable the identification of a problem situation before an error occurs.

The Six Sigma approach also includes measuring process capability—a measure of whether a process is actually capable of producing the desired output—and benchmarking it against other similar processes in other organizations. Quality function deployment is used to match customer requirements (voice of the customer) with process capabilities given that trade-offs must be made. Poka-yoke is employed selectively to mistake-proof parts of a process.

Lean

Process improvement projects focused on eliminating waste and improving flow in the system or process can use many of the tools that are part of the Lean approach (Chapter 9). The kaizen philosophy, which is the basis for Lean, includes the following steps:

- *Specify value:* Identify activities that provide value from the customer's perspective.
- *Map and improve the value stream:* Determine the sequence of activities or the current state of the process and the desired future state. Eliminate non–value-added steps and other waste.

- *Flow:* Enable the process to flow as smoothly and quickly as possible.
- *Pull:* Enable the customer to pull products or services.
- *Perfection:* Repeat the cycle to ensure a focus on continuous improvement.

An important part of Lean is value stream mapping, which is used to define the process and determine where waste is occurring. Takt time is a measure of time needed for the process based on customer demand and can be used to synchronize flow in a process. Standardized work, an important part of the Lean approach, is written documentation of the precise way in which every step in a process should be performed and is a way to ensure that things are done the same way every time in an efficient manner.

Other Lean tools in include the five Ss (a technique to organize the workplace) and spaghetti diagrams (a mapping technique to show the movement of customers, patients, workers, equipment, jobs, etc.). Leveling workload (heijunka) so that the system or process can flow without interruption can be used to improve the value stream. Kaizen blitzes or events are Lean tools used to improve the process quickly, when project management is not needed (Chapter 9).

Simulation

Simulation is used to evaluate "what if" situations. Usually it is less expensive or speedier than changing the real system and evaluating the effects of those changes. The process of simulation is:

- *Model development:* Develop a model of the process or situation of interest.
- *Model validation:* Ensure that the model accurately represents reality.
- *Simulation and analysis of output:* Run the simulation and analyze the output to determine the answers to the questions asked, optimize the process, or manage risk.

Discrete event simulation (based on queueing theory) is used to model system flows to improve the system. Chapter 10 provided an extensive description of the underlying mathematics and the use of simulation to model operating systems. This chapter applies these concepts more broadly to process improvement, with a specific emphasis on patient flow.

Process Improvement Project: VVH Emergency Department

To demonstrate the power of many of the process improvement tools described previously, an extensive patient-flow process improvement project at VVH will be examined.

VVH identified patient flow in the emergency department as an important area on which to focus process improvement efforts. The goal of

the project was to reduce total patient time in the emergency department (both waiting and care delivery) while maintaining or improving financial performance.

The first step for VVH leadership was to charter a multidepartmental team using the project management methods described in Chapter 5. The head nurse for emergency services was appointed project leader. The team felt VVH should take a number of steps to improve patient flow in the emergency department and decided to split the systems improvement project into three major phases. First, they would perform simple data collection and basic process improvement to identify low-hanging fruit and make obvious, straightforward changes.

Once the team felt comfortable understanding the basics of patient flow in the department, they would work to understand the elements of the system more fully by collecting more detailed data. Then, value stream mapping and the theory of constraints would be used to identify opportunities for improvement. Root-cause analysis would be employed on poorly performing processes and tasks. These changes would be made and their effects measured.

The third phase of the project was the use of simulation. Because the team would have complete knowledge of patient flow in the system, they could develop and test a simulation model with confidence. Once the simulation was validated, the team would continuously test process improvements in the simulation model and implement them in the emergency department.

The team also considered a fourth phase that would implement real-time use of a simulation model and match patient arrivals with emergency department resource needs, then effectively deploy those resources.

The specific high-level tasks in this project were:

Phase I
1. Observe patient flow and develop a detailed process map.
2. Measure high-level patient flow metrics for one week:
   - Patients arriving per hour;
   - Patients departing per hour to inpatient;
   - Patients departing per hour to home; and
   - Number of patients in the emergency department, including the waiting area and exam rooms.
3. With the process map and data in hand, use simple process improvement techniques to make changes in the process, then measure the results.

Phase II
4. Set up a measurement system for each individual process and take measurements over one week.

5. Use value stream mapping and the theory of constraints to analyze patient flow and make improvements, then measure the effects of the changes.

Phase III
6. Collect data needed to build a realistic simulation model.
7. Develop the simulation model and validate it against real data.
8. Use the simulation model to conduct virtual experiments on process improvements. Implement promising improvements, and measure the results of the changes.

Phase I

VVH process improvement project team members observed patient flow and recorded the needed data. With the information collected, the team was able to create a fairly detailed process map. They measured the following high-level operating statistics related to patient flow:

- Patients arriving per hour = 10
- Patients departing per hour to inpatient = 2
- Patients triaged to routine emergency care per hour = 8
- Patients departing per hour to home = 8
- Average number of patients in various parts of the system (sampled every 10 minutes) = 20
- Average number of patients in emergency department exam rooms = 4

Using Little's law, the average time in the emergency department (throughput time) is calculated as:

$$
\begin{aligned}
\text{Throughput time} &= T \\
&= I/\lambda \\
&= \frac{24 \text{ Patients}}{8 \text{ Patients}/\text{Hour}} \\
&= 3 \text{ Hours}
\end{aligned}
$$

Hence, each patient spent an average of 3 hours, or 180 minutes, in the emergency department. However, Little's law only gives the average time in the department at steady state. Therefore, the team measured total time in the system for a sample of routine patients and found an average of 165 minutes. They also observed that the number of patients in the waiting room varied from 0 to 20, and that the actual time it took to move through the process varied from 1 to more than 5 hours.

Initially, the team focused on the emergency department admitting subsystem as an opportunity for immediate improvement. Figure 11.2 shows the complete emergency department system with the admitting subsystem highlighted.
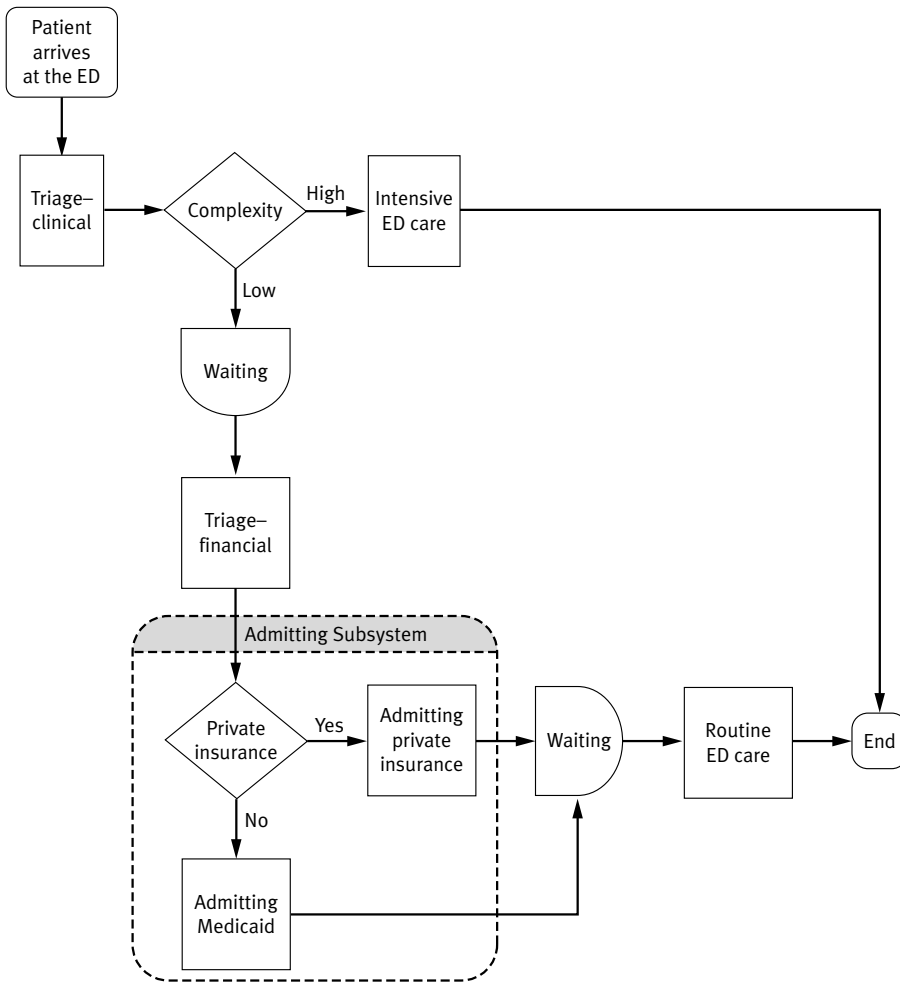
NOTE: Created with Microsoft Visio®.

The team developed the following description of the admitting process from its documentation of patient flow:

Patients who did not have an acute clinical problem were asked if they had health insurance. If they did not have health insurance, they were sent to the admitting clerk who specialized in Medicaid (to enroll them in a Medicaid program). If they had health insurance, they were sent to the other clerk, who specialized in private insurance. If a patient had been sent to the wrong clerk by triage, he was sent to the other clerk.

The team determined that one process improvement change would be to cross-train the admitting clerks on both private insurance and Medicaid eligibility. This would provide for load balancing, as patients would automatically

go to the free clerk and keep the workload balanced. In addition, the system improvement would eliminate triage staff errors in sending patients to the wrong clerk, hence providing quality at the source.

Phase II

Phase I produced some gains in reducing patient time in the emergency department. However, the team felt more detailed data were needed to improve even further. As a first step in collecting these data, the team decided to measure various parameters of the department's processes. Initially, they decided to focus on the time period from 2 p.m. to 2 a.m., Monday through Thursday, as this is the busy period in the emergency department and demand seemed relatively stable during these times.

The team drew a more detailed process map (Figure 11.3) and performed value stream mapping of this process (Figure 11.4). First, they evaluated each step in the process to determine if it was value added, non–value added, or non–value added but necessary. Then, they measured the time a patient spent at each step in the process. The team found that after a patient had given his insurance information, he spent an average of 30 minutes of non–value-added time in the waiting room before a nurse was available to take his history and record the presenting complaint, a process that took an average of 20 minutes. The percentage of value-added time for these two steps is:

$$(\text{Value-added time}/\text{Total time})100 =$$

$$(20 \text{ Minutes}/[30 \text{ Minutes} + 20 \text{ Minutes}])100 = 40\%$$

The team believed the waiting room process could be improved through automation. Patients were given a tablet personal computer in the waiting area and asked to enter their symptoms and history via a series of branched questions. The results were sent via a wireless network to VVH's electronic medical record (EMR). This step usually took patients about 20 minutes. Staff knew which patients had completed the electronic interview by checking the EMR and could then prioritize which patient would be seen next. This new procedure also reduced the time needed by the nurse to 10 minutes because it enabled the nurse to verify, rather than actually record, presenting symptoms and patient history. The percentage of value-added time for the new procedure is:

$$(\text{Value-added time}/\text{Total time})100 =$$

$$([\text{Patient history time} + \text{Nurse history time}]/$$
$$[\text{Patient history time} + \text{Wait time} + \text{Nurse history time}])100 =$$

$$([20 \text{ Minutes} + 10 \text{ Minutes}]/[20 \text{ Minutes} + 10 \text{ Minutes} +$$
$$10 \text{ Minutes}])]100 = 75\%$$
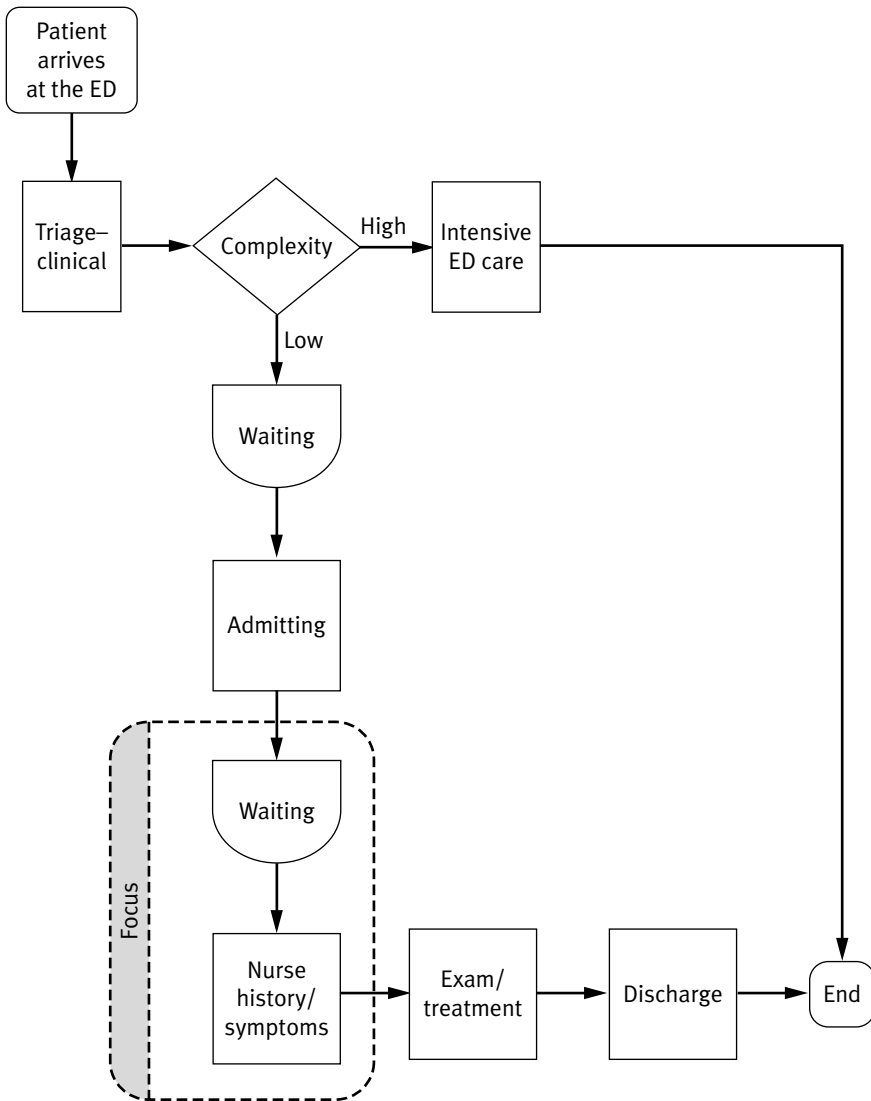
FIGURE 11.3
VVH
Emergency
Department
(ED) Process
Map: Focus on
Waiting and
History

The average throughput time for a patient in the emergency depart-
ment was reduced by 10 minutes. The average time for patients to flow
through the department (throughput time) prior to this improvement was
155 minutes. Because this step was on the critical path of the complete rou-
tine care emergency department process, throughput time for noncomplex
patients was reduced to 145 minutes, a 7 percent productivity gain. An ana-
lyst from the VVH finance department (a member of the project team) was

Created with eVSM software from GumshoeKI, Inc., a Microsoft Visio add-on.
NOTE: NM = Number; FTE = full-time equivalent.

able to clearly demonstrate that the capital/software costs for the tablet computers would be recovered within 12 months by the improvement in patient flow. This phase of the project used three of the basic process improvement tools discussed in this chapter:

• Have the customer (patient) do it;
• Provide quality at the source; and
• Gain information feedback and real-time control.

Although the process improvements already undertaken had a visible effect on flow in the emergency department, the team believed more improvements were possible. There were bottlenecks in the process, as evidenced by two waiting lines, or queues: (1) the waiting room queue, where patients waited before being moved to an exam room; and (2) the most visible queue for routine patients, the discharge area, where patients occasionally had to stand because all of the area's chairs were occupied. In the discharge area, patients waited a significant amount of time for final instructions and prescriptions.

The theory of constraints suggests that the bottleneck should be identified and optimized. However, alleviating or eliminating the patient examination and treatment or discharge bottlenecks would require significant changes in a long-standing process. Because this process improvement step seemed to have the probability of a high payoff but was a significant departure from existing practice, it was decided to move to phase III of the project and use simulation to model different options to improve patient flow in the examination/treatment and discharge processes.

Phase III: Simulation

First, the team reviewed the basic terminology of simulation.

- An *entity* is what flows through a system. Here, the entity is the patient. However, in other systems the entity could be materials (e.g., blood sample, drug) or information (e.g., diagnosis, billing code). Entities usually have attributes that will affect their flow through the system (e.g., male/female, acute/chronic condition).
- Each individual *process* in the system transforms (adds value) to the entity being processed. Each process takes time and consumes resources such as staff, equipment, supplies, and information.
- *Time* and *resource* use can be defined as an exact value (e.g., ten minutes) or a probability distribution (e.g., normal—mean, standard deviation). Chapter 7 discusses probability distributions in detail. Most healthcare tasks and processes will not require the same amount of time each time they are performed—they will require a variable amount of time. These variable usage rates are best described as probability distributions.
- The geographic location of a process is called a *station*. Entities flow from one process to the next via *routes*. The routes can branched based on *decision points* in the process map.
- Finally, because a process may not be able to handle all incoming entities in a timely fashion, *queues* will occur at each process and can be measured and modeled.

The team next developed a process map and simulation model for routine patient flow (Figure 11.5) in the emergency department using Arena simulation software from Rockwell Automation (2006) (see ache.org/books/OpsManagement for links to videos detailing this model and its operation). The team focused on routine patients rather than those requiring intensive emergency care because of the high proportion of routine patients seen in the department. Routine patients are checked in and their self-recorded history and presenting complaint(s) are verified by a nurse. Then, patients move to an exam/treatment room and, finally, to the discharge area. Of the ten patients who come to the emergency department per hour, eight follow this process.

Next, to build a simulation model that accurately reflects this process, the team needed to determine the probability distributions of treatment time, admitting time, nurse history time, discharge time, and arrival rate for routine patients. To determine these probability distributions, they collected data on time of arrival in the department and time to perform each step in the routine patient care process.

Probability distributions were determined using the Input Analyzer function in Arena. Input Analyzer takes raw input data and finds the best-fitting probability distribution for them. Figure 11.6 shows the output of
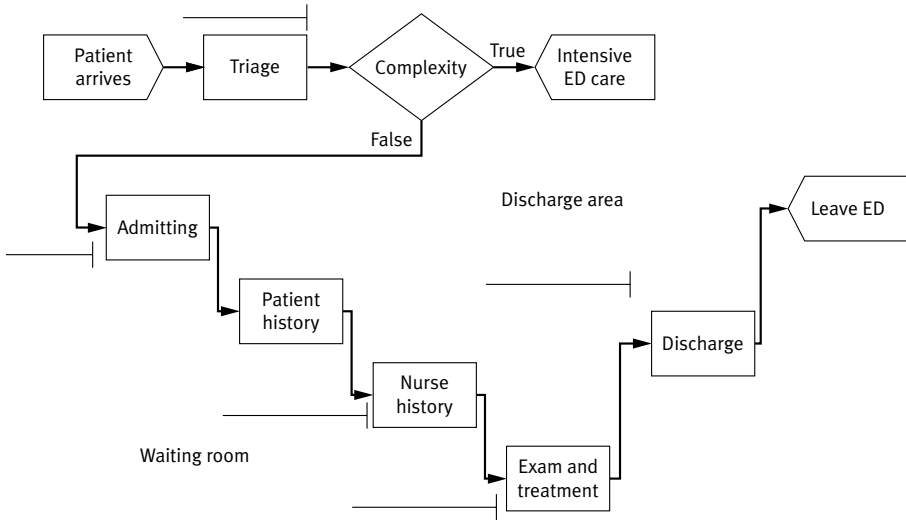
NOTE: Model created in Arena®, Rockwell Automation.

Arena Input Analyzer for 500 observations of treatment time for emergency department patients requiring routine care. Input Analyzer suggested that the best-fitting probability distribution for these data was triangular, with a minimum of 9 minutes, mode of 33 minutes, and maximum of 51 minutes.

The remaining data were analyzed in the same manner, and the following best-fitting probability distributions were determined:

• Emergency routine patient arrival rate: exponential (7.5 minutes between arrivals)
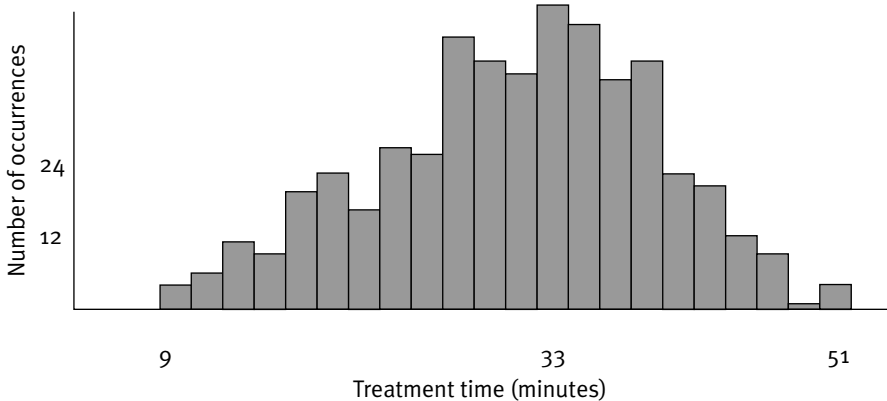
- Triage time: triangular (2, 5, 7 minutes)
- Admitting time: triangular (3, 8, 15 minutes)
- Patient history time: triangular (15, 20, 25 minutes)
- Nurse history time: triangular (5, 11, 15 minutes)
- Exam/treatment time: triangular (14, 36, 56 minutes)
- Discharge time: triangular (9, 19, 32 minutes)

The Arena model simulation was based on 12-hour intervals (2 p.m. to 2 a.m.) and replicated 100 times. Note that increasing the number of replications decreases the half-width and, therefore, gives tighter confidence intervals. The number of replications needed depends on the desired confidence interval for the outcome variables. However, as the model becomes more complicated, more replications will take more simulation time; this model is fairly simple, so 100 replications take little time and are more than sufficient.

Most simulation software, including Arena, has the capability of using different arrival rate probability distributions for different times of the day and days of the week, allowing for varying demand patterns. However, the team believed that this simple model using only one arrival-rate probability distribution represented the busiest time for the emergency department, having observed that by 2 p.m. on weekdays there were usually no queues in either the waiting room or discharge area. The results of the simulation were reviewed by the team and compared with actual data and observations to ensure that the model was, in fact, simulating the reality of the emergency department. The team was satisfied that the model accurately reflected reality.

