Contents

Preface

The seventh edition of *Managing Engineering and Technology* maintains the focus of prior editions on supporting the growth of engineers into engineering managers, while considering the changing professions of engineering and engineering management. Engineers are talented problem solvers who often lack the training or expertise to solve problems through others. To build that expertise, *Managing Engineering and Technology* provides readers with the foundations of engineering management in five parts. In Part 1, we introduce the concept of engineering management, its relationship to engineering, and its historical underpinnings. In Part 2, we provide the core of management thought, including the four traditional roles of management—planning, organizing, leading, and controlling—with a particular focus on leadership and how leadership fits into an engineering management context. In addition, we provide tools to understand how human motivation and leadership are used to promote effectively working with and managing technical professionals. In Part 3, we explore both traditional (e.g., managing design) and non-traditional (e.g., managing marketing) roles of the engineering manager when managing technology. In Part 4, we provide an overview of the Project Management process. And in Part 5, we provide tools and discuss key topics needed to be successful in an engineering management career, including an exploration of engineering ethics, tools for career management, and key concepts of the forces changing the worlds of engineering and engineering management, including globalization.

WHAT'S NEW IN THIS EDITION?

This edition welcomes a new author with substantial experience as a practicing engineering manager and engineering management educator. That change brings a number of new and improved content to assist in the development of students' engineering management skills. The text is updated throughout, with new and revised content in each chapter. Key enhancements include:

- **New vignettes** in each chapter that explore modern developments in the management of engineering and technology with an application or example tied to the material from that chapter. These include discussions of highly successful engineering managers and those with headline grabbing ethical failings.
- **An entirely rewritten Chapter 13 on marketing**, with a focus on the movement toward digital marketing and how an engineering toolset can be used in this data-driven world.

- **Extensive new material in Chapter 16 on ethics**, with new ethical models incorporated that are typically easier for undergraduate students to relate to and utilize.
- **A substantially rewritten Chapter 18**, updated to reflect the current state of globalization and aspects of political unrest around the world.
- **Refreshed and updated content** in each chapter that highlights current trends and topics, such as the many roles of engineering in Amazon, Inc., updated leadership models, and examinations of leadership and management from beyond the Western world. In addition, changes to modernize the language and make it more welcoming and inclusive were made throughout the text. These updates included substantial streamlining of several chapters, reducing the overall text length by 10% while maintaining all key concepts and content.

FOR THE INSTRUCTOR

All of these considerable enhancements were made while retaining the same organization and topical flow from the sixth edition to allow for a smoother adoption for instructors. At the same time, this new material has led to considerable changes in the exercises for each chapter. Most chapters have 25%+ new questions from the prior edition. An updated instructor's guide and chapter slides are available at www.pearson.com/engineering-resources.

Acknowledgments

Together we'd like to thank Dan Babcock for his initial vision for this text and all of our colleagues at the American Society for Engineering Management and the American Society for Engineering Education who have helped clarify our thinking and writing about Engineering Management and Engineering Management education over the years. Those acknowledged in prior editions whose work continues to contribute to this edition include Henry Metzner (Missouri S&T), Jean Babcock, Ted Eschenbach (U. Alaska-Anchorage), Thomas A. Crosby (Pal's Sudden Service), Charles W. Keller (U. Kansas), Brian Goldiez (U. Central Florida), Nabeel Yousef (Daytona State College), and C. Steven Griffin (CSR).

Notable supporters for the thinking that went into this edition include Craig Downing (Rose-Hulman), Ted Eschenbach (U. Alaska-Anchorage), and Paul Kauffmann (East Carolina University). In addition, we thank our students who, over the years, have both intentionally and unwittingly helped us to identify opportunities to improve the text and areas of new knowledge that needed to be incorporated. For this edition we are extremely grateful to Norm Asbjornson of AAON, Inc. and Doug Melton of the Kern Entrepreneurial Engineering Network for use of their materials when developing the vignettes for Chapters 4 and 9, and to the team at Pearson for their guidance and support.