The focus of this simulation is the queueing occurring at both the waiting room and in the discharge area and the total time in the system. Figure 11.7 shows the results of this base (current status) model. On average, a patient spent 2.4 hours in the emergency department.

The team decided to examine the discharge process in depth because patient waiting time was greatest there. The emergency department had two rooms devoted to discharge and used two nurses to handle all discharge tasks, such as making sure prescriptions are given and home care instructions are understood. However, because there were only two nurses and four exam rooms, queuing was inevitable. In addition, the patient treatment information needed to be handed off from the treatment team to the discharge nurse. The process improvement team therefore decided to simulate having the discharge process carried out by the examination and treatment team. Because the examination and treatment team knew the patient information, the handoff task would be eliminated. The team estimated that this change would save about five minutes and, therefore, decided to simulate the new system by eliminating discharge as a separate process.

They estimated the probability distribution of the combined exam/treatment/discharge task by first estimating the probability distribution

Replications: 100   Time Unit: Hours

Total Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Routine patient	2.4207	0.08	1.7953	3.4082	1.2004	5.2448

Queue

Time

Waiting Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admitting queue	0.00526930	0.00	0.00048553	0.01668610	0.00	0.2235
Discharge queue	0.3972	0.26	0.06416692	0.8865	0.00	2.0531
Exam and treatment queue	0.3382	0.38	0.04167122	1.1956	0.00	2.5777
Nurse history queue	0.01764541	0.01	0.00272715	0.05309733	0.00	0.3694
Triage queue	0.06437939	0.05	0.01703829	0.1402	0.00	0.6506

Other

Waiting Time	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admitting queue	0.03458032	0.00	0.00267040	0.1001	0.00	2.0000
Discharge queue	2.2481	0.26	0.2888	5.1713	0.00	13.0000
Exam and treatment queue	2.1930	0.38	0.2062	9.4408	0.00	22.0000
Nurse history queue	0.1136	0.01	0.01298461	0.4069	0.00	5.0000
Triage queue	0.5394	0.05	0.1145	1.7216	0.00	10.0000

Resource

Usage

Instantaneous Utilization	Average	Half-Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Discharge nurse 1	0.8285	0.01	0.6715	0.8972	0.00	1.0000
Discharge nurse 2	0.8360	0.01	0.6673	0.9105	0.00	1.0000
Exam room 1	0.8441	0.01	0.6253	0.9497	0.00	1.0000
Exam room 2	0.8329	0.01	0.6548	0.9297	0.00	1.0000
Exam room 3	0.8182	0.02	0.5358	0.9200	0.00	1.0000
Exam room 4	0.8075	0.02	0.6135	0.9156	0.00	1.0000
Financial clerk 1	0.4615	0.01	0.3320	0.5636	0.00	1.0000
Financial clerk 2	0.4580	0.01	0.3286	0.5823	0.00	1.0000
History nurse 1	0.5294	0.01	0.3886	0.6796	0.00	1.0000
History nurse 2	0.5240	0.01	0.3937	0.7107	0.00	1.0000
Triage nurse	0.6267	0.01	0.4861	0.8373	0.00	1.0000

NOTE: Figure created in Arena®, Rockwell Automation.

for handoff as triangular (4, 5, 7 minutes). The team used Input Analyzer to simulate 1,000 observations of exam/treatment time, discharge time, and handoff time using the previously determined probability distributions for each. For each observation, they added exam/treatment time to discharge time and subtracted handoff time to find total time. Input Analyzer found the best-fitting probability distribution for the total time for the new process as triangular (18, 50, 82 minutes).

The team simulated the new process and found that patients would spend an average of 2.95 hours in the emergency department—this change

would actually increase time spent there. However, it would also eliminate the need for discharge rooms. The team decided to investigate the effect of converting the former discharge rooms to exam rooms and ran a new simulation incorporating this change (Figure 11.8). The result of this simulation is shown in Figure 11.9: Both the number of patients in the waiting room (examine and treatment queue) and the amount of time they waited were reduced substantially. The staffing levels were not changed, as the discharge nurses were now treatment nurses. Physician staffing was also not increased, as some delay inside the treatment process itself had always existed due to the need to wait for lab results; this delayed a final physician diagnosis. Having more patients available for treatment filled this lab delay time for physicians with patient care.

The most significant improvement resulting from the process improvement initiative was that total patient throughput time now averaged 1.84 hours (110 minutes). This 33 percent reduction in throughput time exceeded the team's goal and was celebrated by VVH's senior leadership. The summary of process improvement steps is displayed in Table 11.1.
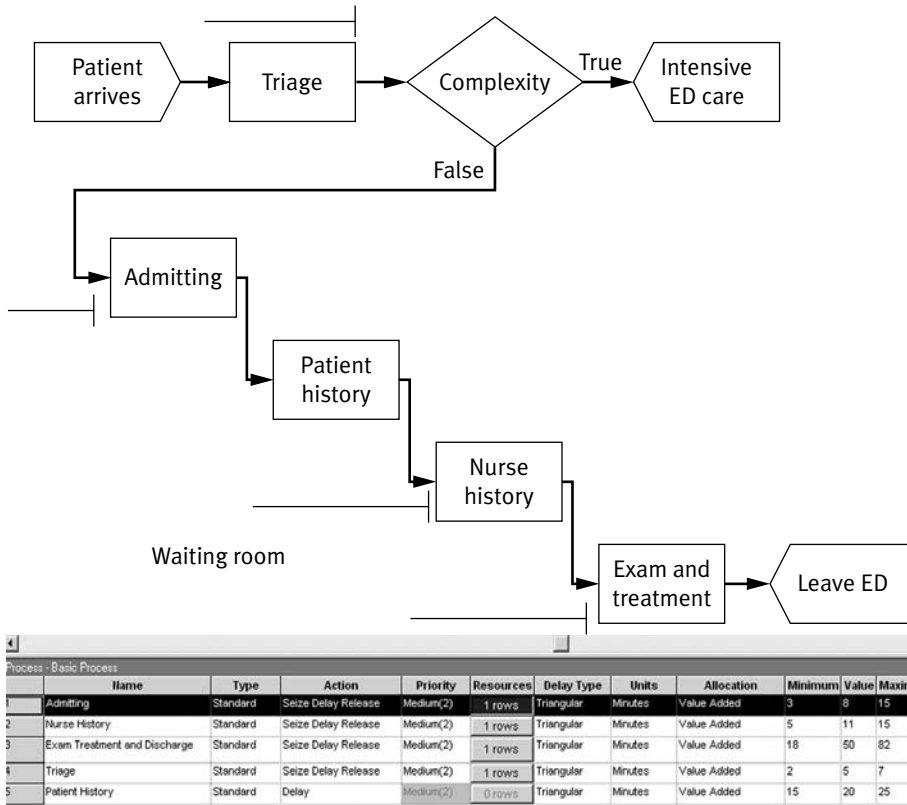
FIGURE 11.8

VVH Emergency Department (ED) Proposed Change Simulation Model

Name	Type	Action	Priority	Resources	Delay Type	Units	Allocation	Minimum	Value	Maximu
Admitting	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	3	8	15
Nurse History	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	5	11	15
Exam Treatment and Discharge	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	18	50	82
Triage	Standard	Seize Delay Release	Medium(2)	1 rows	Triangular	Minutes	Value Added	2	5	7
Patient History	Standard	Delay	Medium(2)	0 rows	Triangular	Minutes	Value Added	15	20	25

NOTE: Figure created in Arena®, Rockwell Automation.

Category Overview

4:11:35 PM   February 8, 2007

Values Across All Replications

VVH Emergency

Replications: 100   Time Unit: Hours

Entity

Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Routine patient	1.8376	0.05	1.5459	2.8729	1.0063	4.5989

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admitting queue	0.00519434	0.00	0.00041085	0.01364095	0.00	0.2235
Exam and treatment and discharge queue	0.2039	0.04	0.00197293	1.1105	0.00	2.2943
Nurse history queue	0.01791752	0.00	0.00244500	0.07537764	0.00	0.3417
Triage queue	0.06635691	0.01	0.01863876	0.2547	0.00	0.8065

Other

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admitting queue	0.03400433	0.00	0.00218978	0.0946	0.00	3.0000
Exam and treatment and discharge queue	1.3571	0.31	0.00838496	7.8288	0.00	19.0000
Nurse history queue	0.1098	0.01	0.01120623	0.5716	0.00	4.0000
Triage queue	0.5629	0.08	0.1227	2.5046	0.00	11.0000

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Exam room 1	0.7827	0.02	0.5405	0.9303	0.00	1.0000
Exam room 2	0.7644	0.02	0.5468	0.9103	0.00	1.0000
Exam room 3	0.7626	0.02	0.5577	0.9052	0.00	1.0000
Exam room 4	0.7478	0.02	0.4984	0.8993	0.00	1.0000
Exam room 5	0.7859	0.02	0.5420	0.9313	0.00	1.0000
Exam room 6	0.8030	0.02	0.4990	0.9472	0.00	1.0000
Financial clerk 1	0.4606	0.01	0.3250	0.5985	0.00	1.0000
Financial clerk 2	0.4529	0.01	0.2968	0.6119	0.00	1.0000
History nurse 1	0.5236	0.01	0.3642	0.6766	0.00	1.0000
History nurse 2	0.5154	0.01	0.3403	0.6982	0.00	1.0000
Triage nurse	0.6226	0.02	0.4742	0.8185	0.00	1.0000

NOTE: Figure created in Arena®, Rockwell Automation.

Process Improvement Change	Throughput Time, Routine Patients
Baseline, before any improvement	165 minutes
Combine admitting functions	155 minutes
Patients enter their own history into computer	145 minutes
Combine discharge tasks into examination and treatment process and convert discharge rooms to treatment rooms	110 minutes

TABLE 11.1
Summary of VVH Emergency Department Throughput Improvement Project

The Arena software packaged with this book contains a demonstration simulation model named Emergency Room. This model is both more realistic and more complicated than the one presented here and demonstrates a more powerful use of the software, including submodels and a high level of animation. Readers are encouraged to explore this model.

Conclusion

The theory of swift, even flow (Schmenner 2001, 2004; Schmenner and Swink 1998) provides a framework for process improvement and increased productivity. The efficiency and effectiveness of a process increase as the speed of flow through the process increases and the variability associated with that process decreases.

The movement of patients in a healthcare facility is one of the most critical and visible processes in healthcare delivery. Reducing flow time and variation in processes has a number of benefits:

- Patient satisfaction increases.
- Quality of clinical care improves as patients have reduced waits for diagnosis and treatment.
- Financial performance improves.

This chapter demonstrates many approaches to the challenges of reducing flow time and process variation. Starting with the straightforward process map, many improvements can be found immediately by inspection. In other cases, the powerful tool of computer-based discrete event simulation can provide a roadmap to sophisticated process improvements.

Ensuring quality of care is another critical focus of healthcare organizations. The process improvement tools and approaches in this chapter could also be used to reduce process variation and eliminate errors. Healthcare

organizations need to employ the disciplined approach described in this chapter to achieve the needed improvements in flow and quality.

Discussion Questions

1. How do you determine which process improvement tools should be used in a given situation? What is the cost and return of each approach?
2. Which process improvement tool can have the most powerful effect and why?
3. How can barriers to process improvement, such as staff reluctance to change, lack of capital, technological barriers, or clinical practice guidelines, be overcome?
4. How can the EMR be used to make significant process improvements for both efficiency and quality increases?

Chapter Exercises

1. Access the National Guideline Clearinghouse (www.guideline.gov/) and translate one of the guidelines described into a process map. In addition, add decision points and alternative paths to deal with unusual issues that might occur in the process. (Use of Microsoft Visio is encouraged here.)
2. Access the following process maps on the companion web site:
   • Operating Suite
   • Cancer Treatment Clinic
   Use basic improvement tools, theory of constraints, Six Sigma, and/or Lean tools to determine possible process improvements (Sepúlveda et al. 1999).
3. Access the following Arena models on the companion web site:
   • Pharmacy Distribution
   • Clinic Billing
   Develop an improvement plan and use Arena to evaluate it. Compare the results from the base model with your results.

References

Clark, J. J. 2005. "Unlocking Hospital Gridlock." *Healthcare Financial Management* 59 (11): 94–104.

Deming, W. E. 1998. "Deming Web Site—The Deming Philosophy." [Online information; retrieved 6/9/06.] deming.ces.clemson.edu/pub/den/deming_philosophy.htm.

Institute for Healthcare Improvement. 2006. *Managing Patient Flow: Smoothing OR Schedule Can Ease Capacity Crunch, Researchers Say.* [Online information; retrieved 7/12/06.] www.ihi.org/IHI/Topics/Flow/PatientFlow/ImprovementStories/ManagingpatientflowSmoothingORschedulecaneasecapacitycrunchesresearcherssay.htm.

———. 2003. *Optimizing Patient Flow: Moving Patients Smoothly Through Acute Care Settings.* Boston: Institute for Healthcare Improvement.

Institute of Medicine. 1999. *To Err Is Human: Building a Safer Health System.* Washington, D.C.: National Academies Press.

Rockwell Automation. 2006. "Arena." [Online information; retrieved 6/6/06.] www.arenasimulation.com/products/basic_edition.asp.

Rodi, S. W., M. V. Grau, and C. M. Orsini. 2006. "Evaluation of a Fast Track Unit: Alignment of Resources and Demand Results in Improved Satisfaction and Decreased Length of Stay for Emergency Department Patients." *Quality Management in Healthcare* 15 (3): 163–70.

Schmenner, R. W. 2004. "Service Businesses and Productivity." *Decision Sciences* 35 (3): 333–47.

———. 2001. "Looking Ahead by Looking Back: Swift, Even Flow in the History of Manufacturing." *Production and Operations Management* 10 (1): 87–96.

Schmenner, R. W., and M. L. Swink. 1998. "On Theory in Operations Management." *Journal of Operations Management* 17 (1): 97–113.

Schmidt, C., and M. Messer. 2005. A Pragmatic Approach to Improving Patient Efficiency Throughput. [Online information; retrieved 6/15/06.] www.ihi.org/IHI/Topics/Flow/PatientFlow/ImprovementStories/APragmaticApproachtoImprovingPatientEfficiencyThroughput.htm.

Sepúlveda, J. A., W. J. Thompson, F. F. Baesler, M. I. Alvarez, and L. E. Cahoon III. 1999. "The Use of Simulation for Process Improvement in a Cancer Treatment Center." In *Proceedings of the 31st Conference on Winter Simulation: Simulation—A Bridge to the Future*, Vol. 2. New York: ACM Press.

Walley, P., K. Silvester, and R. Steyn. 2006. "Managing Variation in Demand: Lessons from the UK National Health Service." *Journal of Healthcare Management* 51 (5): 309–22.

Recommended Reading

Anupindi, R., S. D. Deshmukh, and S. Chopra. 1999. *Managing Business Process Flows,* 1st ed. Upper Saddle River, NJ: Prentice Hall.

12

SCHEDULING AND CAPACITY MANAGEMENT

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

advanced access
appointment scheduling schemes
appointment scheduling systems, see
	appointment scheduling schemes
backlog, bad and good
Bailey-Welch rule
block appointment schedule
capacity
contingency plan
critical ratio (CR)
earliest due date (EDD)
first come, first served (FCFS)
individual appointment schedule
kanban system
linear programming, see mathemati-
	cal programming
Little's law
mathematical programming

mixed block–individual appointment
	schedule
National Association of Public
	Hospitals (NAPH)
optimal outpatient appointment
	scheduling tool
patient demand
PCP coverage
PCP match
primary care physician (PCP)
schedule function (Arena)
sequencing rules
set function (Arena)
shortest processing time (SPT)
slack time remaining (STR)
staff scheduling
tardiness
utilization
wait time for next appointment

Operations Management in Action

In 2001, the National Association of Public Hospitals (NAPH) sponsored the publication of Advanced Access: A New Paradigm in the Delivery of Ambulatory Care Services *(Singer 2001). When that initial report was written, the concept of advanced access was new to NAPH members. However, the monograph generated strong interest among members, and use of the model by safety-net hospitals and health systems has become much more widespread. Specialty services in which NAPH members have begun using advanced access include behavioral health, dermatology, neurology, ophthalmology, orthopedics, and radiology.*

The top two reasons NAPH members have turned to advanced access appear to be a desire to improve patient satisfaction by reducing wait times for appointments and to reduce appointment no-show rates. Given the extraordinary volume of ambulatory visits handled by NAPH clinics, there is a general desire among ambulatory care leaders to remove inefficiencies and drive out waste. With no-show rates as high as 50 percent, health systems are eager to find ways to make demand more predictable and provider workloads steadier while increasing productivity. Other reasons for adopting an advanced access model include the desire to improve provider and staff satisfaction and continuity of care.

The results of implementing these advanced access scheduling systems are remarkable (Tables 12.1 and 12.2) considering the high volume of patients and their complex medical conditions and social situations.

Overview

Matching the supply of goods or services to the demand for those goods or services is a basic operational problem. In a manufacturing environment, inventory can be used to respond to fluctuations in demand. In the healthcare environment, safety stock can be used to respond to fluctuations in demand for supplies (see Chapter 13), but it is not possible to inventory healthcare services. Capacity must, therefore, be matched to demand. If capacity is greater than demand, resources are underutilized and costs are high. Idle staff, equipment, or facilities increase organizational costs without increasing revenues. If capacity is lower than demand, patients incur long waits or find another provider.

To match capacity to demand, organizations can use demand-influencing strategies or capacity management strategies. Pricing and promotions are often used to influence demand and demand timing; however, this is often not

Organization	Preimplementation	Postimplementation
Arrowhead Regional Medical Center (Colton, CA)	28	8
Boston Medical Center (Boston)	25–30	12–15
Cambridge Health Alliance (Cambridge, MA)	30	20
Contra Costa Regional Medical Center (Martinez, CA)	30	15
Denver Health (Denver)	25–35	7–17
NYCHHC–Bellevue Hospital Center (New York)	39	32
NYCHHC–Woodhull Medical & Mental Health Center (Brooklyn, NY)	50	25
Parkland Health & Hospital System (Dallas)	40	20
Riverside County Medical Center (Riverside, CA)	40	18
Santa Clara Valley Health & Hospital System (San Jose, CA)	30–50	14
University of Colorado Hospital (Denver)	8–10	8–10

TABLE 12.1
No-Show Rates (%) Before and After Implementation of Advanced Access Scheduling for Selected NAPH Members as of 2003

SOURCE: Singer and Regenstein (2003). Reprinted with permission from the National Association of Public Hospitals and Health Systems.

Organization	Wait Time
Arrowhead Regional Medical Center (Colton, CA)	0
Boston Medical Center (Boston)	0–2
Cambridge Health Alliance (Cambridge, MA)	2.5
Contra Costa Regional Medical Center (Martinez, CA)	0–1
Denver Health (Denver)	0–1
NYCHHC–Bellevue Hospital Center (New York)	3
NYCHHC–Woodhull Medical & Mental Health Center (Brooklyn, NY)	1–2
Parkland Health & Hospital System (Dallas)	7–14
Riverside County Medical Center (Riverside, CA)	0–7
Santa Clara Valley Health & Hospital System (San Jose, CA)	10
University of Colorado Hospital (Denver)	3–4

TABLE 12.2
Wait Time (Days) for Advanced Access Appointments for Selected NAPH Members as of 2003

SOURCE: Singer and Regenstein (2003). Reprinted with permission from the National Association of Public Hospitals and Health Systems.

a viable strategy for healthcare organizations. In the past, many healthcare organizations used the demand-leveling strategy of appointment scheduling; more recently, many have begun moving to advanced access scheduling. Capacity management strategies allow the organization to adjust capacity to meet fluctuating demand and include using part-time employees, on-call employees, cross-training, and overtime. Effective and efficient scheduling of patients, staff, equipment, facilities, or jobs can help to match capacity to demand and ensure that scarce healthcare resources are utilized to their fullest extent.

This chapter outlines issues and problems faced in scheduling and discusses tools and techniques that can be employed in scheduling patients, staff, equipment, facilities, or jobs. Topics covered include:

• Staff scheduling;
• Job/operation scheduling and sequencing rules;
• Patient appointment scheduling models; and
• Advanced access patient scheduling.

The scheduling of patients is a unique, but important, subproblem of patient flow. Since the mid-twentieth century, much patient care delivery has moved from the inpatient setting to the ambulatory clinic. Because this trend is likely to continue, matching clinic capacity to patient demand becomes a critical operating skill. In addition, if this capacity can be deployed to meet a patient's desired schedule, marketplace advantage can be gained. Therefore, this chapter focuses on advanced access (same-day scheduling) for ambulatory patients. Topics covered include:

• Advantages of advanced access;
• Implementation steps;
• Metrics to measure the operations of advanced access scheduling systems; and
• Arena simulation of an advanced access clinic with alternative staffing and scheduling rules.

Many of the operations tools and approaches detailed in earlier chapters are employed to optimize the operations of an advanced access clinic.

Staff Scheduling

For fairly small schedule-optimization problems, where demand is reasonably known and staffing requirements can therefore be estimated with certainty, mathematical programming (Chapter 6) can be used to optimize staffing levels and schedules. A simple example of this type of problem is illustrated below. A more detailed problem is illustrated in "Using Linear Programming to Minimize the Cost of Nursing Personnel"

(Matthews 2005), and a summary of various optimization models can be found in "Nurse Rostering Problems—A Bibliographic Survey" (Cheang et al. 2003).

As the problems become larger and more complex, developing and using a mathematical programming model becomes time and cost prohibitive. In those cases, simulation can be used to answer "what if" scheduling questions: "What if we added another nurse?" or "What if we cross-trained employees?" See Chapter 11 and the advanced access section of this chapter for examples of these types of applications.

Riverview Clinic Urgent Care Staffing Using Linear Programming

Nurses who staff the Riverview Clinic after-hours urgent care clinic have been complaining about their schedules. They would like to work five consecutive days and have two consecutive days off every seven days. Additionally, different nurses prefer different days off and believe that their preferences should be assigned based on seniority; the most senior nurses should get their most desired days off.

Riverview Urgent Care Clinic (UCC) has collected patient demand data by day of the week and knows how many nurses should be on staff each day to service demand. Riverview UCC management wants to minimize nurse payroll while reducing the nurses' complaints about their schedules. They decide to use linear programming to help determine a solution for this problem. Target staffing levels and salary expenses are shown in Table 12.3.

First, Riverview needs to determine how many nurses should be assigned to each possible schedule. There are seven possible schedules (Monday and Tuesday off, Tuesday and Wednesday off, etc.).

The goal is to minimize weekly salary expense, and the objective function is:

Minimize: ($320 × Sun. # of nurses) + ($240 × Mon. # of nurses) +
($240 × Tues. # of nurses) + ($240 × Wed. # of nurses) +
($240 × Thurs. # of nurses) + ($240 × Fri. # of nurses) +
($320 × Sat. # of nurses)

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Nurses needed/day	5	4	3	3	3	4	6
Salary and benefits/ nurse-day	320	240	240	240	240	240	320

TABLE 12.3
Riverview UCC Target Staffing Level and Salary Expense

The constraints are:

- The number of nurses scheduled each day must be greater than the number of nurses needed each day.

Sunday # of nurses ≥ 5	(1)
Monday # of nurses ≥ 4	(2)
Tuesday # of nurses ≥ 3	(3)
Wednesday # of nurses ≥ 3	(4)
Thursday # of nurses ≥ 3	(5)
Friday # of nurses ≥ 4	(6)
Saturday # of nurses ≥ 6	(7)

- The number of nurses assigned to each schedule must be greater than zero and an integer.

# A (B, C, D, E, F, or G) nurses ≥ 0	(8–14)
# A (B, C, D, E, F, or G) nurses = integer	(15–21)

Figure 12.1 shows the Excel Solver setup of this problem.

Solver (Figure 12.2) finds that the Riverview UCC needs six nurses and should assign one nurse to schedules A, B, C, and D; two nurses to schedule E; and no nurses to schedules F and G. The total salary expense with this optimal schedule is:

$$\text{Minimize: } (\$320 \times 5) + (\$240 \times 4) + (\$240 \times 4) + (\$240 \times 4) +$$
$$(\$240 \times 3) + (\$240 \times 4) + (\$320 \times 6) = \$8,080/\text{Week}$$

Next, Riverview needs to determine which nurses to assign to which schedule based on their preferences and seniority. Each nurse is asked to rank

FIGURE 12.1

Initial Excel Solver Setup of Riverview UCC Optimization

Schedule	Days off	Employees	Daily Schedule							Number of Employees/Day								
			Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat		
A	Sun, Mon	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1		
B	Mon, Tues	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1		
C	Tues, Wed	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1		
D	Wed, Thurs	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1		
E	Thurs, Fri	2	1	1	1	1	0	0	1	2	2	2	2	0	0	2		
F	Fri, Sat	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0		
G	Sat, Sun	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0		

	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Total
Nurses Scheduled/Day:	5	4	4	4	3	4	6	30
Nurses Needed/Day:	5	4	3	3	3	4	6	28
Salary&Benefits/Nurse-Day:	320	240	240	240	240	240	320	
Total Salary & Benefits/Day:	1600	960	960	960	720	960	1920	

Salary & Benefits/Week: $8,080

Employee	Seniority (years)	Seniority factor	Preference of employees					Weighted preference of employees					Schedule assigned to					Total	Preference score
			A	B	C	D	E	A	B	C	D	E	A	B	C	D	E		
Mary	5	0.71	3	1	2	4	5	2.14	0.71	1.43	2.86	3.57	0	0	0	0	0	0	0.00
Anne	6	0.86	3	2	1	4	5	2.57	1.71	0.86	3.43	4.29	0	0	0	0	0	0	0.00
Susan	4	0.57	2	3	5	1	4	1.14	1.71	2.86	0.57	2.29	0	0	0	0	0	0	0.00
Tom	7	1.00	3	2	4	1	5	3.00	2.00	4.00	1.00	5.00	0	0	0	0	0	0	0.00
Cathy	3	0.43	3	4	5	2	1	1.29	1.71	2.14	0.86	0.43	0	0	0	0	0	0	0.00
Jane	2	0.29	5	4	3	2	1	1.43	1.14	0.86	0.57	0.29	0	0	0	0	0	0	0.00
Maximum	7											Actual:	0	0	0	0	0		0
												Needed:	1	1	1	1	2		

schedules A through E in order of preference for that particular schedule. The nurses' preferences on a scale of one to five, with five being the most preferred schedule, are then weighted by a seniority factor. Riverview decides to use a seniority weighting factor based on the number of years a particular nurse has worked at the UCC compared with the number of years the most senior nurse has worked at the UCC.

The goal is to maximize the nurses' total weighted preference scores (WPS), and the objective function is:

Maximize: Mary's WPS + Anne's WPS + Susan's WPS + Tom's WPS + Cathy's WPS + Jane's WPS

The constraints are:

- Each nurse must either be assigned to a particular schedule or not assigned to that schedule.
  Mary assigned to schedule A (B, C, D, or E) = 0 or 1 (binary)   (1–5)
  Anne assigned to schedule A (B, C, D, or E) = 0 or 1 (binary)   (6–10)
  Susan assigned to schedule A (B, C, D, or E) = 0 or 1 (binary) (11–15)
  Tom assigned to schedule A (B, C, D, or E) = 0 or 1 (binary)   (16–20)
  Cathy assigned to schedule A (B, C, D, or E) = 0 or 1 (binary) (21–25)
  Jane assigned to schedule A (B, C, D, or E) = 0 or 1 (binary)   (26–30)
- The number of nurses assigned to each schedule must be as required.
  # of nurses assigned to schedule A (B, C, or D) = 1   (31–34)
  # of nurses assigned to schedule E = 2   (35)
- Each nurse can only be assigned to one schedule.
  Mary (Anne, Susan, Tom, Cathy, or Jane) A + B + D + C + E = 1   (36–41)

Figure 12.2 Shows the Excel setup of this problem.
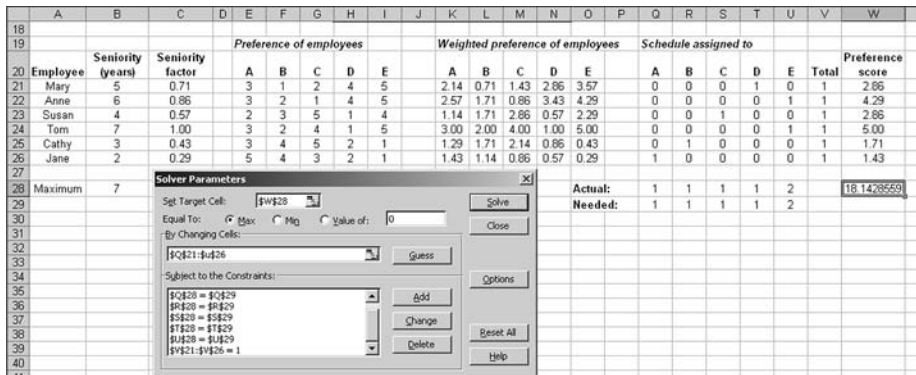
Solver (Figure 12.3) finds that Mary should be assigned to schedule D (her second choice), Anne to schedule E (her first choice), Susan to schedule C (her first choice), Tom to schedule E (his first choice), Cathy to schedule B (her second choice), and Jane to schedule A (her first choice). All of the nurses now have 2 consecutive days off every 7 days and are assigned to either their first or second choice of schedule. Note that even this simple problem has 20 decision variables and 41 constraints.

Job/Operation Scheduling and Sequencing Rules

Job/operation scheduling looks at the problem of how to sequence a pool of jobs (or patients) through a particular operation. For example, a clinic laboratory has many patient blood samples that need to be tested—in what order should the lab work on the samples? Or, a hospital has many surgeries waiting to be performed—in what order should those surgeries occur?

The simplest sequencing problems consist of a pool of jobs waiting for only one resource. Sequencing of those jobs is usually based on a desire to meet due dates (time at which the job is supposed to be complete) by minimizing the number of jobs that are late, minimizing the average amount of time by which jobs will be late, or minimizing the maximum late time of any job. It may also be desirable to minimize the time jobs spend in the system or average completion time.

Various sequencing rules can be used to schedule jobs through the system. Commonly used rules include:

- *First come, first served (FCFS):* Jobs are sequenced in the same order in which they arrive.
- *Shortest processing time (SPT):* The job that takes the least amount of time to complete is first, followed by the job that will take the next least amount time, and so on.

- *Earliest due date (EDD):* The job with the earliest due date is first, followed by the job with the next earliest due date, and so on.
- *Slack time remaining (STR):* The job with the least amount of slack (time until due date – processing time) is first, followed by the job with the next least amount of slack time, and so on.
- *Critical ratio (CR):* The job with the smallest critical ratio (time until due date/processing time) is first, followed by the job with the next smallest critical ratio, and so on.

When there is only one resource or operation for the jobs to be processed through, the SPT rule will minimize average completion time, and the EDD rule will minimize average lateness and maximum lateness; however, no single rule will accomplish both objectives. When jobs (or patients) must be processed through a series of resources or operations with different possible sequencing at each, the situation becomes more complex, and a particular rule will not result in the same outcome for the entire system as for the single resource. Often, simulation is used to evaluate these more complex systems and help determine optimum sequencing.

For a busy resource, the SPT rule is often used. This rule will complete a greater number of jobs in a shorter amount of time, but some jobs with long completion times may never be finished. To alleviate this problem, the SPT rule is often used in combination with other rules. For example, in some emergency departments, less severe cases (those with a shorter processing time) are separated and fast tracked to free up examination rooms quickly.

For time-sensitive operations, where lateness is not tolerated, the EDD rule is appropriate. Because it is the easiest to apply, the FCFS rule is typically used when the resource has excess capacity and no jobs will be late. In a Lean environment, sequencing rules become irrelevant because the ideal size of the pool of jobs is reduced to one and a kanban system (a form of FCFS) can be used to pull jobs through the system (Chapter 9).

Vincent Valley Hospital and Health System Laboratory Sequencing Rules

The laboratory at Vincent Valley Hospital and Health System (VVH) recently lost one of its lab technicians, and the lab manager, Jessica Simmons, does not believe she will be able to find a qualified replacement for at least one month. This has greatly increased the workload in the lab, and physicians have been complaining that their requested blood work is not being completed in a timely manner.

In the past, Jessica has divided the blood testing among the technicians and had them complete the tests on an FCFS basis. She is considering using a different sequencing rule to try to satisfy more of the physicians. In anticipation of this change, she requested that each physician put a desired completion time on each request for blood testing. To investigate the effects of changing the sequencing rules, she decides to take the first five requests for bloodwork from

one of the technicians and analyze job completion under various scheduling rules. Note that, for five jobs, there are 120 possible sequences in which the jobs could be completed. Table 12.4 shows the time to complete blood work on each sample and the time when the physician has requested that it be complete.

Table 12.5 shows the order in which jobs will be processed and results under different sequencing rules. Table 12.6 compares the various sequencing rules. The FCFS rule performs poorly on all measures. The SPT rule minimizes average completion time, and the EDD rule minimizes average tardiness. Under both rules, three jobs are tardy and the maximum tardiness is 150 minutes. After looking at these results, Jessica decides to implement the EDD rule for laboratory blood tests to minimize the number of tardy jobs and the average tardiness of jobs. She hopes this will reduce physician complaints until a new technician can be hired.

Patient Appointment Scheduling Models

Appointment scheduling models attempt to minimize patient waiting time while maximizing utilization of the resource (clinician, machine, etc.) the patients are waiting to access. Soriano (1966) classifies appointment scheduling systems into four basic types: block appointment, individual appointment, mixed block–individual appointment, and other.

A block appointment scheme schedules the arrival of all patients at the start of a clinic session. Patients are usually seen FCFS, but other sequencing rules can be used. This type of scheduling system maximizes utilization of the clinician, but patients can experience long wait times. An individual appointment scheme assigns different, equally spaced appointment times to each individual patient. In a common modification of this type of system, different appointment lengths are available and assigned based on the type of patient. This system reduces patient waiting time but decreases utilization of the clinician. Increasing the interval between arrivals results in a reduction of both waiting time and utilization. A mixed block–individual appointment scheme schedules a group of

	TABLE 12.4 VVH Laboratory Blood Test Information			
Sample	Processing Time (Minutes)	Due Time (Minutes from Now)	Slack	CR
A	50	100	100 − 50 = 50	100/50 = 2.00
B	100	160	160 − 100 = 60	160/100 = 1.60
C	20	50	50 − 20 = 30	50/20 = 2.50
D	80	120	120 − 80 = 40	120/80 = 1.50
E	60	80	80 − 60 = 20	80/60 = 1.33

Sequence	Start Time	Processing Time	Completion Time	Due Time	Tardiness
FCFS					
A	0	50	50	100	
B	50	100	150	160	
C	150	20	170	50	170 − 50 = 120
D	170	80	250	120	250 − 120 = 130
E	250	60	310	80	310 − 80 = 230
		Average	186		(120 + 130 + 230)/5 = 96
SPT					
C	0	20	20	50	
A	20	50	70	100	
E	70	60	130	80	130 − 80 = 50
D	130	80	210	120	210 − 120 = 90
B	210	100	310	160	310 − 160 = 150
		Average	148		(50 + 90 + 150)/5 = 58
EDD					
C	0	20	20	50	
E	20	60	80	80	
A	80	50	130	100	130 − 100 = 30
D	130	80	210	120	210 − 120 = 90
B	210	100	310	160	310 − 160 = 150
		Average	150		(30 + 90 + 150)/5 = 54
STR					
E	0	60	60	80	
C	60	20	80	50	80 − 50 = 30
D	80	80	160	120	160 − 120 = 40
A	160	50	210	100	210 − 100 = 110
B	210	100	310	160	310 − 160 = 150
		Average	164		(30 + 40 + 110 + 150)/5 = 66
CR					
E	0	60	60	80	
D	60	80	140	120	140 − 120 = 20
B	140	100	240	160	240 − 160 = 80
A	240	50	290	100	290 − 100 = 190
C	290	20	310	50	310 − 50 = 260
		Average	208		(20 + 80 + 190 + 260)/5 = 110

All times in table are in minutes.

TABLE 12.6
Comparison
of VVH
Blood Test
Sequencing
Rules

Sequencing Rule	Average Completion Time	Average Tardiness	Number of Tardy Jobs	Maximum Tardiness
FCFS	186	96	3*	230
SPT	148*	58	3*	150*
EDD	150	54*	3*	150*
STR	164	66	4	150*
CR	208	110	4	260

*Best values. Times are in minutes.

patients to arrive at the start of the clinic session, followed by equally spaced appointment times for the remainder of the session. This type of system can be used to balance the competing goals of increased utilization and decreased waiting time. Other appointment schemes are modifications of the first three types.

Simulation has been used to study the performance of various appointment scheduling models and rules. See Cayirli and Veral (2003) for a review of these studies. More recently, Hutzschenreuter (2004) and Kaandorp and Koole (2007a) evaluated some of these rules, taking into account realistic environmental factors such as no-shows and variable service time. Although no scheduling rule or scheme was found to be universally superior, the Bailey-Welch rule (Bailey and Welch 1952) performed well under most conditions. This rule schedules two patients at the beginning of a clinic session, followed by equally spaced appointment times for the remainder of the session.

Kaandorp and Koole (2007b) developed a mathematic model to determine an optimal schedule using a weighted average of expected waiting times of patients, idle time of the clinician, and tardiness (the probability that the clinician has to work later than scheduled multiplied by the average amount of added time) as the objective. This tool uses simulation to compare a user-defined schedule to the optimal schedule found using the model and is available online at http://obp.math.vu.nl/healthcare/software/ges/.

Riverview Clinic Appointment Schedule

Physicians at VVH's Riverview Clinic typically see patients for six consecutive hours each day. Each appointment takes an average of 20 minutes; therefore, each clinician is scheduled to see 18 patients/day. Two percent of patients are no-shows. Currently, Riverview is using an individual appointment scheme with appointments scheduled every 20 minutes. However, clinicians have been complaining that they often have to work late but are idle at various points during the course of the day. Riverview decides to use the Optimal Outpatient Appointment Scheduling Tool (Kaandorp and Koole 2007b) to see if a better scheduling model could be used to alleviate these complaints without increasing patient waiting time to an unacceptable level.

Figure 12.4 shows the results of this analysis when waiting time weight is 1.5, idle time weight is 0.2, and tardiness weight is 1.0. The optimal schedule follows the Bailey-Welch rule. Under this rule, patient waiting is increased by 5 minutes, but both idleness and tardiness are decreased. Riverview does not believe that the additional waiting time

FIGURE 12.4

Riverview Clinic Appointment Scheduling

		Optimal outpatient appointment scheduling tool	
Average service time	20 minutes		
Number of intervals	18		
Length of interval	20 minutes	Press the button to	
Total number of arrivals	18	compute the solutions	
Percentage no-shows	2 %		
alpha waiting	1.5	Finished searching.	
alpha idle time	0.2		
alpha tardiness	1		

Interval	Time	☑ Number of patients of your choice (calc time: several seconds)	☑ ⦿ Small Neighborhood (Suboptimal, calc time: several minutes) ○ Full Neighborhood (Optimal, calc time: several hours)
1	0:00	1	2
2	0:20	1	1
3	0:40	1	1
4	1:00	1	1
5	1:20	1	1
6	1:40	1	1
7	2:00	1	1
8	2:20	1	1
9	2:40	1	1
10	3:00	1	1
11	3:20	1	1
12	3:40	1	1
13	4:00	1	1
14	4:20	1	1
15	4:40	1	1
16	5:00	1	1
17	5:20	1	1
18	5:40	1	0

Waiting time	31 minutes	35.85 minutes	
Idle time	57.53 minutes	40.53 minutes	
Tardiness	52.47	40.96	
Fraction of excess	79.82 %	63.75 %	
Makespan	410.33 minutes	393.33 minutes	
Lateness	50.33 minutes	33.33 minutes	
Object Value	110.47	102.84	

is unacceptable and decides to implement this new appointment scheduling scheme.

Advanced Access Patient Scheduling

Advanced Access for an Operating and Market Advantage

In the early 1990s, Mark Murray, M.D., M.P.A., and Catherine Tantau, R.N., developed the concept of advanced access at Kaiser Permanente in Northern California. Their goal was to eliminate long patient waits for appointments and bottlenecks in clinic operations (Singer 2001). The principles they developed and refined have now been implemented by many leading healthcare organizations globally.

Because most clinics today use traditional scheduling systems, long wait times are prevalent, and appointments are only available weeks, or even months, in advance. The further in advance visits are scheduled, the greater the fail (no-show) rate becomes. To compensate, providers double- or even triple-book appointment slots. Long delays and queues occur when all patients scheduled actually appear for the same appointment slot. This problem is compounded by patients who have urgent needs requiring that they be seen immediately. These patients are either worked into the schedule or sent to an emergency department, decreasing both continuity of care and revenue to the clinic. At the emergency department, patients are frequently told to see their primary care physicians (PCPs) in one to three days, further complicating the problem.

Advanced access is implemented by beginning each day with a large portion of each provider's schedule open for urgent, routine, and follow-up appointments. Patients are seen when they want to be seen. This dramatically reduces the fail rate, as patients do not have to remember clinic visits they booked long ago. Because there is no double- or triple-booking, patients are seen on time and schedules run smoothly inside the clinic. Clinics using advanced access can provide patients with the convenience of walk-in or urgent care, with the added advantage of maintaining continuity of care with their own doctors and clinics.

Parente, Pinto, and Barber (2005) studied the implementation of advanced access in a large Midwestern clinic with a patient panel of 10,000. After implementation of this system, the average number of days between calling for an appointment and actually being seen by a doctor decreased from 18.7 to 11.8. However, the most significant finding was that 91.4 percent of patients now saw their own PCP, as opposed to 69.8 percent before the implementation of advanced access.

Implementing Advanced Access

Implementing advanced access is difficult. Changing from a long-standing system, albeit a flawed one, is challenging. However, following a few well-

prescribed steps increases the probability of success. In a study of large urban public hospitals, Singer (2001) developed the following methodology to implement advanced access.

Obtain buy-in

Leadership is key to making this major change, and the advanced access system must be supported by senior leaders and providers themselves. It may be helpful to tour other clinics that have implemented advanced access to get a sense of how this system can work successfully.

For large systems, it is best to start small in one or two clinical settings. Once initial operating problems are resolved and clinic staff is positive about the change, advanced access can be carefully implemented in a number of additional clinics in the system.

Predict demand

The first quantitative step in implementation is to measure and predict demand from patients. For each day during a study period, demand is calculated as the volume of patients requesting appointments (today or in the future), walk-in patients, patients referred from urgent care clinics or emergency departments, and number of calls deflected to other providers. After initial demand calculations are performed, they can be made more sophisticated by considering day of the week, seasonality, demand for same-day versus scheduled appointments, and even clinical characteristics of patients.

Predict capacity

The capacity of the clinic needs to be determined once demand is calculated. In general, this is the sum of appointment slots available each day. Capacity can vary dramatically from day to day, as providers usually have obligations for their time other than seeing patients in the clinic.

Determining whether a clinic's capacity can meet expected demand is relatively easy using Little's law (described in detail in Chapter 11). Singer (2001) reported that many public hospital clinics initially felt that demand exceeded capacity in their operations. However, many of these clinics found hidden capacity in their systems by more effectively using providers (e.g., minimizing paperwork) and using for exams space that had been used for storage.

Another opportunity to improve the capacity of a clinic is to standardize and minimize the length of visit times. A clinic with high variability in appointment times will find that it has many small blocks of unused time (Sanderson 2007).

Assess operations

The implementation of advanced access provides the opportunity to review and improve the core patient flow and operations in a clinic. The tools and techniques of process mapping and process improvement, particularly value

stream mapping and the theory of constraints, should be applied before advanced access is implemented.

Work down the backlog

Working down the backlog is one of the most challenging tasks in implementing advanced access, as providers must see more patients per day until they have caught up to same-day access. For example, each provider could work one extra hour per day and see three additional patients until the backlog is eliminated. The number of days to work off a backlog can be calculated by:

$$\text{Days to work down backlog} = \text{Current backlog/Increase in capacity}$$

where

$$\begin{aligned}\text{Current backlog} = \text{Appointments on the books/} \\ \text{Average number of patients seen per day}\end{aligned}$$

and

$$\begin{aligned}\text{Increase in capacity} = (\text{New service rate [Patients/Day]/} \\ \text{Old service rate [Patients/Day]}) - 1\end{aligned}$$

Going live

Once a clinic is ready to go live, it must first determine how many appointment slots to reserve for same-day access. Singer and Regenstein (2003) report that public hospital clinics are leaving 40 percent to 60 percent of their slots available for same-day access, but other clinics have reported leaving up to 75 percent of slots available.

It is important to educate patients, as they will be surprised by the ability to see a provider the day they request an appointment. Many elderly patients may not choose this option, as they may need more time for preparation or to arrange transportation.

No clinic operates in a completely stable environment, so it is useful to prospectively develop contingency plans in case a provider is ill or called away on an emergency. Contingencies can also be predictable increases in demand such as routine physicals in the weeks preceding the start of school. Good contingency planning will ensure the smooth and efficient operation of an advanced access system.