Most importantly, we thank our families for their continued support and encouragement. Without the love and patience of Jack Selter and Melanie, Ana, Megan, and William Griffin Schell the journey to create this text would not have been possible.

Part I

Introduction to Engineering Management

1

Engineering and Management

PREVIEW

Today's technological society is constantly changing, and with this change comes a need for the engineer to be able to address society's technological challenges as well as the opportunities for the future. Engineers play a key role in maintaining technological leadership and a sound economy as the world becomes flatter in today's global economy. To do this, the engineer needs to remain alert to changing products, processes, technologies, and opportunities. To make the transition from successful engineer to successful engineering manager, engineers must learn and apply a new set of tools.

To assist the engineer prepare for a productive life and position of leadership, this chapter begins with a discussion of the origins of engineering practice and education, the nature of the engineering profession, and the types of engineers, their work, and their employers. Next, management is defined and managerial jobs and functions are characterized. Finally, these topics are synthesized by defining engineering management and a discussion of the expectation of managerial responsibilities in an engineering career.

LEARNING OBJECTIVES

When you have finished studying this chapter, you should be able to do the following:

- Describe the origins of engineering practice.
- Identify the functions of management.
- Explain what engineering management is.
- Explain the need for engineers in management.

ENGINEERING

Origins of Engineering

The words *engineer* and *ingenious* both stem from the Latin *ingenium,* which means a talent, natural capacity, or clever invention. Early applications of *clever inventions* often were military ones, and *ingeniarius* became one of several words applied to builders of such *ingenious* military machines.

Heritage of the Engineer. By whatever name, the roots of engineering lie much earlier than the time of the Romans, and the engineer today stands on the shoulders of giants. William Wickenden said this well in 1947:

> Engineering was an art for long centuries before it became a science. Its origins go back to utmost antiquity. The young engineer can say with truth and pride, "I am the heir of the ages. Tubal Cain, whom Genesis places seven generations after Adam and describes as the instructor of every artificer in brass and iron, is the legendary father of my technical skills. The primitive smelters of iron and copper; the ancient workers in bronze and forgers of steel; the discoverers of the lever, the wheel, and the screw; the daring builders who first used the column, the arch, the beam, the dome, and the truss; the military pioneers who contrived the battering ram and the catapult; the early Egyptians who channeled water to irrigate the land; the Romans who built great roads, bridges, and aqueducts; the craftsmen who reared the Gothic cathedrals; all these are my forbears. Nor are they all nameless. There are: Hero of Alexandria; Archimedes of Syracuse; Roger Bacon, the monk of Oxford; Leonardo da Vinci, a many-sided genius; Galileo, the father of mechanics; Volta, the physician; the versatile Franklin. Also, there are the self-taught geniuses of the industrial revolution: Newcomen, the ironmonger; Smeaton and Watt, the instrument makers; Telford, the stone mason; and Stephenson, the mine foreman; Faraday and Gramme; Perronet, Baker, and Roebling; Siemens and Bessemer; Lenoir and Lavassor; Otto and Diesel; Edison, Westinghouse, and Steinmetz; the Wright brothers, and Ford. These are representative of the trail blazers in whose footsteps I follow."

Beginnings of Engineering Education. Florman contrasts the French and British traditions of engineering education in his *Engineering and the Concept of the Elite,* and the following stems both from that and from Daniel Babcock's writings. In 1716 the French government, under Louis XV, formed a civilian engineering corps, the *Corps des Ponts et Chausées*, to oversee the design and construction of roads and bridges, and in 1747 founded the *Ecole des Ponts et Chausées* to train members of the corps. This was the first engineering school in which the study of mathematics and physics was applied not only to roads and bridges, but also to canals, water supply, mines, fortifications, and manufacturing. The French followed by opening other technical schools, most notably the renowned *Ecole Polytechnique* under the revolutionary government in 1794. In England, on the other hand, gentlemen studied the classics, and it was not until 1890 that Cambridge added a program in *mechanical science,* and 1909 when Oxford established a chair in *engineering science.* True, the Industrial Revolution began in England, but *[k]nowledge was gained pragmatically, in the workshop and on construction sites, and engineers learned their craft—and such science as seemed useful, by apprenticeship.*

America is heir to both traditions. Harvard and other early colleges followed the British classical tradition, and during the Revolutionary War, we borrowed engineers from France and elsewhere to help build (and destroy) military roads, bridges, and fortifications. "In the early days of the United

States, there were so few engineers—less than 30 in the entire nation when the Erie Canal was begun in 1817—that America had no choice but to adopt the British apprenticeship model. The canals and shops—and later the railroads and factories—were the 'schools' where surveyors and mechanics were developed into engineers. As late as the time of World War I, half of America's engineers were receiving their training 'on the job."'

The U.S. Military Academy was established in 1802, at the urging of Thomas Jefferson and others, as a school for engineer officers, but they did not distinguish themselves in the War of 1812. Sylvanus Thayer, who taught mathematics at the Academy, was sent to Europe to study at the *Ecole Polytechnique* and other European schools; on his return in 1817 as superintendent of the Academy, he introduced a four-year course in civil engineering, and hired the best instructors he could find. As other engineering schools opened, they followed this curriculum and employed Academy graduates to teach from textbooks authored by Academy faculty. Florman continues:

> Perhaps the most crucial event in the social history of American engineering was the passage by Congress of the Morrill Act—the so-called "land grants" act—in 1862. This law authorized federal aid to the states for establishing colleges of agriculture and the so-called "mechanic arts." The founding legislation mentioned "education of the industrial classes in their several pursuits and professions in life." With engineering linked to the "mechanic arts," and with engineers expected to come from the "industrial classes," the die was cast. American engineers would not be elite polytechnicians. They would not be gentlemen attending professional school after graduation from college [as law and medicine became]. . . . Engineering was to be studied in a four-year undergraduate curriculum.

Engineering as a Profession

The first issue (1866) of the English journal *Engineering* began with a description of

> the profession of the engineer as defined in the charter that Telford obtained [in 1818 for the Institute of Civil Engineers] for himself and his associates from [King] George the Fourth—"the art of directing the great sources of power in nature, for the use and convenience of man."

A more modern definition was created in 1979 by American engineering societies, acting together through the Engineers' Council for Professional Development (ECPD), the precursor to ABET (previously the Accrediting Board for Engineering and Technology). ECPD's definition focused on the application of math and science knowledge to develop novel solutions for the benefit of mankind.

This definition was modernized again in 2013 by the International Engineering Alliance (whose members include ABET). This update expands the definition to acknowledge the potential adverse consequences of engineering activity and note the ethical responsibility of engineers to to manage these risks and safeguard society and the environment.

Certainly, engineering meets all the criteria of a proud profession. Engineering undergraduates recognize the need for "intensive preparation" to master the specialized knowledge of their chosen profession, and practicing engineers understand the need for lifelong learning to keep up with the march of technology. In Part V of this book, we look at engineering societies and their ethical responsibilities in maintaining standards of conduct. Finally, engineers provide a public service not only in the goods and services they create for the betterment of society, but also by placing the safety of the public high on their list of design criteria. Each generation of engineers has the opportunity and obligation to preserve and enhance by its actions the reputation established for this profession by its earlier members.

What Engineers Do

Engineering. Before a description of engineers can be made, the term *engineering* must be defined. We can define engineering as follows:

> En-gi-neer-ing *n*: a branch of science and technology concerned with the invention, design, building, maintenance, and improvement of structures, machines, devices, systems, materials, and processes.

In other words, engineering is the means by which people make possible the realization of human dreams by extending our reach in the real world. Engineers are the practitioners of the art of managing the application of science and mathematics, a practice that is generally accomplished through projects. By this description, engineering has a limitless variety of possible disciplines.