Metrics

Gupta et al. (2006) developed a set of key indicators that can be used to evaluate the performance of advanced access scheduling systems:

- *PCP match:* percentage of same-day patients who see their own PCP
- *PCP coverage:* percentage of same-day patients seen by any physician
- *Wait time for next appointment* (or third next available appointment)
- *Good backlog:* appointments scheduled in advance because of patient preference
- *Bad backlog:* appointments waiting because of lack of slots

Most well-functioning advanced access systems have high PCP match and PCP coverage. Depending on patient mix and preferences the good backlog can be relatively large, but a large or growing bad backlog can be a signal that capacity or operating systems in the clinic need to be improved.

Advanced Access at Vincent Valley-East

VVH operates a small primary care clinic—VVH-East—on the city's east side. The clinic has four family physicians. Dr. Smith is the senior provider, and he has a high number of elderly patients. Because he is also VVH's medical director for quality, he works a limited schedule each week and is not accepting any new patients. Drs. Anderson and Billings have both worked at the clinic for a number of years and have relatively full patient panels. Dr. Kumarin was recently added to the clinic to accommodate growth.

The staff at VVH-East has decided to implement advanced access as a model for the rest of the VVH primary care system. However, before implementation of this new scheduling system, VVH-East decided to develop a simulation model using Arena to determine the optimal mix of providers and scheduling rules. Dr. Smith led this simulation work, as he had been impressed with results achieved in the VVH emergency department. He was concerned that advanced access might hinder his long-standing relationships with many of his elderly patients.

Arena advanced access simulation model

Before constructing the model, the advanced access team identified the goals of the simulation.

- In consideration of Dr. Smith's long-standing work at the clinic, the simulation would focus on how well the new advanced access model allowed him to maintain primary care continuity (PCP match) with his patients and ensure that most could be seen on the same day as requested.
- The simulation results would help to determine the best policies for balancing work among the four physicians and ensure that as many patients as possible could be seen during the providers' work schedules.

The unit of simulation was one week, and all appointments were assumed to be requested as same day. Although approximately 25 percent of

appointments would likely be scheduled in advance (good backlog), assuming 100 percent same-day requests was a way to test the flexibility and performance of the system.

This simulation is an approximate, but not exact, model of the operations of the clinic. If two patients appear at the clinic simultaneously and want to see the same doctor, this model assumes that one is seen and the other is put into a queue. In actuality, because most same-day scheduling is done on the phone, the clinic scheduling staff would ask the patient if a slightly different time would work; most patients would willingly accept this slight change. Therefore, the queue statistics in this model are not strictly representative of the detailed clinic operations but give a good feel for how much difficulty the clinic scheduling staff will have in finding a slot for patients on the day they request. Modeling every slot in a same-day schedule is possible but requires a much more complex model. The interested reader is directed to Chapter 5 of *Simulation with Arena* (Kelton, Sadowski, and Sturrock 2004). The level of simulation presented here tracks actual operations closely enough to allow the VVH-East team to model different staffing and coverage scenarios to make reasonable decisions.

The model contains five patient flows—one for each doctor's existing patients and one for new patients. The physicians have determined a backup schedule in case they are busy. Most patients are willing to be treated by the backup doctor. The Arena model is shown in Figure 12.5. The construction and operation of this model are available on the companion web site.

FIGURE 12.5
VVH-East Base
Simulation of
Advanced
Access
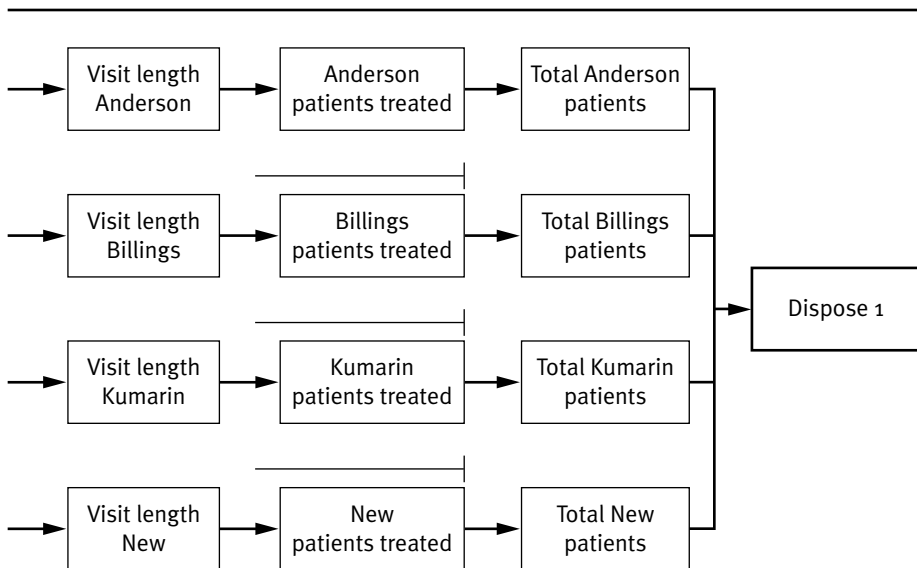
NOTE: Model created in Arena®, Rockwell Automation, Inc.

Arena allows the user to provide multiple resources for each process using the "set" function. The initial backup rules for the doctors are displayed in Table 12.7. In addition, Arena provides the capability to specify when a resource is available with the "schedule" function. The modeling team decided to model one week, with each day containing eight one-hour slots (9 a.m. to noon and 1 p.m. to 6 p.m.). The initial physician schedules are shown in Table 12.8.

TABLE 12.7
Initial Physician Backup Rules

Patient's Primary Physician	Primary Backup	Secondary Backup	Tertiary Backup
Smith	Smith	Anderson	Billings
Billings	Billings	Kumarin	
Anderson	Anderson	Billings	
Kumarin	Kumarin		
New patient	Billings	Kumarin	

TABLE 12.8
Initial Physician Schedule

	Monday Hours								Tuesday Hours							
Physician	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Anderson						1	1	1	1	1	1	1	1	1		
Billings	1	1	1	1	1				1	1	1	1				
Kumarin	1	1	1	1	1	1					1	1	1	1	1	1
Smith						1	1	1			1	1	1	1	1	1

	Wednesday Hours								Thursday Hours							
Physician	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Anderson					1	1	1						1	1	1	1
Billings	1	1	1	1					1	1	1	1				
Kumarin	1	1	1	1	1	1			1	1	1	1	1	1	1	1
Smith					1	1	1	1						1	1	

	Friday Hours								Total Weekly Hours
Physician	1	2	3	4	5	6	7	8	
Anderson	1	1	1	1					20
Billings	1	1	1	1					21
Kumarin			1	1	1	1	1	1	32
Smith									15
All									88

Data on arrival rate and service time were collected by physician and patient type. Probability distributions for each doctor's patient arrival rate and service time were determined using Arena's Input Analyzer (Table 12.9). Dr. Smith's patients had longer treatment times, as they were predominantly elderly. New patients also had longer treatment times, as initial clinical histories needed to be gathered.

Because the VVH-East team wanted to track specifically what happened to Dr. Smith's patients during the simulation runs, a submodel for the flow of his patients was created. This submodel, which routed patients to backup physicians based on availability (Figure 12.6), simulates the set func-

TABLE 12.9
Initial Arrival Rate and Service Time Distributions

Physician	Arrival Rate Exponential Distribution Mean (Hours)	Triangular Distribution of Service Time: Minimum, Mode, Maximum (Hours)
Smith	1.0	0.15, 0.50, 0.80
Billings	1.2	0.10, 0.20, 0.60
Anderson	1.0	0.10, 0.20, 0.60
Kumarin	2.0	0.15, 0.50, 0.80
New patient	0.8	0.25, 0.50, 1.00

FIGURE 12.6
VVH-East Advanced Access Submodel for Dr. Smith's Patients
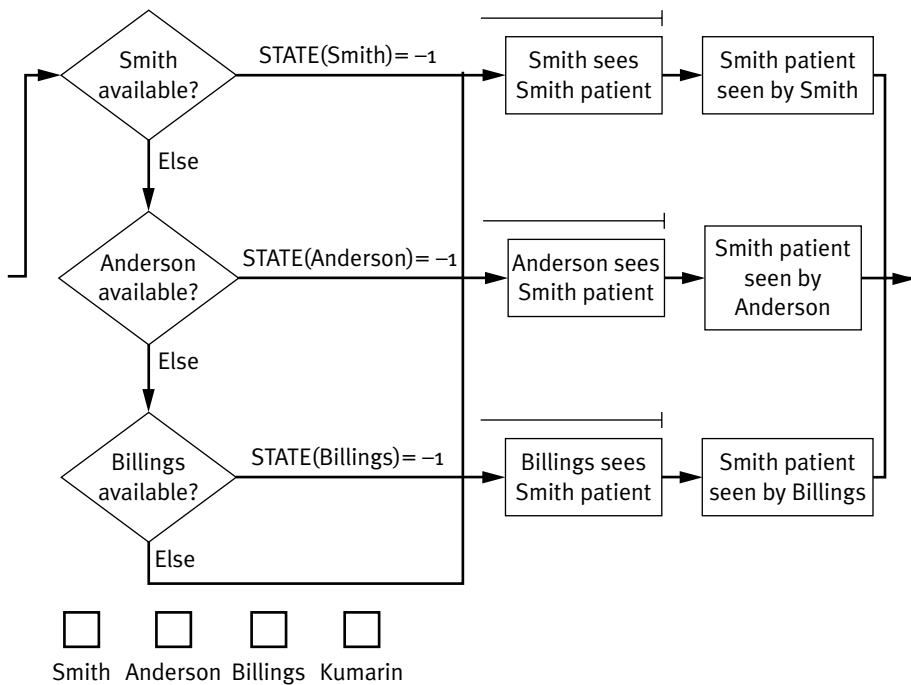
NOTE: Model created in Arena®, Rockwell Automation, Inc.

tion in Arena but also records the needed data. First running this submodel at slow speed, a useful feature of the software, allowed the team to observe that patient flow and physician coverage were operating as predicted.

The submodel is designed to check in turn whether each doctor is busy and, if so, move the patient to the next doctor in the backup schedule. If all physicians are busy, the patient is returned to Dr. Smith's queue. This allows Dr. Smith to see as many of his own patients as possible. Another advantage of the Arena animation feature is that the entire model can be run incrementally, one step at time, with a focus on queues that may occur. The timing of large queues can then be matched to provider staffing schedules to suggest modifications and improvements.

Results from base simulation

The simulation was replicated 100 times with these parameters; results are shown in Figure 12.7. The modeling team made a number of important observations regarding this base case. First, Dr. Smith was seeing an average of 33.4 patients each week (Figure 12.7). Because he was only working 15 hours per week and his patients averaged 0.5 hour per visit, he could not keep up; some of these patients were being moved to future weeks for appointments. This was also indicated by Dr. Smith's long average queue time of 3.5 hours. Although the scheduling staff probably could work hard to minimize this effect, Dr. Smith's bad backlog was likely increasing by at least 3.4 patients/week.

$$\left[\frac{33.4 \text{ Patients}}{\text{Week}} - \left(\frac{15 \text{ Hours}}{\text{Week}} \right) \times \frac{2 \text{ Patients}}{\text{Hour}} \right] = 3.4 \text{ Patients/Week}$$

Some of Dr. Smith's patients were being seen by his colleagues. Of the 44.8 patients who wanted to see Dr. Smith, only 33.4 actually saw him—a PCP coverage ratio of 74.5 percent. Another interesting observation was that although three of the four doctors were quite busy, Dr. Anderson was busy for only 56.5 percent of her scheduled hours.

Improved and optimized model

The VVH-East staff decided to simulate the following changes to this base model:

1. Dr. Anderson was moved to the first choice for new patients, as this was where the highest volume was and she had room in her schedule. Dr. Billings was removed from new patients.
2. As consequence of adding new patients to Dr. Anderson, Dr. Billings was now allocated as the first backup to Dr. Smith. The new coverage rules are displayed in Table 12.10.

FIGURE 12.7
VVH-East
Advanced
Access
Simulation:
Arena Output
of Base Case,
Patients Seen
by Each
Physician

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Smith patient seen by Smith	33.4500	0.77	26.0000	43.0000
Smith patient seen by Anderson	10.4500	0.56	5.0000	18.0000
Smith patient seen by Billings	1.9400	0.22	1.0000	6.0000
Total Anderson patients	33.3400	1.20	21.0000	47.0000
Total Billings patients	37.4700	1.22	23.0000	53.0000
Total Kumarin patients	20.5400	0.82	11.0000	34.0000
Total New patients	47.6300	1.16	36.0000	62.0000
Total Smith patients	45.8400	1.09	36.0000	58.0000

Scheduled Physician Utilization	Average	Half Width	Minimum Average	Maximum Average
Anderson	0.5653	0.02	0.3381	0.8118
Billings	0.9911	0.01	0.8545	1.0659
Kumarin	0.9695	0.01	0.8031	1.0505
Smith	0.9001	0.02	0.6758	1.0989

Queue

Watiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Anderson patients treated.Queue	0.8739	0.06	0.3526	1.9739	0.00	5.2846
Anderson sees Smith patient.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Billings patients treated.Queue	2.2280	0.20	0.5012	4.7427	0.00	8.2147
Billings sees Smith patient.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Kumarin patients treated.Queue	2.4131	0.20	0.5130	5.2605	0.00	9.0715
New patients treated.Queue	2.1809	0.19	0.6180	4.7080	0.00	8.2618
Smith sees Smith patient.Queue	3.5750	0.27	1.2700	8.5842	0.00	17.3846

NOTE: Model created in Arena®, Rockwell Automation, Inc.

TABLE 12.10
New Physician
Backup Rules

Patient's Primary Physician	Primary Backup	Secondary Backup	Tertiary Backup
Smith	Smith	Billings	Anderson
Billings	Billings	Kumarin	
Anderson	Anderson	Billings	
Kumarin	Kumarin		
New patient	Anderson	Kumarin	

3. Because the entire system seemed understaffed based on the queue times, it was agreed that Drs. Anderson and Billings would increase their hours of work in the clinic (Table 12.11).

The revised model was replicated 100 times; results are shown in Figure 12.8. The team observed that this staffing system improved key metrics in the VVH-East advanced access system. Dr. Smith was now seeing an average of only 28.6 patients per week, which should help to eliminate his bad backlog. This was also indicated by a reduction in his effective queue time from 3.5 to 2.4 hours. The utilization of all staff was now more balanced, and no single physician had a utilization rate of more than 91 percent. Because the scheduled utilization of Dr. Billings dropped from 99 percent to 75 percent, he asked the simulation team to rerun the model with his hours reduced to the base case, allowing him to have Friday afternoons off.

TABLE 12.11 Optimized Case Physician Schedule*

Physician	Monday Hours 1	2	3	4	5	6	7	8	Tuesday Hours 1	2	3	4	5	6	7	8
Anderson	1	1	1	1	1				1	1	1	1	1	1		
Billings	1	1	1	1	1	1			1	1	1	1				
Kumarin						1	1	1		1	1	1	1	1	1	
Smith						1	1	1		1	1	1	1	1	1	

Physician	Wednesday Hours 1	2	3	4	5	6	7	8	Thursday Hours 1	2	3	4	5	6	7	8
Anderson					1	1	1				N	N	1	1	1	1
Billings	1	1	1	1					1	1	1	1				
Kumarin	1	1	1	1	1	1			1	1	1	1	1	1	1	1
Smith					1	1	1	1					1	1		

Physician	Friday Hours 1	2	3	4	5	6	7	8	Total Weekly Hours
Anderson	1	1	1	1					24
Billings	1	1	1	1		N	N	N	24
Kumarin			1	1	1	1	1	1	32
Smith									15
All									95

*New hours indicated by N.

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Smith patient seen by Smith	28.6300	0.94	18.0000	43.0000
Smith patient seen by Anderson	2.9500	0.38	0.00	10.0000
Smith patient seen by Billings	6.6600	0.47	2.0000	14.0000
Total Anderson patients	33.4100	1.04	19.0000	47.0000
Total Billings patients	40.4200	1.37	23.0000	56.0000
Total Kumarin patients	20.8700	0.95	9.0000	33.0000
Total New patients	48.9400	1.36	34.0000	66.0000
Total Smith patients	38.2400	1.14	25.0000	52.0000

Scheduled Physician Utilization	Average	Half Width	Minimum Average	Maximum Average
Anderson	0.8274	0.02	0.5471	1.0260
Billings	0.7526	0.02	0.5731	0.9364
Kumarin	0.9008	0.01	0.6737	1.0235
Smith	0.7658	0.03	0.4841	1.0841

Queue

Watiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Anderson patients treated.Queue	0.5937	0.06	0.2012	1.8313	0.00	4.0748
Anderson sees Smith patient.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Billings patients treated.Queue	0.6397	0.60	0.2287	1.7219	0.00	4.5518
Billings sees Smith patient.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Kumarin patient treated.Queue	1.3949	0.11	0.1771	3.0453	0.00	7.3276
New patients treated.Queue	0.8708	0.08	0.2487	2.4176	0.00	5.3610
Smith sees Smith patient.Queue	2.4854	0.19	0.8435	5.1536	0.00	13.0790

NOTE: Model created in Arena®, Rockwell Automation, Inc.

Conclusion

Advanced access is a more efficient and patient-friendly method to deliver ambulatory care. However, it is difficult to implement and maintain unless leadership and staff are committed to its success. The use of simulation tools such as Arena can help clinic leaders explore various options such as scheduling rules to optimize their advanced access systems.

Discussion Questions

1. What job sequencing rule do you see most often in healthcare? Why? Can you think of any additional job sequencing rules not described in this text?

2. How could advanced access techniques be used for:
    a. An ambulatory surgery center?
    b. A freestanding imaging center?
3. What are the consequences of using advanced access in a multispecialty clinic? How could these tools be applied to provide same-day scheduling?
4. Can advanced access techniques be used with appointment scheduling schemes? Why or why not?

Chapter Exercises

1. Two of the nurses (Mary and Joe) at Riverview UCC have decided to work part-time rather than full-time. They would like to work only two (consecutive) days per week. Because they would be part-time employees, salary and benefits per nurse-day for these nurses would be reduced to $160 on weekdays and $220 on weekend days. Riverview could hire an additional full-time nurse if needed. Should Riverview UCC agree to this request? If the clinic does agree, will additional nurses need to be hired? Assuming that part-time nurses and any new hires will accept any schedule and preferences for the remainder of the nurses are the same, what new schedule would you recommend for each nurse?
2. The VVH radiology department currently uses FCFS to determine how to sequence patient x-rays. On a typical day, the department collects data related to patient x-rays. Use these data to compare various sequencing rules. Assuming these data are representative, what rule should the radiology department be using and why? (An Excel spreadsheet containing these data can be found on ache.org/books/OpsManagement.) Use these data to compare various sequencing rules. Assuming these data are representative, what rule should the radiology department be using and why?

Patient	Processing Time (Minutes)	Due Time (Minutes from Now)
A	35	140
B	15	180
C	35	360
D	25	290
E	30	420
F	25	20
G	35	180
H	30	290
I	20	110

(Continued)

Patient	Processing Time (Minutes)	Due Time (Minutes from Now)
(*Continued*)		
K	25	150
L	15	270
M	30	390
N	20	220
O	20	400
P	10	330
Q	10	80
R	15	230
S	20	370

3. Go to ache.org/books/OpsManagement to use the Optimal Outpatient Appointment Scheduling Tool (Kaandorp and Koole 2007b) to compare various appointment scheduling schemes. First, assume an eight-hour day that can be divided into 10-minute time blocks (48 time intervals), 15-minute service time for patients, 24 patients seen according to the individual appointment scheme (a patient is scheduled to be seen every 20 minutes), and 5 percent no-shows. Compare this to the small neighborhood optimal schedule with waiting time weight of one, idle time weight of one, and tardiness weight of one. What are the differences in the two schedules? Which would you choose? Why? Increase the waiting time weight to three and compute small neighborhood optimal schedule. How is this optimal schedule different from the previous one? Finally, change the service time to 20 minutes and compare the individual appointment schedule scheme to the small neighborhood optimal schedule with a waiting time weight of one and three. Which schedule would you choose and why?

4. A clinic wants to work down its backlog to implement advanced access. The clinic currently has 1,200 booked appointments and sees 100 patients a day. The staff has agreed to extend their schedules and can now see 110 patients per day. What is their current backlog, and how many days will it take to reduce this to 0?

5. Use the VVH-East Arena model and remove all physician backups. How would you evaluate the results based on the advanced access metrics?

6. Use the VVH-East Arena model and modify it by increasing patient demand for Drs. Anderson and Billings by 20 percent. Modify provider schedules and rules to accommodate this increase, and evaluate the results based on the advanced access metrics.

References

Bailey, N. T. J., and J. D. Welch. 1952. "Appointment Systems in Hospital Outpatient Departments." *Lancet* 259: 1105–8.

Cayirli, T., and E. Veral. 2003. "Outpatient Scheduling in Health Care: A Review of the Literature." *Production and Operations Management* 12: 519–49.

Cheang, B., H. Li, A. Lim, and B. Rodrigues. 2003. "Nurse Rostering Problems— A Bibliographic Survey." *European Journal of Operational Research* 151 (1): 447–60.

Gupta, D., S. Potthoff, D. Blowers, and J. Corlett. 2006. "Performance Metrics for Advanced Access." *Journal of Healthcare Management* 51 (4): 246–59.

Hutzschenreuter, A. 2004. "Waiting Patiently: An Analysis of the Performance Aspects of Outpatient Scheduling in Healthcare Institutes." Master's thesis, Virje Universiteit, Amsterdam.

Kaandorp, G. C., and G. Koole. 2007a. "Optimal Outpatient Appointment Scheduling." *Health Care Management Science* 10 (3): 217–29.

———. 2007b. "Optimal Outpatient Appointment Scheduling Tool." [Online information; retrieved 6/24/07.] http://obp.math.vu.nl/healthcare/software/ges/.

Kelton, D. W., R. P. Sadowski, and D. P. Sturrock. 2004. *Simulation with Arena,* 3rd ed. New York: McGraw Hill.

Matthews, C. H. 2005. "Using Linear Programming to Minimize the Cost of Nurse Personnel." *Journal of Healthcare Finance* 32 (1): 37–49.

Parente, D. H., M. B. Pinto, and J. C. Barber. 2005. "A Pre-Post Comparison of Service Operational Efficiency and Patient Satisfaction Under Open Access Scheduling." *Health Care Management Review* 30 (3): 220–28.

Sanderson, P. 2007. Personal correspondence with author.

Singer, I. A. 2001. *Advanced Access: A New Paradigm in the Delivery of Ambulatory Care Services.* Washington, D.C.: National Association of Public Hospitals and Health Systems.

Singer, I. A., and M. Regenstein. 2003. *Advanced Access: Ambulatory Care Redesign and the Nation's Safety Net.* Washington, D.C.: National Association of Public Hospitals and Health Systems.

Soriano, A. 1966. "Comparison of Two Scheduling Systems." *Operations Research* 14 (3): 388–97.

SUPPLY CHAIN MANAGEMENT

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

ABC inventory classification system

autoregressive integrated moving average (ARIMA)

bar coding

causal forecasting

economic order quantity (EOQ)

enterprise resources planning (ERP)

e-procurement

forecasting

group purchasing organization (GPO)

just-in-time (JIT)

kanban

linear regression, linear trend

material requirements planning (MRP)

mean absolute deviation (MAD)

mean squared error (MSE)

Pareto principle

point of use, point of service (POS)

radio frequency identification (RFID)

reorder point (R)

safety stock (SS)

service level (SL)

simple moving average (SMA)

single exponential smoothing (SES)

stockout

supply chain management (SCM)

time series analysis, see forecasting

trend-adjusted exponential smoothing

two-bin system

vendor-managed inventory (VMI)

weighted moving average (WMA)

Winter's triple exponential smoothing

Operations Management in Action

Chief financial officers searching for ways to cut costs while jump-starting service might want to spend an afternoon with Allen Caudle, vice president of supply chain at Swedish Medical Center in Seattle, Washington. Caudle's supply-chain strategies saved Swedish more than $30 million in 2005. As his peers increasingly rely on group purchasing organizations (GPOs) to get better prices from vendors, Caudle and his team manage Swedish's spending the old-fashioned way, through strict internal buying policies, central purchasing, self-contracting, and tight vendor control.

It wasn't always that way. Swedish switched from the GPO model to self-contracting seven years ago, bucking the strong industry trend that fueled the growth of purchasing powerhouses like Novation, Premier, and Neoforma (now Global Health Exchange). The homegrown system works—94 percent of Swedish's spending is done on contract—partly because internal department heads and vendors alike must abide by the golden rule: Nobody gets paid without an approved purchase order. New-manager orientation includes an hour long supply-chain primer from Caudle to drive the lesson home. After that, "It only takes one time for them to learn. If a manager has a plausible excuse, I give them one 'mulligan.' But I also say, 'Don't ask for another chance.'"

New vendors are adept at finding ways around the rule, but soon realize their reward is nonpayment, he adds. So that there are no surprises, all vendors first have to pass a 10-question quiz on Swedish's contracting arrangements. The first sentence of the document reads, "I understand that I will not be paid if I don't have a purchase order for this project," Caudle says.

A devotee of Toyota's "lean management" approach, he also eyes everything from anesthesiology technicians' work habits to the location of infusion pumps in patient rooms with waste elimination in mind. His slogan is: "Use our minds before we spend our bucks." And though he works for a healthcare provider that encompasses four hospitals, more than a dozen clinics, a home-care service, and affiliated physician offices, his approach could be adapted to most industries, Caudle says.

For instance, an in-house time-and-efficiency study found that Swedish's anesthesiology technicians "spent 34 percent of their time looking for and stocking supplies rather than giving care to patients under sedation . . . also, 30 percent of the anesthetic drugs were out of date," Caudle reports. Outpatient surgery was another problem child. Clinicians had to leave the operating room area an average of eight times per case *to find and retrieve equipment, tools, or supplies. To remedy both the anesthesiology and outpatient surgery dilemmas, Swedish overhauled the physical environment.*

"We cleaned up the area and got rid of wasted space. Moved rooms of equipment that were rarely or never used. Put inventories of items that were used right outside the operating rooms, at the point of use. Created case-carts as needed, instead of ahead of time," he explains. "It was like cleaning out your garage. Most of it was pretty basic." Through the reorganization, Caudle says they focused on a general guideline of less variability and greater standardization. No work process escaped scrutiny. Even the clinical "procedure lists"—sort of like recipes naming tools, positioning devices, and the like required to perform a gallbladder removal or hernia repair—were examined for unnecessary items. Now, "go-gets" in outpatient surgery are down from eight to one per case. "My goal is to get mundane supply-chain duties out of their way so they can spend more time with patients," he adds.

Swedish is just one example of how supply chain management can operationally transform healthcare, according to Louis Fierens, senior vice president of supply chain and capital project management for Trinity Health. Based in Novi, Michigan, Trinity is the fourth-largest Catholic health system in the United States, with just under 45,000 employees, 44 hospitals (29 owned, 15 managed), and 379 outpatient clinics. Revenues were $5.7 billion in 2005.

Fierens cites a much-quoted statistic that 31 percent of hospital expenses, on average, are attributed to supplying the facility, which he aptly describes as "an argument for a higher level of management."

But instead of going the Swedish route, many hospitals are turning to companies like Westminster, Colorado–based Global Health Exchange, provider of an electronic trading exchange. Members—buyers and sellers—are healthcare players and include manufacturers, distributors, facilities such as hospitals, nursing homes, clinics and hospices, GPOs, and supply-chain firms.

Global "lets hospitals connect to us once, and connect to providers, kind of like Amazon.com," explains spokeswoman Karen Conway. Hospital members save time and money by handling supply chain functions with multiple trading partners through the exchange's automated environment, she adds. Bottom line, healthcare utilization of companies like Global "can impact the national economy."

That's a big claim, but Conway has numbers to back it up. For instance, according to a study by the Healthcare Distribution Management Association, many hospitals overpay medical/surgical suppliers by 2–7 percent. Another industry study found that 40 percent of a hospital buyer's time and 68 percent of an accounts-payable worker's time is spent on "manual processing and rework," she continues. Another common problem is data synchronization, in which the hospital's data and the supplier's data don't match. Conway says there is an average 35 percent inconsistency between hospital and supplier data that,

obviously, causes errors and leads to more rework. "The average cost shared by a hospital and supplier to research and correct a single order discrepancy is $15 to $50," she adds.

Then there's the human factor to consider. Many hospitals buy expensive materials management software, but don't get the expected return on investment due to inadequate user training—too little instruction or too short a learning curve—or high turnover among trained personnel. "We forget that it takes time to change," Conway comments, adding that failed IT implementations are often followed by a trip through "the trough of disillusionment."

Going Global offers stunning efficiencies through its process automation, she says: Requisitions are filled three times faster; purchase orders completed seven to 15 times faster; invoices processed twice as fast. Errors go down, too. For instance, Conway cites a 50 percent reduction in purchase-order discrepancy between order initiation, acknowledgment, and invoice. Other customers report spending half as much time researching invoice discrepancies thanks to automation. The goal, she says, is to "boost automation between financials, materials and clinical, and to increase data accuracy."

"This is not a revolution," Conway concludes. "It's definitely an evolution."

SOURCE: Knowledge@W.P. Carey. "Transforming U.S. Health Care: Supply-Chain Makeover Rejuvenates Medical Center." W. P. Carey School of Business, Arizona State University. knowledge.wpcarey.asu.edu/index.cfm?fa= viewArticle&id=1223&specialId=42. Reprinted with permission.

Overview

Escalating costs are driving many healthcare organizations to examine and optimize their supply chains. Efficient and effective supply chain management (SCM) is becoming increasingly important in the healthcare arena. This chapter introduces the concept of SCM and the various tools, techniques, and theories that can enable supply chain optimization. The major topics covered include:

- SCM basics;
- Tools for tracking and managing inventory;
- Forecasting;
- Inventory models;
- Inventory systems;
- Procurement and vendor relationship management; and
- Strategic SCM.

After completing this chapter, readers should have a basic understanding of SCM, which will help them understand how SCM could be used in

their organizations and enable them to begin to employ SCM-related tools, techniques, and theories to optimize supply chains.

Supply Chain Management

The supply chain includes all of the processes involved in getting supplies and equipment from the manufacturer to use in patient care areas. SCM is the management of all activities and processes related to both upstream vendors and downstream customers in the value chain. Because SCM requires managing relationships outside as well as inside an organization, SCM is a broad field of thought.

SCM is becoming increasingly important in the healthcare arena. Supply costs in hospitals account for between 15 percent and 25 percent (Healthcare Financial Management Association 2002, 2005) of operating costs. Transaction costs are estimated at $150 per order for the buyer and seller (Healthcare Financial Management Association 2001). SCM is aimed at reducing costs and increasing efficiencies associated with the supply chain.

Effective SCM is enabled by new technologies and "old" methodologies used to not only reduce supply-associated costs and effort but also to improve the efficiency of supply processes. Many of the techniques used to improve supply chain performance in other industries are applicable to healthcare. Technology-enabled solutions include e-procurement, radio frequency identification (RFID), bar coding, point-of-use data entry and retrieval, and data warehousing and management. These technologies have been used in other industries, and healthcare is increasingly finding that they can not only reduce cost, but also increase safety.

A systems view of the supply chain can lead to a better understanding of processes and how best to improve and optimize them. SCM is really about managing relationships with vendors and customers to enable the optimization of the entire chain (rather than just pieces of it) and results in benefits for all members of the chain.

For SCM to be effective, information is needed. Reliable and accurate data are needed to determine where the greatest improvements and gains can be made by improving the supply chain.

Tracking and Managing Inventory

Inventory is the stock of items held by the organization either for sale or to support the delivery of a service. In healthcare organizations, inventory typically includes supplies and pharmaceuticals. This stock allows organizations

to cope with variations in supply and demand while making cost-effective ordering decisions.

Inventory management is concerned with determining how much inventory to hold, when to order, and how much to order. Effective and efficient inventory management requires a classification system, inventory tracking system, reliable forecast of demand, knowledge of lead times, and reasonable estimates of holding, ordering, and shortage costs.

Inventory Classification System

Not all inventory is equal: Some items may be critical for the organization's operations, some may be costly or relatively inexpensive, and some may be used in large volumes while others are seldom needed. A classification system can enable organizations to manage inventory more effectively by allowing them to focus on the most important inventory items and place less emphasis on less important items.

The ABC classification system divides inventory items into three categories based on the Pareto principle. Vilfredo Pareto studied the distribution of wealth in 19th-century Milan and found that 80 percent of the wealth was controlled by 20 percent of the people (Reh 2007). This same idea of the vital few and the trivial many is found in quality management (Chapter 8) and sales (80 percent of sales come from 20 percent of customers) as well as inventory management. The A items have a high dollar volume (70 percent to 80 percent) but account for only 5 percent to 20 percent of items, B items are moderate dollar (30 percent) and item (15 percent) volume, and C items are low dollar (5 percent to 15 percent) and high item (50 percent to 65 percent) volume. The classification of items is not related to their unit cost; an A item may have high dollar volume because of high usage and low cost or high cost and low usage. Items vital to the organization should be assigned to the A category even if their dollar volume is low to moderate.

The A items are the most important and, therefore, the most closely managed. The B and C items are less important and less closely managed. In a hospital setting, pacemakers are an example of A items and facial tissue might be a C item. The A items are likely ordered more often, and inventory accuracy is checked more often. These items are good candidates for bar coding and point-of-use systems. The C items do not need to be as closely managed and, often, a two-bin system is used for management and control.

Inventory Tracking Systems

An effective inventory management system requires a means of determining how much of a particular item is available. In the past, inventory records were updated manually and were typically not very accurate. Bar coding and point-of-use systems have eliminated much of the data input inaccuracy, but inven-

tory records are still imperfect. A physical count must usually be performed to ensure that the actual and recorded amounts are the same.

Although many organizations perform inventory counts on a periodic basis (e.g., once a month), cycle counting has been found to be more helpful in ensuring accuracy and eliminating errors. More accurate inventory records not only enable efficient inventory management, but they can also help to eliminate the hoarding that occurs when providers are concerned the item will be unavailable when needed. In a typical cycle-counting system, a physical inventory is performed on a rotating schedule based on item classification. The A items might be counted every day and C items only once a month.

Electronic medication orders and matching can not only allow an organization to track demand, but it can also result in greater patient safety—the patient and order are matched at the time of administration. Rules can be input into the system to alert providers to adverse drug interactions and, thus, help to eliminate errors. Systems are being developed that allow for complete, current patient records available bedside. The availability of patient and drug history can make care better and safer.

Radio frequency identification

RFID is a tool for identifying objects, collecting data about them, and storing that data in a computer system with little human involvement. RFID tags are similar to bar codes, but they emit a data signal that can be read without actually scanning the tag. RFID tags can also be used to determine the location of the object to which they are attached. However, RFID tags are more expensive than bar coding.

The study "RFID in Healthcare" (BearingPoint and National Alliance for Healthcare Information Technology 2006) found that RFID technology is being used in a variety of applications within the healthcare industry, including patient flow management, access control and security, supply chain systems, and smart shelving. Real-time medical equipment tracking systems and patient safety systems, such as those for identification and medication administration, were found to be the major areas where RFID is expected to be used in the future.

PinnacleHealth hospital in Harrisburg, Pennsylvania, has successfully implemented RFID technology to track and locate expensive medical equipment (Wright 2007). The system can be queried to determine where a particular piece of equipment is currently located, enabling employees to quickly find the needed equipment rather than search the hospital for it. PinnacleHealth believes the system will pay for itself in two years by enabling the hospital to determine real usage of purchased and rented equipment and eliminating theft.

Warehouse Management

Warehouse management systems can enable healthcare organizations to manage and decrease their storage and facility costs. Bar coding and point-of-use systems can reduce the labor needed by automating data entry in receiving. Automated data entry will also reduce errors and allow for more accurate determination of actual inventory held. Information about demand to the warehouse or storage facility can be used to organize that facility so that more heavily demanded items are more accessible and less frequently demanded items are not as accessible. This can significantly reduce labor costs associated with the storage facility.

Demand Forecasting

Knowledge of demand and demand variation within the system can enable improved demand forecasting, which, in turn, can allow inventory reductions and greater assurance that something will be available when needed. Bar coding and point-of-use systems allow organizations to track when and how many supplies are being consumed, use that information to forecast demand organization wide, and plan how to meet that demand in the most effective manner.

Forecasting, or time series analysis, is used to predict what will happen in the future, based on data obtained at set intervals in the past. For example, forecasting could be used to predict the number of patients who will be seen in the emergency department in the next year (month, day) based on the number of patients who have been seen there in the past. Time series analysis accounts for the fact that data taken over time may be related to one another and, therefore, violate the assumptions of linear regression. Forecasting methods range from simple to complex. Here, the simpler methods are described; only a brief discussion of the more complicated methods is provided.

Averaging Methods

All averaging methods assume that the variable of interest is stable or stationary—not growing or declining over time and not subject to seasonal or cyclical variation.

Simple moving average

A simple moving average (SMA) takes the last p-values and averages them to forecast the value in the next period.

$$F_t = \frac{D_{t-1} + D_{t-2} + ... + D_{t-p}}{p}$$

where F_t = forecast for period t (or the coming period), D_{t-1} = value in the previous time period, and p = # of time periods.

Weighted moving average

In contrast to the SMA, where all values from the past are given equal weight, a weighted moving average (WMA) weights each of the previous time periods. Typically, the more recent periods are assumed to be more relevant and are given higher weight.

$$F_t = w_1 D_{t-1} + w_2 D_{t-2} + ... + w_p D_{t-p}$$

where F_t = forecast for period t (or the coming period), D_{t-1} = value in the previous time period, w_p = weight for time period p, and $w_1 + w_2 + ... + w_p = 1$.

Exponential smoothing

The problem with the previous two methods, SMA and WMA, is that a large amount of historical data are required. With single exponential smoothing (SES), the oldest data are eliminated once new data have been added. The forecast is calculated by using the previous forecast as well as the previous actual value with a weighting or smoothing factor, alpha. Alpha can never be greater than one, and higher values of alpha put more weight on the most recent periods.

$$F_t = \alpha D_{t-1} + (1-\alpha)F_{t-1}$$

where F_t = forecast for period t (or the coming period), D_{t-1} = value in the previous time period, and α = smoothing constant ≤ 1.

Trend, Seasonal, and Cyclical Models
Holt's trend-adjusted exponential smoothing technique

SES assumes that the data fluctuate around a reasonably stable mean (no trend or consistent pattern of growth or decline). If the data contain a trend, Holt's trend-adjusted exponential smoothing model can be used.

Trend-adjusted exponential smoothing works much like simple smoothing except that two components—level and trend—must be updated each period. The level is a smoothed estimate of the value of the data at the end of each period, and the trend is a smoothed estimate of average growth at the end of each period. Again, the weighting or smoothing factors, alpha and delta, can never exceed one, and higher values put more weight on more recent time periods.

$$FIT_t = F_t + T_t$$
and
$$F_t = \alpha D_{t-1} + (1-\alpha)FIT_{t-1}$$
$$T_t = T_{t-1} + \delta(F_{t-1} - FIT_{t-1})$$

where FIT_t = forecast for period t including the trend, F_t = smoothed forecast for period t, T_t = smoothed trend for period t, D_{t-1} = value in the previous time period, $0 \le \alpha$ = smoothing constant ≤ 1, and $0 \le \delta$ = smoothing constant ≤ 1.

Linear regression

Alternatively, when a trend exists in the data, regression analysis (Chapter 7) is often used for forecasting. Demand is the dependent, or Y, variable, and the time period is the predictor, or X, variable. The regression equation

$$\hat{Y} = b(X) + a$$

can be restated using forecasting notation:

$$F_t = b(t) + a$$

where F_t = forecast for period t, b = slope of the regression line, and a = Y intercept. To find b and a, D = actual demand, $\bar{D}$ = average of all actual demands, t = time period, and $\bar{t}$ = average of time periods: $b = \Sigma(t - \bar{t})(D - \bar{D})/\Sigma(t - \bar{t})^2$ and $a = \bar{D} - b\bar{t}$.

In time series forecasting, the predictor variable is time. Regression analysis is also used in forecasting when a causal relationship exists between a predictor variable (not time) and the demand variable of interest. For example, if the number of surgeries to be performed at some future date is known, that information can be used to forecast the number of surgical supplies needed.

Winter's triple exponential smoothed model

In addition to adjusting for a trend, Winter's triple exponential smoothed model adjusts for a cycle or seasonality.

Autoregressive integrated moving average models

Autoregressive integrated moving average (ARIMA) models, developed by Box and Jenkins (1976), are able to model a wide variety of time series

behavior. However, ARIMA is a complex technique; although it often produces appropriate models, it requires a great deal of expertise to use.

Model Development and Evaluation

Forecasting models are developed based on historical time series data using the previously described techniques. Typically, the "best" model is the simplest model that minimizes the forecast error associated with that model. Mean absolute deviation (MAD) and/or mean squared error (MSE) can be used to determine error levels.

$$MAD = \frac{\sum_{t=1}^{n} |D_t - F_t|}{n} \qquad\qquad MSE = \frac{\sum_{t=1}^{n} (D_t - F_t)^2}{n}$$

t = Period number $\qquad\qquad$ F = Forecast demand for the period

D = Actual demand for the period $\qquad$ n = Total number of periods

(Many of these forecasting models are available as downloads on the companion web site, www.ache.org/books/OpsManagement).

VVH Diaper Demand Forecasting

Jessie Jones, purchasing agent for Vincent Valley Hospital and Health System (VVH), wants to forecast demand for diapers. She gathers information related to past demand for diapers (Table 13.1) and plots it (Figure 13.1). The plot of weekly demand shows no cycles or trends, so Jessie believes that an averaging method would be most appropriate. She compares the forecasts obtained with a five-period SMA; WMA with weights of 0.5, 0.3, and 0.2; and exponentially smoothed forecast with alpha of 0.25.

SMA forecast:

$$F_t = \frac{A_{t-1} + A_{t-2} + ... + A_{t-p}}{p}$$

$$F_{14} = \frac{A_{13} + A_{12} + A_{11} + A_{10} + A_9}{5} = \frac{60 + 43 + 53 + 54 + 45}{5} = 51$$

WMA forecast:

$$F_t = w_1 A_{t-1} + w_2 A_{t-2} + ... + w_p A_{t-p}$$

$$F_{14} = w_1 A_{13} + w_2 A_{12} + .w_3 A_{11} = 0.5 \times 60 + 0.3 \times 43 + 0.2 \times 53 = 53.5$$

Period	Week of	Cases of Diapers
1	1-Jan	70
2	8-Jan	42
3	15-Jan	63
4	22-Jan	52
5	29-Jan	56
6	5-Feb	53
7	12-Feb	66
8	19-Feb	61
9	26-Feb	45
10	5-Mar	54
11	12-Mar	53
12	19-Mar	43
13	26-Mar	60

FIGURE 13.1
Plot of VVH
Weekly Diaper
Demand
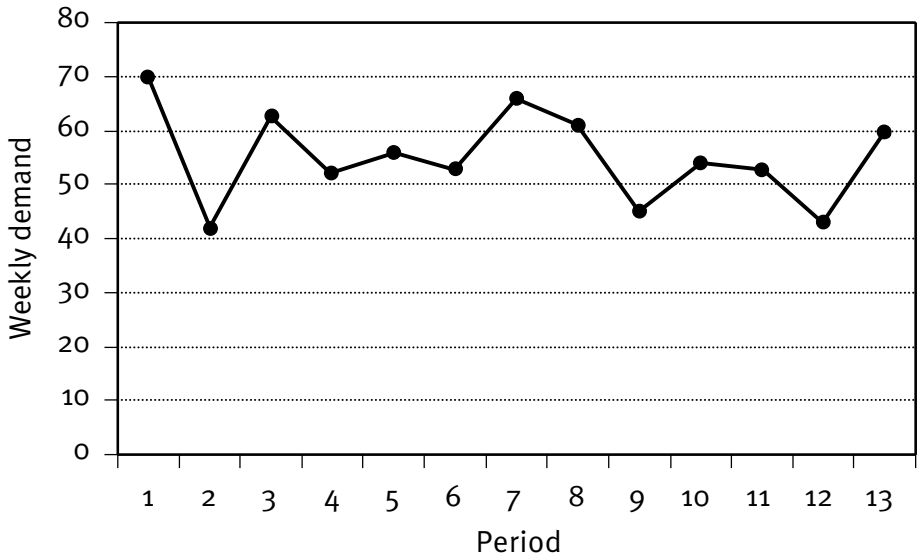
Exponentially smoothed forecast:

$$F_t = \alpha A_{t-1} + (1-\alpha)F_{t-1}$$
$$F_{14} = 0.25 \times A_{13} + 0.75 \times F_{13} = 0.25 \times 60 + 0.75 \times 52 = 54$$

Because each method gives a different forecast, Jessie decides to compare the methods to try to determine which is best. She uses the Excel Forecasting Template (found on the companion web site) to perform the calculations (Figure 13.2). She finds that both MAD and MSE are lowest with the WMA method and decides to use that method for forecasting. Therefore, she forecasts that 53.5 cases of diapers will be demanded the week of April 2, period 14.

Order Amount and Timing

Inventory management is concerned with the following questions:

- How much inventory should the organization hold?
- When should an order be placed?
- How much should be ordered?

To answer these questions, organizations need to have reasonable estimates of holding, ordering, and shortage costs. Knowledge of lead times and
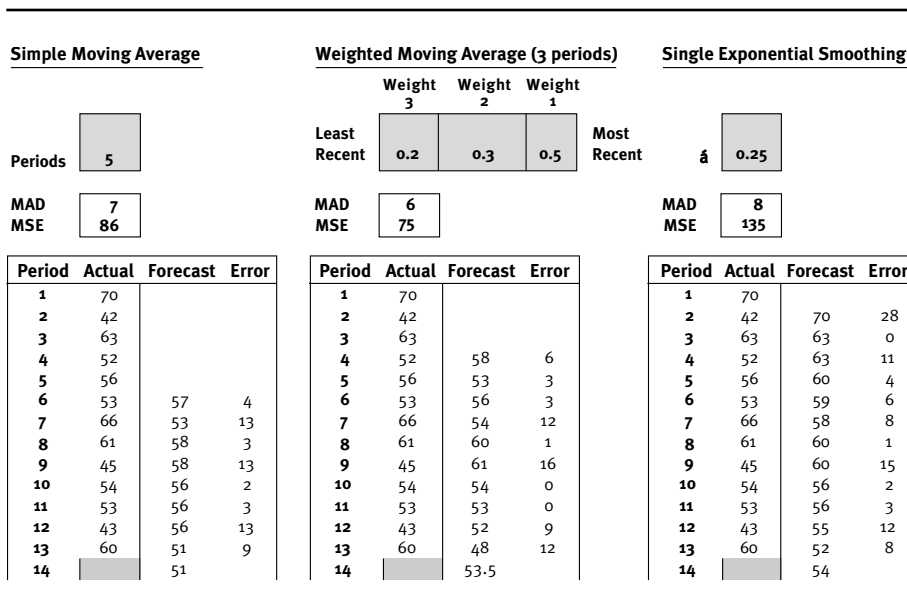
FIGURE 13.2

Excel Forecasting Template Output: VVH Diaper Demand

Simple Moving Average

Periods	5

MAD	7
MSE	86

Period	Actual	Forecast	Error
1	70		
2	42		
3	63		
4	52		
5	56		
6	53	57	4
7	66	53	13
8	61	58	3
9	45	58	13
10	54	56	2
11	53	56	3
12	43	56	13
13	60	51	9
14		51	

Weighted Moving Average (3 periods)

	Weight 3	Weight 2	Weight 1	
Least Recent	0.2	0.3	0.5	Most Recent

MAD	6
MSE	75

Period	Actual	Forecast	Error
1	70		
2	42		
3	63		
4	52	58	6
5	56	53	3
6	53	56	3
7	66	54	12
8	61	60	1
9	45	61	16
10	54	54	0
11	53	53	0
12	43	52	9
13	60	48	12
14		53.5	

Single Exponential Smoothing

á	0.25

MAD	8
MSE	135

Period	Actual	Forecast	Error
1	70		
2	42	70	28
3	63	63	0
4	52	63	11
5	56	60	4
6	53	59	6
7	66	58	8
8	61	60	1
9	45	60	15
10	54	56	2
11	53	56	3
12	43	55	12
13	60	52	8
14		54	

demand forecasts is also essential to determining the best answers to inventory questions.

Economic Order Quantity Model

In 1915, F. W. Harris developed the economic order quantity (EOQ) model to answer inventory questions. Although the assumptions of this model limit its usefulness in real situations, it provides important insights into effective and efficient inventory management.

To aid in understanding the model, definitions for some key inventory terms are provided.

- *Lead time* is the interval between placing an order and receiving it.
- *Holding (or carrying) costs* are associated with keeping goods in storage for a period of time, usually one year. The most obvious of these costs is the cost of the space and the cost of the labor and equipment needed to operate the space. Less obvious costs include the opportunity cost of capital and those costs associated with obsolescence, damage, and theft of the goods. These costs are often difficult to measure and are commonly estimated as one-third to one-half the value of the stored goods per year.
- *Ordering (or setup) costs* are the costs of ordering and receiving goods. They may also be the costs associated with changing or setting up to produce another product.
- *Shortage costs* are the costs of not having something in inventory when it is needed.
- *Independent demand* is generated by the customer and is not a result of demand for another good or service.
- *Dependent demand* results from another demand. For example, the demand for hernia surgical kits (dependent) is related to the demand for hernia surgeries (independent).
- *Back orders* cannot be filled when received, but the customer is willing to continue waiting for the order to be filled.
- *Stockouts* occur when the desired good is not available.

The basic EOQ model is based on the following assumptions:

- Demand for the item in question is independent;
- Demand is known and constant;
- Lead time is known and constant;
- Ordering costs are known and constant; and
- Back orders, stockouts, and quantity discounts are not allowed.

The EOQ inventory order cycle (Figure 13.3) consists of stock or inventory being received at a point in time. An order is placed when the amount of stock on hand is just enough to cover the demand that will be experienced during lead time. The new order arrives at the exact point when

the stock is completely depleted. The point at which new stock should be ordered, the reorder point (R), is the quantity of stock demanded during lead time.

$$\text{Reorder point} = R = \bar{d}L$$

where R = reorder point, $\bar{d}$ = average demand per time period, and L = lead time (in the same units as above).

The EOQ inventory order cycle shows that the average amount of inventory held will be:

$$\frac{\text{Order quantity}}{2} = \frac{Q}{2}$$

The number of orders placed in one year will be:

$$\frac{\text{Yearly demand}}{\text{Order quantity}} = \frac{D}{Q}$$

Total costs are the sum of holding and ordering costs. Yearly holding costs are:

$$\text{Cost to hold one item one year} \times \text{Average inventory} = h \times Q/2$$
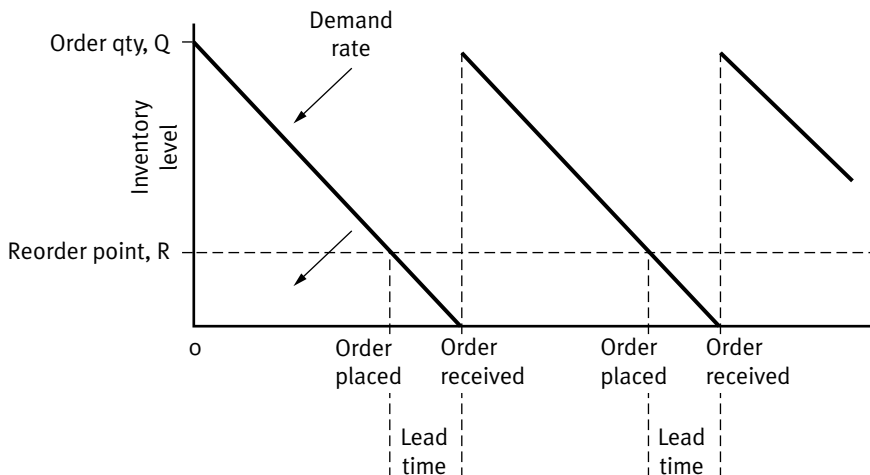
FIGURE 13.3
EOQ Inventory Order Cycle

Yearly ordering costs are:

$$\text{Cost to place one order} \times \text{Yearly number of orders} = o \times D/Q$$

Total yearly costs are then:

$$h \times Q/2 + o \times D/Q$$

Figure 13.4 illustrates these relationships. An inspection of this graph shows that total cost will be minimized when holding costs equal ordering costs. (This can also be proven using calculus.) The order quantity that will minimize total costs is found when:

$$h \times Q^*/2 = o \times D/Q^*$$

Rearranging this equation, the optimal order quantity is:

$$Q^2 = (2 \times o \times D)/h$$
$$\text{and}$$
$$Q^* = \sqrt{\frac{2 \times o \times D}{h}}$$

FIGURE 13.4
EOQ Model
Cost Curves
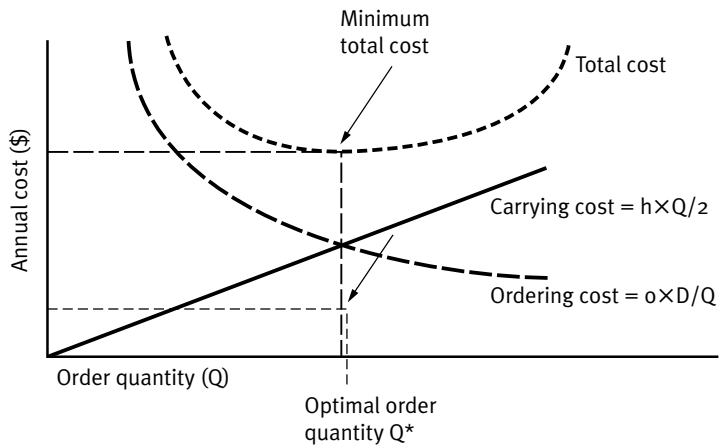
Several important insights into inventory management can be gained from an examination of this simple model. There are trade-offs between holding costs and ordering costs: As holding costs increase, optimal order quantity decreases, and as ordering costs increase, optimal order quantity increases. Many organizations, including those in the healthcare industry, believe that the costs of holding inventory are much higher than was previously thought. As a consequence, these organizations are decreasing order quantities and working to decrease order costs by streamlining procurement processes.

VVH Diaper Order Quantity

Jessie Jones, VVH's purchasing agent, wants to determine the optimal order quantity for diapers. From her forecasting work, she knows that annual demand for diapers, D, is:

$$\bar{d} \times \text{Time Period} = \frac{53.5 \text{ Cases}}{\text{Week}} \times \frac{52 \text{ Weeks}}{\text{Year}} = \frac{2,782 \text{ Cases}}{\text{Year}}$$

Each case of diapers costs \$5, and Jessie estimates holding costs at 33 percent. It costs \$100 to place an order. Lead time for diapers is 1 week. She calculates the EOQ, Q^*, as:

$$\sqrt{\frac{2 \times o \times D}{h}} = \sqrt{\frac{2 \times \$100 \times 2,782 \text{ Cases}}{\$1.67 / \text{ Case}}}$$
$$= \sqrt{333,174 \text{ Cases}^2} = 577 \text{ Cases}$$

She calculates the reorder point, R, as:

$$\bar{d}L = \frac{53.5 \text{ Cases}}{\text{Week}} \times 1 \text{ Week} = 53.5 \text{ Cases}$$

Jessie will need to place an order for 577 cases of diapers when 53.5 cases remain in stock.

Fixed Order Quantity with Safety Stock Model

The basic EOQ model assumes that demand is constant and known. This means that the amount of stock carried in inventory only needs to match demand. In reality, demand is seldom constant, and excess inventory must be held to meet variations in demand and avoid stockouts. This excess inventory is called safety stock (SS) and is defined as the amount of inventory carried over and above expected demand. Figure 13.5 illustrates this model.

FIGURE 13.5

Variable
Demand
Inventory
Order Cycle
with Safety
Stock
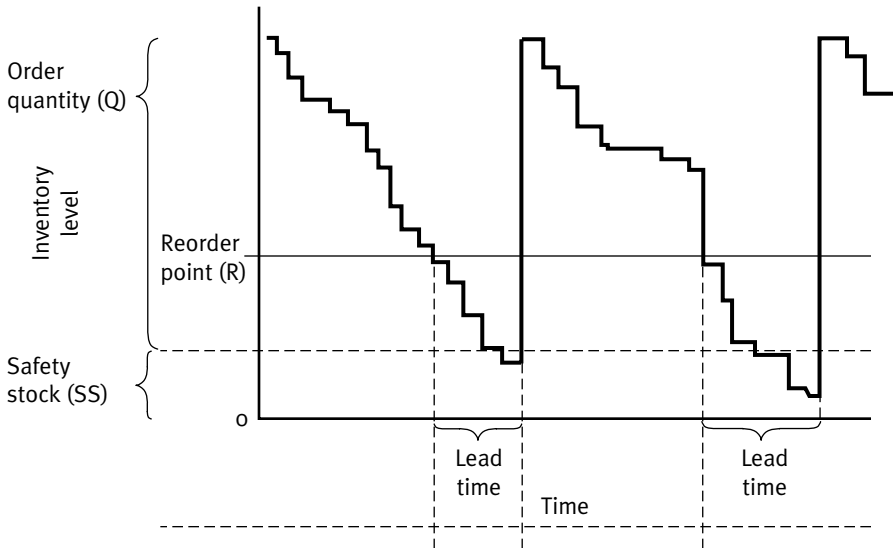
This SS model assumes that demand varies and is normally distributed (Chapter 7). The model also assumes that a fixed quantity equal to EOQ will always be ordered. The EOQ will remain the same as in the basic model, but the reorder point will be different because of the need for SS.

$$R = \bar{d}L + SS$$

The amount of SS to carry is determined by variation in demand and desired service level. Service level is defined as the probability of having an item on hand when needed. For example, suppose that orders are placed at the beginning of a time period and received at the end of that period. If demand is expected to be 100 units in the next time period with a standard deviation of 20 units and 100 units on hand at the start of the period, the probability of stocking out is 50 percent and the service level is 50 percent. If demand is normally distributed, there is a 50 percent probability of its being higher than the mean and a 50 percent probability of its being lower than the mean. Demand would be greater than the stock on hand in half of the time periods.

To increase the service level, SS is needed. For example, if the stock on hand at the start of the time period is 120 units (20 units of SS), the service level would increase to 84 percent and the probability of a stockout would be reduced to 16 percent. Because demand is assumed to follow a normal dis-

tribution and 120 units is exactly one standard deviation higher than the mean of 100 units, the probability of being less than one standard deviation above the mean is 84 percent. There is a 16 percent probability of being more than one standard deviation above the mean (Figure 13.6). A service level of 95 percent is typically used in industry. However, if one stockout every 20 time periods is unacceptable, a higher service level target is needed.

SS is the z-value associated with the desired service level (number of standard deviations above the mean) times the standard deviation of demand during lead time.

$$SS = z \times \sigma_L$$

Note that with this model, the only time demand variability can be a problem is during lead time. Because an order is triggered when a certain level of stock is reached, any variation in demand prior to that time does not affect the reorder point.

This model also provides some important insights into inventory management. There are trade-offs between the amount of SS held and service level. As the desired service level increases, the amount of SS needed—and therefore the amount of inventory held—increases. As the variation in demand during lead time increases, the amount of SS increases. If demand variation or lead time can be decreased, the amount of SS needed to reach a desired service level will also decrease. Many healthcare organizations are working with their suppliers to reduce lead time and, therefore, SS levels.
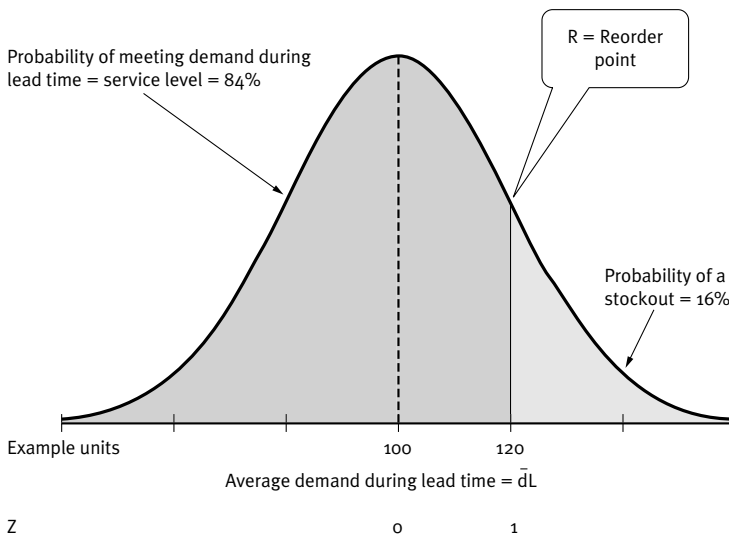
FIGURE 13.6
Service Level and Safety Stock

VVH Diaper Order Quantity

After learning more about inventory models, Jessie Jones realized that the reorder point that she had decided on using the basic EOQ model would cause the hospital to be out of diapers during 50 percent of the order cycles. Because diapers would be ordered five times per year, this meant that the hospital would be out of diapers at least twice a year. Jessie believed that this was an unacceptable amount of stockouts and decided that SS was needed to avoid them. She decided that a service level of 95 percent, or one stockout every 4 years, would be acceptable.

Jessie gathered more information related to demand for diapers over the past year and determined that the standard deviation of demand during lead time was 11.5 cases of diapers. She calculated the amount of SS needed as:

$$z \times \sigma_L = 1.64 \times 11.5 = 18.9 \text{ Cases}$$

Her new reorder point is:

$$\bar{d}L + SS = \left(\frac{53.5 \text{ Cases}}{\text{Week}} \times 1 \text{ Week} \right) + 18.9 \text{ Cases} = 72.4 \text{ Cases}$$

She will need to place an order for 577 cases of diapers when 72.4 cases remain in stock. The forecasting template found on the companion website can be used to perform these calculations, and the output related to Jessie's problem is shown in Figure 13.7.

Additional Inventory Models

Many inventory models that address some of the limiting assumptions of the EOQ model have been developed. One that may be of interest is the fixed time period with SS model. In the fixed order quantity with SS model, the order quantity is fixed and the time when the order is placed varies. In the fixed time period with SS model, the order quantity varies and the time when

FIGURE 13.7
VVH 95 Percent Service Level Reorder Point

Reorder Point (ROP) with EOQ Ordering

Average daily demand	d =	7.64	Units
Average lead time	L =	7	Days
Std dev demand during lead time	L =	11.5	Units
Service level	SL =	0.95	▲
increment	SL =		▼
Stockout risk		0.05	
z associated with service level		1.64	
Average demand during lead time	dL =	53.48	Units
Safety stock	SS =	18.9	Units
Reorder point	ROP =	72.4	Units
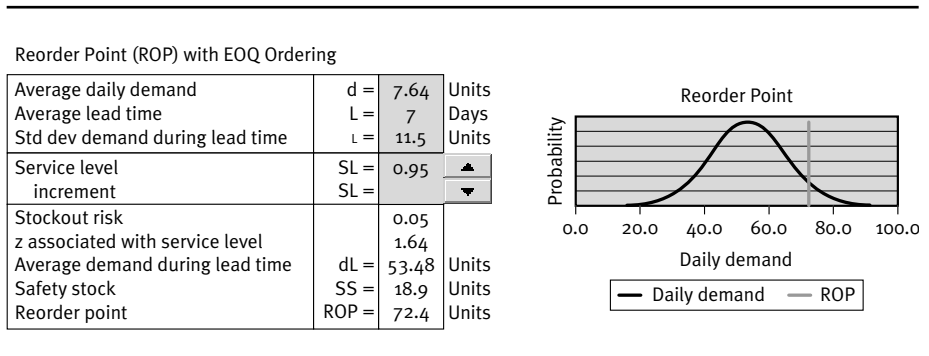
the order is placed is fixed. This type of model is applicable when vendors deliver on a set schedule or if one supplier is used for many different products and orders are bundled and delivered together on a set schedule. Generally, this situation requires more SS because stockouts are possible during the entire time between orders, not just the lead time for the order.

Models that account for quantity discounts and price breaks have also been developed. More information on these higher-level models can be found in most inventory management textbooks.

Inventory Systems

In practice, various types of systems are employed for management and control of inventory. They range from simple to complex, and organizations typically employ a mixture of these systems.

Two-Bin System

The two-bin system is a simple, easily managed system often used for B- and/or C-type items. In this system, inventory is separated into two bins. These do not necessarily have to be actual bins or containers; a means of identifying the items as being in the first or second bin is simply needed. Inventory is taken from the first bin. When that bin is emptied, an order is placed. Inventory from the second bin is used during the lead time for the order to be received. The amount of inventory held in each bin can be determined from the fixed order quantity with SS model. The amount of inventory held in the first bin would ideally be the EOQ minus the reorder point. The amount of inventory in the second bin would equal the reorder point.

Just-in-Time

Just-in-time (JIT) inventory systems are based on Lean concepts and employ a type of two-bin system called the kanban system. (See Chapter 9 for a description of this type of system.) Because inventory levels are controlled by the number of kanbans in the system and inventory is "waste" in a Lean system, organizations try to decrease the number of kanbans as much as possible.

Material Requirements Planning and Enterprise Resources Planning

Material requirements planning (MRP) systems were first employed by manufacturing organizations in the 1960s when computers became commercially available. These systems were used to manage and control the purchase and production of dependent-demand items.

A simple example illustrates the logic of MRP (Figure 13.8). A table manufacturer knows (or forecasts) that 50 tables, consisting of a top and four

legs, will be demanded five weeks in the future. The manufacturer knows that it takes one week to produce a table if both the legs and tops are available. The company also knows that there is a two-week lead time for table legs and a three-week lead time for table tops. From this information, MRP determines that for the organization to have 50 tables in week 5, it needs to have 50 table tops and 200 table legs in week 4. The company also needs to order 200 table legs in week 2 and 50 table tops in week 1.

The same type of logic can be employed in healthcare for dependent-demand items. For example, if the demand for a particular type of surgery is known or can be forecast, supplies related to this type of surgery can be ordered based on MRP-type logic.

Enterprise resources planning (ERP) systems evolved from these relatively simple systems as computing power grew and software applications became more sophisticated. ERP-type systems found in healthcare today encompass the entire organization and include finance, accounting, human resources, patient records, and so on, in addition to inventory management and control functions. Technology can enable improvement in many aspects of healthcare organizations.

Procurement and Vendor Relationship Management

Analyzing the processes used for procurement and improving them can result in significant savings to an organization. Technology can be used to not only streamline processes but also to improve data reliability, accuracy, and visibility. Streamlining procurement processes can reduce associated labor costs. E-procurement is one example of how technology can be employed to make procurement more efficient. The ease of obtaining product information,

FIGURE 13.8
MRP Logic
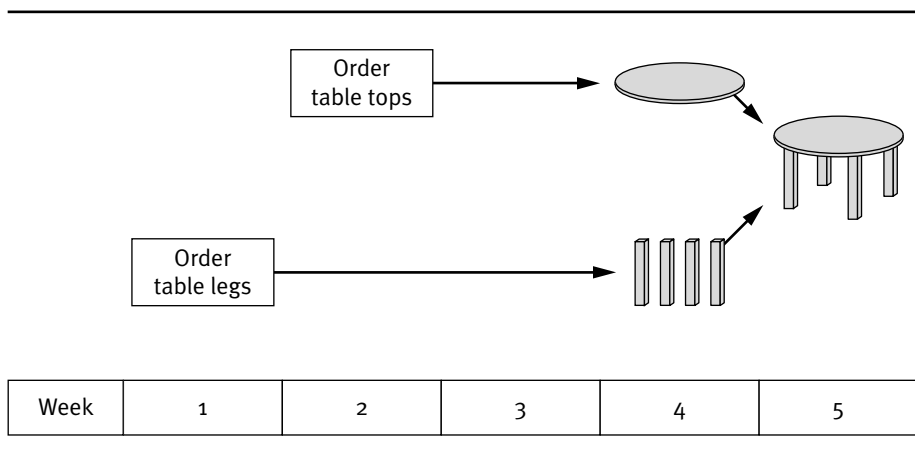
reduced time associated with the actual procurement process, and increased use of a limited number of suppliers can significantly reduce costs.

Information about supplier reliability can be maintained in these systems to allow organizations to make informed choices about vendors. For example, one vendor may be much less expensive but extremely unreliable, whereas another may be slightly more expensive but more reliable and faster. An analysis may show that it is less costly to use the slightly more expensive vendor because the amount of SS held or the need to expedite shipments may be reduced. Tracking and reviewing supplier performance can aid in ensuring that quality suppliers are being used.

Value-based standardization can be employed to reduce both the number and quantity of items held. Focusing on high-use or high-cost items can leverage the benefits of standardization and reduce the number of suppliers to the organization. Fewer supplies and suppliers can result in both labor and material cost savings.

Outsourcing can be an effective means of ensuring supply availability and reducing internal labor. Distributors can break orders down by point of use and deliver directly to that point as needed rather than having the organization's personnel perform that function. Prepackaged supply packs or surgical carts can reduce the amount of in-house labor needed to organize these supplies and ensure that the correct supplies are available when needed. Vendor-managed inventory is another way to outsource some of the work involved with procurement. Automated supply carts or cabinets and point-of-use systems can enable vendor-managed inventory. GPOs can be employed to increase order quantities and reduce costs.

Disintermediation is another possible means of supply chain improvement. Reducing the number of organizations in the chain can result in lower costs and faster, more reliable delivery.

Strategic View

Most importantly, effective SCM requires a strategic systems analysis and design. This strategic view enables systems solutions rather than individual solutions. A strategic design will enable systems integration, allowing for improved decision making across the organization.

Successful SCM initiatives require the same things as Six Sigma, Lean, and the Baldrige criteria:

- Top management support and collaboration, including time and money.
- Employee buy-in, including clinician support and front-line empowerment.
- Evaluation of the structure and staffing of the supply chain to ensure that it will support the desired improvements and that all relevant functions

are represented in a meaningful way. Cross-functional teams may be the best way to ensure this.

- Process analysis and improvement, including a thorough and complete understanding of existing systems, processes, and protocols (through process mapping) and their improvement.
- Collection and analysis of relevant, accurate data and metrics to determine areas of improvement, means of improvement, and whether improvement was achieved.
- Evaluation of technology-enabled solutions in terms of both costs and benefits.
- Training in the use of new technologies and techniques. This is essential for broad application and use in the organization and for success.
- Internal awareness programs to highlight both the need for and benefits of strategic SCM.
- Improved inventory management through better understanding of the systems consequences of unofficial inventory, JIT systems, and improved inventory tracking systems.
- Enhancement of vendor partnerships through information sharing and the investigation and determination of mutually beneficial solutions. Performance tracking should be employed to determine the best vendors to involve in this process.
- Finally, the organization must continually educate and support a systemwide view of the supply chain and seek improvement for the system rather than individual departments or organizations in that system.

Conclusion

In the past, healthcare organizations did not really focus on SCM issues; today, increasing cost pressures are driving them to examine and optimize their supply chains. The ideas and tools presented in this chapter will help the healthcare supply chain professional to achieve these goals.

Discussion Questions

1. Why is SCM important to healthcare organizations?
2. List some inventory items found in your organization. Which of these might be classified as A, B, or C items? Why? How would you manage these items differently depending on their classification?
3. Think of an item for which your organization carries SS. Why is SS needed for this item? Can the amount of SS needed be reduced? How?

4. Describe the ERP system(s) found in your organization. How could they be improved?

Chapter Exercises

1. Use the web to investigate and summarize commercially available software solutions for healthcare organizations.
2. This problem uses information from a data set available on the companion web site. The data set contains the raw data as well as reduced/reorganized data for ease of analysis.

    Use the forecasting template found on the companion web site or Minitab to forecast total U.S. healthcare expenditures for 2010 using SMA, WMA, SES, trend-adjusted (or double) exponential smoothing, and linear trend.
    a. Which model do you believe gives the best forecast?
    b. Do you see any problems with your model?
    c. Repeat the above for hospital care, physician services, other professional services, dental services, home health care, prescription drugs, and other. Is any one of these driving the increase in healthcare expense?
3. The Excel inventory template found on the companion web site may be helpful for this problem. An Excel spreadsheet with data for the problem can also be downloaded from ache.org/books/ OpsManagement.

    Hospital purchasing agent Abby Smith needs to order examination gloves. Currently, she orders 1,000 boxes of gloves whenever she thinks there is a need. Abby has heard that there is a better way to do this and wants to use EOQ to determine how much to order and when. She collects the following information.

Cost of gloves:	$4.00/box
Carrying costs:	33%, or $_____/box
Cost of ordering:	$150/order
Lead time:	10 days
Annual demand:	10,000 boxes/year

   a. What quantity should Abby be ordering? Prove that your order quantity is "better" than Abby's by graphing ordering costs, holding costs, and total costs for 1,000, 1,500, and 2,000 boxes.
   b. How often will Abby need to order? About how many days will there be between orders?

c. Assuming that Abby is not worried about SS, when should she place her order? Draw another graph to illustrate why she needs to place her order at that particular point.

d. Abby is concerned that the reorder point she determined is wrong because demand for gloves varies. She gathers the following usage information:

Period (10 Days Each)	Demand
1	274
2	274
3	284
4	274
5	254
6	264
7	264
8	284
9	274
10	294
11	274
12	284
13	264
14	274
Average	274

e. Abby decides she will be happy if the probability of a stockout is 5 percent. How much SS should Abby carry?

f. If Abby were to set up a two-bin system for gloves, how many boxes of gloves would be in each bin?

References

BearingPoint and National Alliance for Healthcare Information Technology. 2006. *RFID in Healthcare: Poised for Growth.* [Online information; retrieved 2/15/07.] www.bearingpoint.com.

Box, G. E. P., and G. M. Jenkins. 1976. *Time Series Analysis: Forecasting and Control,* 2nd ed. San Francisco: Holden-Day.

Harris, F. W. 1913. "How Many Parts to Make at Once." *Factory, The Magazine of Management* 10 (2): 135–136, 152.

Healthcare Financial Management Association. 2005. *HFMA's 2005 Supply Chain Benchmarking Survey*. [Online information; retrieved 8/9/06.] www.hfma.org/library/accounting/costcontrol/2005_Supply_Chain_Benchmk.htm.

———. 2002. *Resource Management: The Healthcare Supply Chain 2002 Survey Results*. [Online information; retrieved 2/19/07.] www.hfma.org/library/accounting/costcontrol/Supply_Chain_2002_Survey.htm.

———. 2001. *Resource Management Update: Healthcare Supply Chain*. [Online information; retrieved 2/19/07.] www.hfma.org/library/accounting/costcontrol/Update_Healthcare_Supply_Chain.htm.

Knowledge@W.P.Carey. 2006. "Transforming U.S. Health Care: Supply-Chain Makeover Rejuvenates Medical Center." W. P. Carey School of Business, Arizona State University, April 6. [Online information; retrieved 11/5/07.] http://knowledge.wpcarey.asu.edu/index.cfm?fa=viewArticle&id=1223&specialId=42.

Reh, F. J. 2007. "Pareto's Principle—The 80-20 Rule." [Online information; retrieved 2/15/07.] management.about.com/cs/generalmanagement/a/Pareto081202.htm.

Wright, C. M. 2007. "Where's My Defibrillator? More Effectively Tracking Hospital Assets." *APICS* 17 (1): 28–33.

PUTTING IT ALL TOGETHER
FOR OPERATIONAL EXCELLENCE

14

HOLDING THE GAINS

CHAPTER OUTLINE

KEY TERMS AND ACRONYMS

cost-volume-profit analysis (CVP)
diagnosis-related group
human resources (HR) planning
human resources department (HR)

Institute for Clinical Systems
 Improvement
managerial accounting

Overview

This chapter concludes and integrates this book. It includes:

- Three strategies to be used to maintain the gains in operational improvement projects: human resources (HR) planning, managerial accounting, and control systems.
- An algorithm that assists practitioners in choosing and applying the tools, techniques, and methods described in this book.
- An examination of how Vincent Valley Hospital and Health System (VVH) used the tools for operational excellence.
- An optimized healthcare delivery system for the future.

The preceding chapters present an integrated approach to achieving operational excellence. First, strategy execution and change management systems need to be well developed. The balanced scorecard and formal project management techniques are effective methods to employ in these key organizational challenges.

Quantitative tools can now be applied, such as state-of-the-art data collection and analysis tools and problem-solving and decision-making techniques. Processes and scheduling systems can be improved with Six Sigma, Lean, and simulation. Supply chain techniques will maximize value and minimize costs in operations.

The final challenge in achieving healthcare operations excellence is to hold the gains. High energy is usually present when a new initiative is introduced, at the start of a large project, or at the beginning of an effort to solve a problem. However, as time passes, new priorities emerge, team members change, and operations can drift back to unsatisfactory levels.

A strategy for holding the gains must be developed at the beginning of any operations improvement effort. HR planning, managerial accounting, and control systems are the keys to maintaining the gains. Although this book is not focused primarily on HR or finance, these functions are essential to sustaining the improvements achieved. Staff from these support departments should be engaged at the beginning of operations improvement activities and invited to be part of project teams if possible. More extensive information related to these functional areas can be found in *Human Resources in Healthcare—Managing for Success* (Fried, Fottler, and Johnson 2005) and *Healthcare Finance: An Introduction to Accounting and Financial Management* (Gapenski 2005).

Human Resources Planning

The effect of many of the project management and process improvement tools described in this book can be a major change in the work lives of a healthcare organization's employees. Many of these changes will be in the processes of an employee's work, hopefully making it more productive and fulfilling. Some of the more powerful tools, such as Lean, Six Sigma, and simulation, can provide major productivity gains—in some cases, 30 percent to 60 percent increases can be achieved. A clinical process improvement project may significantly change the tasks that fill an employee's workday. In this environment, a disciplined plan for employee redeployment or retraining is essential. Many healthcare organizations fail at this critical step, as they lack processes to capture and maintain gains in productivity and quality improvement.

As part of the executive function of a healthcare organization, the human resources (HR) department serves as a strategic partner in making effective and long-lasting change. During each annual planning cycle, strategic projects to further the goals of the organization are identified. Many of these initiatives become part of the balanced scorecard. At this point, the HR department should be included to undertake planning, placing "the right person in the right job at the right time" (Jackson and Schuler 1990, 223). This process is shown in Figure 14.1.

The HR staff needs to estimate the effect of each project or initiative that will be undertaken during the year. If the project has a goal of providing more service with the same staff, the HR task in the future will be to maintain this staffing level. Broader HR planning can now occur, such as tracking the availability of workers for these positions in external labor pools or identifying and training existing employees to fill these roles if turnover occurs.

If, on the other hand, the likely outcome of a project will be to reduce staff in a department, it is important to be clear to the organization about the next steps. If unfilled positions are no longer needed, the most prudent step is to eliminate them. However, if the position is currently filled, existing employees need to be transferred to different departments in need of full-time equivalents (FTEs). If there are no openings in other departments, these employees may become part of a pool of employees used to fill temporary shortages inside the organization. Retraining for other open positions is also an option if the displaced employee has related skills. Because they have just participated in process improvement projects, these staff members might also receive more training in process improvement tools and be assigned to other departments to aid in their projects.

If none of these options is possible, the last action available to the manager is to lay off the employee. It is difficult to execute projects that will clearly result in job loss—it is almost impossible to get employees to redesign

FIGURE 14.1
Process for HR
Planning
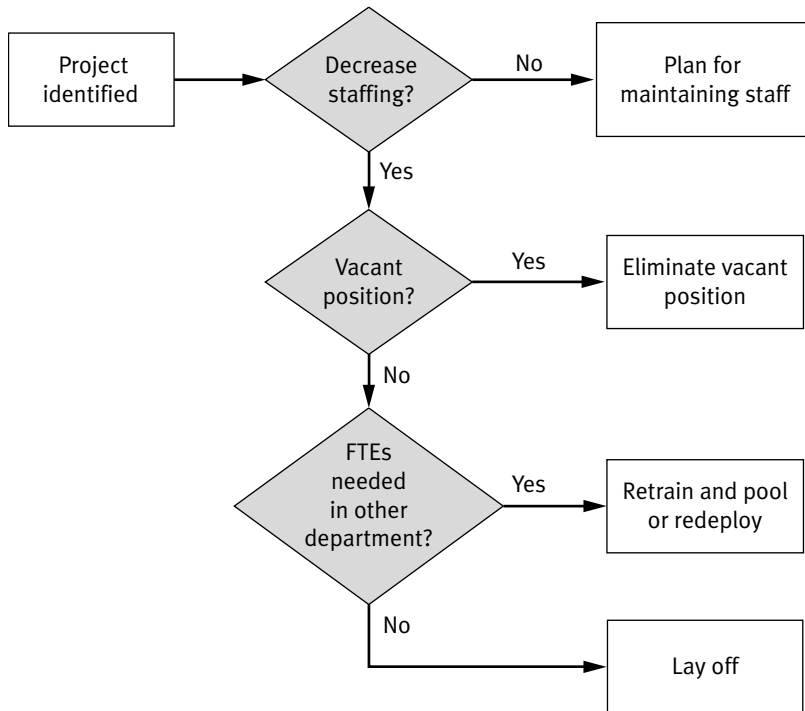
themselves out of a job. However, layoffs can generally be avoided in health-care, as labor shortages are widespread. In addition, most projects identified should be of the first type, those that will increase throughput with existing staff, as these tend to be the most critical for improved patient access and increases in the quality of clinical care.

The HR planning function should be ongoing and comprehensive. A well-communicated plan for employee reassignment and replacement should be in place. By identifying all potential projects during the annual planning cycle, the HR department can develop an organization-wide staffing plan. Without this critical function, many of the gains in operating improvements will be lost.

Managerial Accounting

The second key tool for holding the gains is the use of managerial account-ing (Gapenski 2005, Chapter 5). In contrast to financial accounting, which is used to prepare financial statements (the past), managerial accounting focuses on the future. Managerial accounting can be used to project the prof-itability of a particular project that improves patient flow or model the

revenue gains from a clinical pay-for-performance (P4P) contract. Even projects that appear to have no financial effect can benefit from managerial accounting. For example, a project to reduce hospital-acquired infections may not only provide higher quality care, but it may also reduce the length of stay for these patients and therefore improve the hospital's profitability.

It is useful to have a member of the finance staff engaged with operations improvement efforts. This team member should perform an initial analysis of the expected financial results for a project and monitor the financial model throughout the project. She should also ensure that the financial effect of an individual project flows through to the financial results for the entire organization. Monte Carlo simulation (Chapter 10) can be extremely helpful in evaluating the risks and rewards associated with various projects or decisions.

The first step in managerial accounting is to understand an operating unit's revenue source and how it changes with a change in operations. For example, capitation revenue may flow to a primary care clinic; in this case, a reduction in the volume of services will result in a profitability gain. However, if the revenue source for the clinic is fee-for-service payments, the reduction in volume will result in a revenue loss.

Evaluating many revenue sources in healthcare can be complex. For example, understanding inpatient hospital reimbursement via diagnosis-related group can be complicated, as some diagnoses pay substantially more than others. In addition, many other rules affect net reimbursement to the hospital, so a comprehensive analysis needs to be undertaken.

The trend toward consumer-directed healthcare and healthcare savings accounts means that the retail price of some services will also affect net revenue. If a market-sensitive outpatient service is priced too high, net revenue may decline as consumer demand will be lower.

Next, the costs for the operation must be identified and segmented into three categories: variable, fixed, and overhead. Variable costs are those that vary with the volume of the service; a good example is supplies used with a procedure. Fixed costs are those that do not vary with volume and include such items as space costs and equipment depreciation. Employees are usually designated as fixed costs, although they may be variable if the volume of services changes substantially and staffing levels are adjusted based on volume.

The final cost category is overhead, which is allocated to each department or unit in an organization that generates revenue. This allocation pays for costs of departments that do not generate revenue. Overhead formulas are critical to understanding the effect of making operational changes. For example, an overhead rate based on a percentage of revenue will have a substantially different effect than one based on the square footage a department occupies.

TABLE 14.1

Managerial
Accounting:
CVP Analysis

	Backlogged		Financial Loss	
	Base	Process Improvement Project	Base	Process Improvement Project
Test volume	1,000	1,500	1,000	1,050
Revenue/test	$150	$150	$150	$150
Total revenue	$150,000	$225,000	$150,000	$157,500
Costs				
Variable cost/unit	$38	$38	$38	$38
Fixed costs	$85,000	$85,000	$120,00	$80,000
Overhead	$20,000	$20,000	$20,000	$20,000
Total cost	$143,000	$162,000	$178,000	$139,900
Profit	$7,000	$63,000	($28,000)	$17,600

The next step in the managerial accounting process is to conduct a cost-volume-profit (CVP) analysis. Table 14.1 illustrates a CVP analysis of two outpatient services at VVH.

In the first case, the service is backlogged and current profit (base case) is $7,000 per year. However, if a process improvement project is undertaken, the volume can be increased from 1,000 to 1,500 tests per year. If staffing and other fixed costs remain constant, the net profit is increased to $63,000 per year.

The second example shows a situation where the service is operating at an annual loss of $28,000. In this case, the process improvement goal is to reduce fixed costs (staffing) with a slight increase in volume. The result is a $40,000 reduction in fixed cost, which yields a profit margin of $17,600. HR planning is critical in a project such as this to ensure a comfortable transition for displaced employees.

Control

The final key to holding the gains is a control system. Control systems have two major components: measurement/reporting and monitoring/response.

Chapter 6 discusses many tools for data capture and analysis, with an objective of finding and fixing problems. However, many of the same tools should be deployed for continuous reporting of the results of operations

improvement projects. It is important that data collection systems for monitoring outcomes be built into any operations improvement project from the beginning.

Once data collection is underway, results should be displayed both numerically and graphically. The run chart (Chapter 8) is still one of the most effective tools to monitor the performance of a process. Figure 14.2 illustrates a simple run chart for birthing center patient satisfaction, where a goal of greater than 90 percent satisfied patients has been agreed upon. This type of chart can show progress over time to ensure that the organization is moving toward its goals.

In addition to a robust data capture and reporting system, a plan for monitoring and response is critical. This plan should include identification of the individual or team responsible for the operation and a method for communicating the reports to them. In some cases, these operations improvement activities are of such strategic importance that they may become part of a departmental or organization-wide balanced scorecard.

A response plan should also be part of the ongoing control system. A procedure or plan should be developed to address situations in which a process fails to perform as it should. Jidoka and andon systems (Chapter 9) can help organizations to discover and correct instances where there is a problem with system performance. Control charts (Chapter 8) can be used to identify out-of control situations. Once an out-of-control situation is identified,
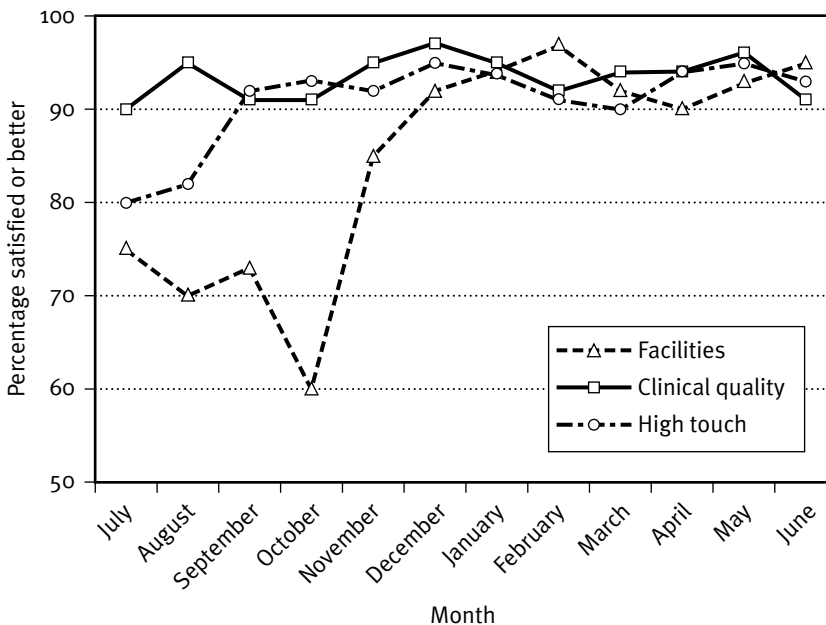
FIGURE 14.2
Run Chart for Birthing Center Patient Satisfaction

action should be taken to determine the special or assignable cause and eliminate it.

Which Tools to Use: A General Algorithm

This book presents an array of techniques, tools, and methods to achieve operational excellence. How does the practitioner choose from this broad array? As in clinical care, there is a mix of art and science in choosing the best approach.

A general algorithm for selecting tools is presented below. (ache.org/books/OpsManagement contains an automated and more detailed version of this algorithm.) The general logic discussion at the beginning of this chapter has been expanded to provide a more finely detailed path through the logic (Figure 14.3).

A. Issue Formulation

First, formulate the issue you wish to address. Determine the current state and a desired state (e.g., competitors have taken 5 percent of our market share in obstetrics and we want to recapture the market, the pediatric clinic lost $100,000 last year and we want to break even next year, public rankings for our diabetes care puts our clinic below the median and we want to be in the top quartile). It is important to frame the problem correctly to ensure that the outcome is the right answer to the right question rather than the right answer to the wrong question. In particular, all relevant stakeholders should be consulted.

A number of effective decision-making and problem-solving tools can be used to:

- Frame the question or problem;
- Analyze the problem and various solutions to the problem; and
- Implement those solutions.

The tools and techniques identified next provide a basis for tackling difficult, complicated problems.

- *The decision-making process:* a generic decision process used for any type of process improvement or problem solving. (Plan-do-check-act [PDCA], define-measure-analyze-improve-control [DMAIC], and project management all follow this same basic outline.)
  - Framing: used to ensure that the "correct" problem or issue is actually being addressed.
  - Gathering intelligence: find and organize the information needed to address the issue (data collection).

FIGURE 14.3   Algorithm for Use of the Tools, Techniques, and Methodologies in This Book
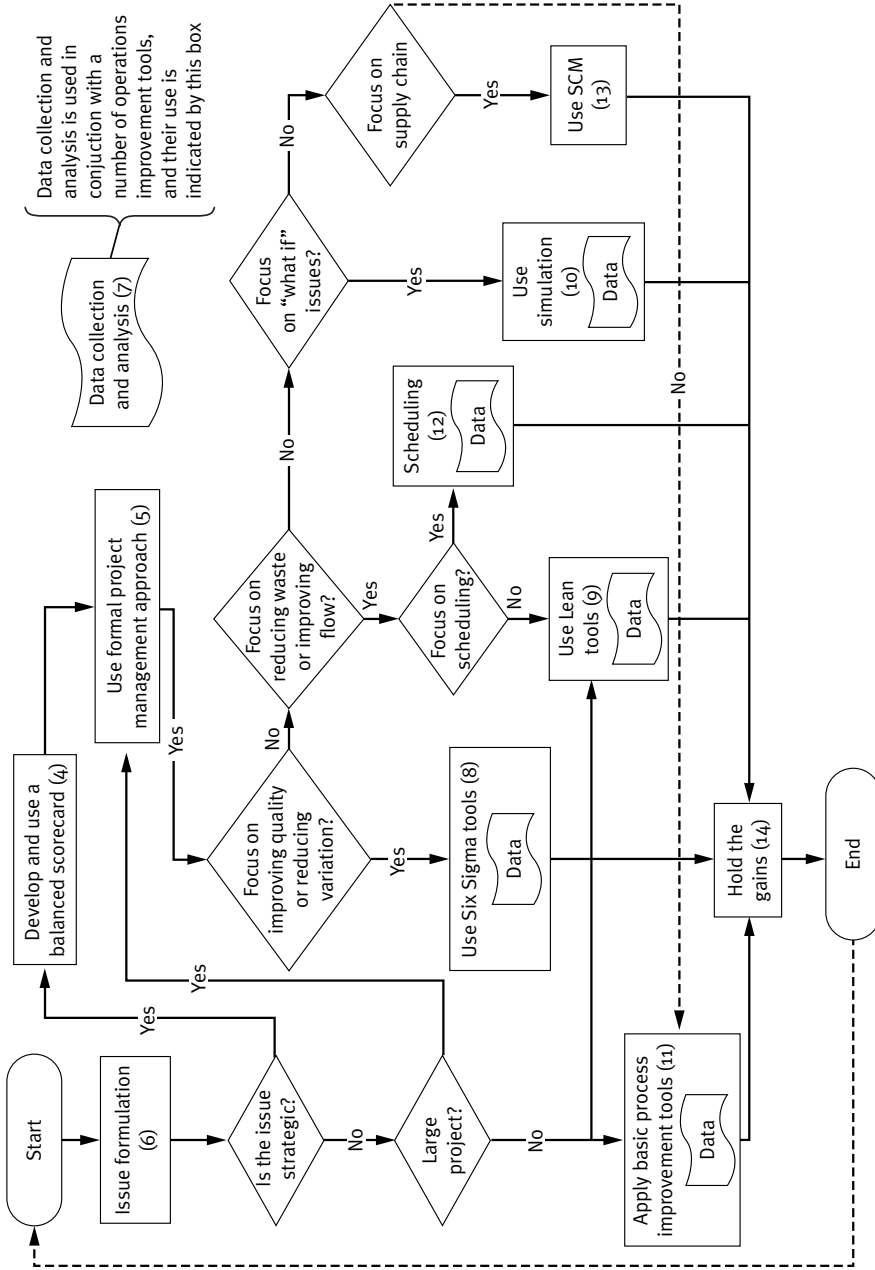
Model created in Microsoft *Visio*®.
NOTE: Chapter numbers are in parentheses.

-Coming to conclusions: determine the "solution" to the problem (data analyses).

-Learning from feedback: ensure that learning is not lost and that the solution actually works (holding the gains).

- *Mapping tools.*
  -Mind mapping: used to help formulate and understand the problem or issue.
  -Process mapping, activity mapping, and service blueprinting: used to "picture" the system and process steps.

- *Root-cause analysis (RCA) tools.*
  -Five whys technique and fishbone diagrams: used to identify causes and root causes of problems to determine how to eliminate those problems.
  -Failure mode and effects analysis (FMEA): a more detailed root cause–type analysis that can be used to identify and plan for both possible and actual failures.

B. Strategic or Operational Issue

Next decide whether the issue is strategic (e.g., major resources and high-level staff will be involved) or part of ongoing operations. If the issue is strategic, go to step C; if it is operational, go to step D or E, depending on the size and scope of possible solutions.

C. The Balanced Scorecard for Strategic Issues

To effectively implement a major strategy, develop a balanced scorecard to link initiatives and measure progress. Elements of the balanced scorecard will include:

- *Strategy map:* used to link initiatives or projects to achieve the desired state
- *Four perspectives:* initiatives and projects that span the four main perspectives of the balanced scorecard—financial, customer/patient, operations, and employee learning and growth
- *Metrics:* used to measure progress; includes both leading (predictive) and lagging (results) measures

If the balanced scorecard contains a major initiative, go to step D, project management; otherwise, go to step E, basic performance improvement tools.

D. Project Management

The formal project management methodology should be used for initiatives that typically last longer than six months and involve a project team. Project management includes these tools:

- *Project charter:* a document that outlines stakeholders, project sponsor, project mission and scope, a change process, expected results, and estimated resources required.
- *Work breakdown structure:* a listing of tasks that will be undertaken to accomplish the project goals, with assigned responsibilities and estimated durations and costs.
- *Schedule:* linking of tasks in precedence and relationship and identification of the critical path that determines the overall duration of the project.
- *Change control:* a method to formally monitor progress and make changes during the execution of a project.
- *Risk management:* an identification of project risks and plans to mitigate each risk.

If the project is primarily concerned with improving quality or reducing variation, use the project management technique and tools described in step G, quality and Six Sigma. If the operating issue is large enough for project management and primarily concerned with eliminating waste or improving flow, go to step H, Lean. If the issue is related to evaluating and managing risk or analyzing and improving flow, go to step I, simulation. If the project is focused on supply chain issues, go to step J, supply chain management (SCM). If the project focus is not encompassed by Six Sigma, Lean, simulation, or SCM, return to step E and use the basic performance improvement tools within the larger project management system.

E. Basic Performance Improvement Tools

Basic performance improvement tools are used to improve and optimize a process. In addition to RCA, the following tools can be helpful in moving toward more effective and efficient processes and systems:

- *Optimization using linear programming:* used to determine the optimal allocation of scarce resources.
- *Theory of constraints (TOC):* used to identify and manage constraints in the system. The TOC technique consists of five steps:
  1. Identify the constraint (or bottleneck).
  2. Exploit the constraint: determine how to get the maximum performance out of the constraint without major system changes or capital improvements.
  3. Subordinate everything else to the constraint: other non–bottleneck resources (or steps in the process) should be synchronized to match the output of the constraint.
  4. Elevate the constraint: do something (capital expenditure, staffing increase, etc.) to increase the capacity of the constraining resource until it is no longer the constraint. Something else will be the new constraint.
  5. Repeat the process for the new constraint.

- *Force field analysis:* used to identify and manage the forces working for and against change (applicable to any change initiative, including TOC, Six Sigma, and Lean).

If these tools provide an optimal solution, go step J, holding the gains. However, sometimes the operating issues are so large that they will benefit from the formal project management discipline. In this case, go to step D. If the project is relatively small and focused on eliminating waste, go to step G, Lean, where the kaizen event tool can be used for quick improvements.

F. Quality and Six Sigma
The focus of quality initiatives and the Six Sigma methodology is on improving quality, eliminating errors, and reducing variation.

- *DMAIC:* the process improvement or problem-solving technique used in Six Sigma. The DMAIC technique consists of five steps:
  1. Define: define the problem or process (see step A, issue formulation).
  2. Measure: determine the current state of the process (see the section Data and Statistics).
  3. Analyze: analyze the collected data to determine how to fix the problem or improve the process.
  4. Improve: make changes to improve the process or solve the problem.
  5. Control: ensure that changes are embedded in the system (see step J, holding the gains).

  Note that at any point in the process it may be necessary to loop back to a previous step. Once the process is complete, start around the loop again.
- *Seven basic quality tools:* used in the DMAIC process to improve the process or solve the problem. The basic quality tools are:
  1. Fishbone diagram: used for analyzing and illustrating the root causes of an effect.
  2. Check sheet: a simple form used to collect data.
  3. Histogram: a graph used to show frequency distributions.
  4. Pareto chart: a sorted histogram.
  5. Flowchart: a process map.
  6. Scatter plot: a graphic technique to analyze the relationship between two variables.
  7. Run chart: a plot of a process characteristic in chronological sequence.
- *Statistical process control:* an ongoing measurement of process output characteristics to ensure quality. Enables the identification of a problem situation before an error occurs.

- *Process capability:* a measure of whether a process is actually capable of producing the desired output.
- *Benchmarking:* the determination of what is possible based on what others are doing. Used for comparison purposes and goal setting.
- *Quality function deployment:* used to match customer requirements (voice of the customer) with process capabilities, given that trade-offs must be made.
- *Poka-yoke:* mistake-proofing.

Once these tools have produced satisfactory results, proceed to step J, holding the gains.

G. Lean

Lean initiatives are typically focused on eliminating waste and improving flow in the system or process.

- *Kaizen philosophy:* the process improvement technique used in Lean. The kaizen technique consists of the following steps:
  1. Specify value: identify activities that provide value from the customer's perspective.
  2. Map and improve the value stream: determine the sequence of activities or the current state of the process and the desired future state. Eliminate non–value-added steps and other waste.
  3. Flow: enable the process to flow as smoothly and quickly as possible.
  4. Pull: enable the customer to pull products or services.
  5. Perfection: repeat the cycle to ensure a focus on continuous improvement.
- *Value stream mapping:* used to define the process and determine where waste is occurring.
- *Takt time:* a measure of time needed for the process based on customer demand.
- *Throughput time:* a measure of the actual time needed in the process.
- *Five Ss:* a technique to organize the workplace.
- *Spaghetti diagram:* a mapping technique to show the movement of customers (patients), workers, equipment, and so on.
- *Kaizen blitz or event:* used to improve the process quickly, when project management is not needed.
- *Standardized work:* written documentation of the precise way in which every step in a process should be performed. A way to ensure that things are done the same way every time in an efficient manner.
- *Jidoka and andon:* techniques or tools used to ensure that things are "done right the first time" to catch and correct errors.
- *Kanban:* scheduling tool used to pull rather than push work.

- *Single-minute exchange of die:* a technique to increase the speed of changeover.
- *Heijunka:* leveling production (or workload) so that the system or process can flow without interruption.

Once these tools have produced satisfactory results, proceed to step J, holding the gains.

H. Simulation

Simulation is used to evaluate "what if" situations. Usually it is less expensive or speedier than changing the real system and evaluating the effects of those changes.

- *The simulation process* consists of the following steps:
    1. Model development: develop a model of the process or situation of interest.
    2. Model validation: ensure that the model accurately represents reality.
    3. Simulate and analyze output: run the simulation and analyze the output to determine the answers to the questions asked, optimize the process, or manage risk.
- *Monte Carlo simulation:* typically used to evaluate and manage the risks associated with various decisions based on random variables.
- *Discrete event simulation:* based on queueing theory. Used to model system flows to improve the system.

Once these tools have produced satisfactory results, proceed to step J, holding the gains.

I. Supply Chain Management

SCM focuses on all of the processes involved in getting supplies and equipment from the manufacturer to use in patient care areas. SCM is the management of all activities and processes related to both upstream vendors and downstream customers in the value chain. Effective and efficient management of the supply chain requires an understanding of all of the following:

- Tools for tracking and managing inventory;
- Forecasting;
- Inventory models;
- Inventory systems;
- Procurement and vendor relationship management; and
- Strategic SCM.

Once these tools have produced satisfactory results, proceed to step J, holding the gains.

J. Holding the Gains

Once successful operational improvements have been completed, three tools can be used to ensure that these changes will endure:

1. *HR planning:* a plan to use employees in new ways after an improvement project is completed.
2. *Managerial accounting:* a study of the expected financial consequences and gains after an operations improvement project has been implemented.
3. *Control systems:* a set of tools to monitor the performance of a new process and methods to take corrective action if desired results are not achieved.

Data and Statistics

All of the aforementioned tools, techniques, and methodologies require data and data analysis. Tools and techniques associated with data collection and analysis include the following:

- *Data collection techniques:* used to ensure that valid data are collected for further analysis.
- *Graphic display of data:* used to "see" the data.
- *Mathematic descriptions of data:* used to compare sets of data and for simulation.
- *Statistical tests:* used to determine whether differences in data exist.
- *Regression analyses:* used to investigate and define relationships among variables.
- *Forecasting:* used to predict future values of random variables.

Operational Excellence

Many leading hospitals, medical groups, and health plans are using the tools and techniques contained in this book. Unfortunately, these tools have not seen widespread use in healthcare, nor have they been as comprehensively applied as in other sectors of the economy. The authors have developed a scale for the application of these tools to gauge progress toward comprehensive operational excellence in healthcare.

Level 1

There are no organized operations monitoring or improvement efforts at level 1. Quality efforts are aimed at compliance and the submission of data to regulating agencies.

Level 2

At level 2, the organization has begun to use operations data for decision making. There are pockets of process improvement activities where process mapping and PDCA or rapid prototyping are employed. Evidence-based medicine (EBM) guidelines are used in some clinical activities.

Level 3

Senior management has identified operations improvement efforts as a priority by level 3. The organization conducts operations improvement experiments, uses a disciplined project management methodology, and maintains a comprehensive balanced scorecard. Some P4P bonuses are received, and the organization obtains above-average scores on publicly reported quality measures.

Level 4

A level-4 organization engages in multiple process improvement efforts using a combination of project management, Six Sigma, Lean, and simulation tools. It has trained a significant number of employees in the advanced use of these tools, and these individuals lead process improvement projects. EBM guidelines are comprehensively used, and all P4P bonuses are achieved.

Level 5

Operational excellence is the primary strategic objective of an organization at level 5. Operations improvement efforts are underway in all departments, led by departmental staff who have been trained in advanced tools. The organization uses real-time simulation to control patient flow and operations. New EBM guidelines and best practices for administrative operations are developed and published by this organization, which scores in the top 5 percent of any national ranking on quality and operational excellence.

A few leading organizations currently are at level 4, but most reside between levels 2 and 3. Our friends at VVH are at the top of 3 and moving toward 4.

VVH Strives for Operational Excellence

As can be recalled from Chapter 3, VVH leadership was encouraged by its board to participate in the Bridges to Excellence (BTE) program. Because the leadership team believed that P4P was an important new trend, they added an initiative to their corporate balanced scorecard: "Conduct projects to optimize P4P and generate at least a 5 percent increase in revenue." VVH

reorganized its structure to combine a number of operations and quality activities into a new organization-wide department known as operations management and quality.

The BTE program is employer sponsored and provides participating medical groups with up to $80 a year per patient with diabetes if they are top performers in diabetes care. The specific goals VVH chose to achieve were:

- Hemoglobin A1c of less than 7 percent
- Low-density lipoprotein cholesterol lower than 100 mg/dL
- Blood pressure lower than 130/80 mm Hg
- Nonsmoking status
- Aspirin for patients over age 40

The first step in the project was to identify a team and develop a project charter and schedule (Chapter 5). Both the HR and finance departments were included in the project team to model financial consequences (new revenues, possible new costs, capital requirements) and the potential effect on staffing levels.

The project team began by collecting data on current performance and summarizing them using visual and mathematic techniques to determine where performance was not meeting goals (Chapter 7). A process map was constructed and compared with Institute for Clinical Systems Improvement guidelines to determine where processes could be improved to achieve the desired results. Various Six Sigma tools (fishbone diagrams, check sheets, Pareto charts, and scatter plots) were employed to further analyze and improve the process (Chapter 8).

The clinicians on the project team performed a careful analysis to determine which areas of the treatment of patients with diabetes could be standard and which needed customization. The standard modules were then examined for both effectiveness and efficiency using value stream mapping (Chapter 9). Patient flow for the standard care modules was also modeled and entered into a simulation model to test various patient movement options (Chapter 10).

Changes were identified, many of them requiring either a staffing change or a change in VVH's electronic medical record. Because many options were available and it was not clear which would achieve the desired results, a decision tree (Chapter 6) was constructed to identify the optimal process improvements. Finally, once the project team began to implement these process improvements, the results were monitored with control charts (Chapter 7). After six months, VVH had realized a gain of 7 percent in revenue from this project.

The Healthcare Organization of the Future

A future healthcare organization operating at level 5 is illustrated in Figure 14.4. This care delivery system would use many of the tools and techniques contained in this text. A demand prediction model (Chapter 13) would generate predictions of demand for inpatient and ambulatory care services. Because much of the care delivered in these sites would be through the use of EBM guidelines (Chapter 3) that have optimized processes (Chapters 7 to 9), the resource requirements could be predicted as well; these predictions would drive scheduling and supply chain systems.

A key component of this future system is a real-time operations monitoring and control system. This system would use the simulation and modeling techniques described in Chapter 10 to monitor, control, and optimize patient flow and diagnostic and treatment resources. Macro-level control systems such as the balanced scorecard (Chapter 4) would ensure that this system meets the organization's strategic objectives. The result would be a finely tuned healthcare delivery system providing high-quality clinical care in the most efficient manner possible.

FIGURE 14.4

An Optimized Healthcare Delivery System of the Future
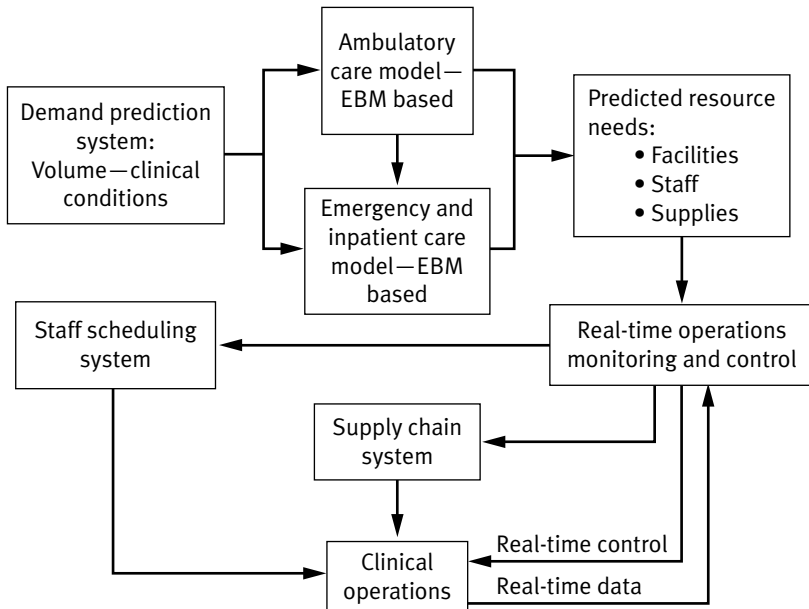
Conclusion

We hope that this text is helpful to you and your organization on your journey toward level 5. We are interested in your progress whether you are a new member of the health administration team, a seasoned department head, or a physician leader—please use the e-mail addresses on the companion web site to inform us of your successes and let us know what we could do to make this a better text.

Because many of the tools discussed in this text are evolving, we will continuously update the companion web site at ache.org/books/OpsManagement with revisions and additions; check there frequently. We too are striving to be level 5.

Discussion Questions

1. Identify methods to reduce employees' resistance to change during an operations improvement project.
2. What should be the key financial performance indicator used to analyze performance changes for hospitals? Clinics? Health plans? Public health agencies?
3. Describe tools (other than control charts) that can be used to ensure that processes achieve their desired results.
4. Describe the tools, methods, and techniques in this book that would be used to address the following operating issues:
   a. A hospital laboratory department provides results late and frequently erroneously.
   b. A clinic's web-based patient information system is not being used by the expected number of patients.
   c. An ambulatory clinic is financially challenged but has a low staffing ratio compared with similar clinics.

Case Study: VVH

VVH has a serious problem: A major strategic objective of the health system was to grow its ambulatory care network, but the organization is facing a number of challenges. Although a new billing system was installed and various reimbursement-maximization strategies were executed, total costs in the system exceed revenue. This was occurring even though the clinic staff felt busy and backlog appointments were growing. Analysis of clinic data

also indicated an increasing number of patients were canceling appointments or were "no shows."

In addition, a new group of multispecialty and primary care physicians had been created from the merger of three separate groups; this clinic is aggressively competing with VVH for privately insured patients. The new large clinic is making same-day clinic appointments available and heavily advertising them.

The board of VVH asked the chief executive officer (CEO) to develop a plan to address this growing concern. The CEO first formed a small strategy team to lead improvement efforts; its first step was to assign the chief operating officer, chief financial officer, and medical director to direct the planning and finance staff on the improvement team.

VVH ultimately decided that it needed to increase the number of patients seen by clinicians and begin to implement advanced access in its clinics. Because VVH believes in knowledge-based management and sharing in improved methods of delivering health services, the organization has made its data and information available on the companion web site. VVH invited students and practitioners to help them improve this system.

1. Frame the original issue for VVH. Mind maps and RCA may be useful here.
2. How would you address the no-shows and cancellations issue?
3. Develop a project charter for one project associated with VVH's problems.
4. Develop a balanced scorecard for VVH's clinics.
5. If VVH decided that it should focus on increasing throughput in the system, how would you go about doing this? Be specific.
6. Would simulation be a useful tool in VVH's quest to implement advanced access? Why or why not? How would you go about implementing advanced access? Be specific.

References

Fried, B. J., M. D. Fottler, and J. A. Johnson, eds. 2005. *Human Resources in Healthcare: Managing for Success*, 2nd ed. Chicago: Health Administration Press.

Gapenski, L. C. 2005. *Healthcare Finance: An Introduction to Accounting and Financial Management*, 4th ed. Chicago: Health Administration Press.

Jackson, S. E., and R. S. Schuler. 1990. "Human Resource Planning: Challenges for Industrial/Organizational Psychologists." *American Psychologist* 45 (2): 223–39.

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