Engineers. Engineering has been differentiated from other academic paths by the need for people to logically apply quantifiable principles. Academic knowledge, practical training, experience, and work-study are all avenues to becoming an engineer. The key attribute for engineers is the direct application of that knowledge and experience. The most up-to-date information on opportunities available for engineers can be found at various websites on the internet, industry publications, professional associations, and personal contacts within industry. Like other fields of endeavor, engineering no longer represents a static career choice. The basic idea is to be adept, adaptable, and aware.

Types of Engineers. The rigid classification of engineers into specific specialties and careers has been eroding swiftly. Many engineering applications require cross-pollination or integration of multiple disciplines. Aerospace engineers require knowledge of metallurgy, electronic control systems, computers, production limitations and possibilities, finance, life cycle logistic planning, and customer service. These are all required to produce a viable commercial product such as an airliner or a fighter. The previous focus on a speciality is no longer as important as being able to communicate and team with others. These teams are composed of various specialists knowledgeable in several primary fields. The primary specialization allows the engineer to contribute in a core area. This knowledge is required to properly integrate and implement the ideas of others. Along those lines, the list of core technologies is expanding and mutating rapidly. During the early age of computers, the late 1950s, software engineers were electrical engineers. The computer operating systems were custom tailored to the internal logic design. As advances in design created the need for software specialists, the electrical engineers evolved into software engineers. Today, software engineers are split among the various types of applications. Desktop, internet, server, Internet of Things (IoT), and mobile operating system gurus are eagerly sought in a wide variety of industries. A similar process can be observed in construction, mechanical systems, chemical engineering, and industrial engineering. Another indicator of the change in engineering has been the development of the field of engineering technology. Engineering technology emerged in direct response to industry needs for a person having a practical applications education. Experience and training will increasingly determine an engineer's actual specialty. Adding to the confusion is the expectation that a person will change careers five or more times in their life, a trend that accelerates with each new generation. Flexibility and interpersonal skills will be the hallmark of the new generation of engineering disciplines.

Engineering Employment. Traditional paths for a career in engineering have mirrored other fields of employment. Rarely will a person work for the same employer for their entire working lifetime. The simple fact is that the corporations and firms of the past no longer exist. Those currently in existence will have to change to meet the needs of customers. Employment opportunities lie with companies of all sizes. Greater size can mean greater work stability, albeit usually limited flexibility. This limitation is accompanied by the fact that larger firms have greater resources to implement change. A smaller firm may be less stable, but can rapidly adapt to changing circumstances. Unfortunately, smaller firms have fewer resources to respond to the changing circumstances. This means that engineers of the future should expect to be constantly improving their skills and marketability. Continuing education, flexibility, and a willingness to shift employment will be required of successful engineers.

Government employment traditionally meant steady employment with a relatively secure career path. This situation changed as government embraced business-based practices to reduce costs by outsourcing and contracting. A greater reliance on information technologies also reduced the workforce requirements through better communications. Although a large number of engineers remain employed by various governmental agencies, their main focus is evolving into oversight managers and controllers. Seniority currently guides progression in government service. However, the same forces found in the civilian market will generate a similar need in government employment for flexibility, continuing education, and willingness to switch jobs.

Engineering Jobs in an Organization. Organizations of all types, from manufacturing to retail and financial services to government offer many types of jobs for engineers. Figure 1-1 displays a depiction of a basic organization chart for Amazon.com, along with some of the types of engineering positions available within the company. Amazon is a large and complex business, with engineers in roles throughout, including many in technology, research and design (R&D), and operations. The role of engineering positions in research and design is discussed in Chapters 9 and 10. Engineering functions in operations are discussed in Chapters 11 and 12. The more technically complex the product, the more engineers will be involved in technical sales, field service engineering, and logistics support, as discussed in Chapter 13. Finally, we discuss how in today's age of technical complexity, many general management positions are held by engineers.

MANAGEMENT

Management Defined

The Australian Edmund Young, in supplementary notes used in teaching from the original edition of this chapter, wrote that

> "[m]anagement" has been one of the most ubiquitous and misused words in the 20th century English language. It has been a "fad" word as well. Civil engineers discuss river basin management and coastal management, doctors discuss disease management and AIDS management, and garbage collectors are now waste management experts.

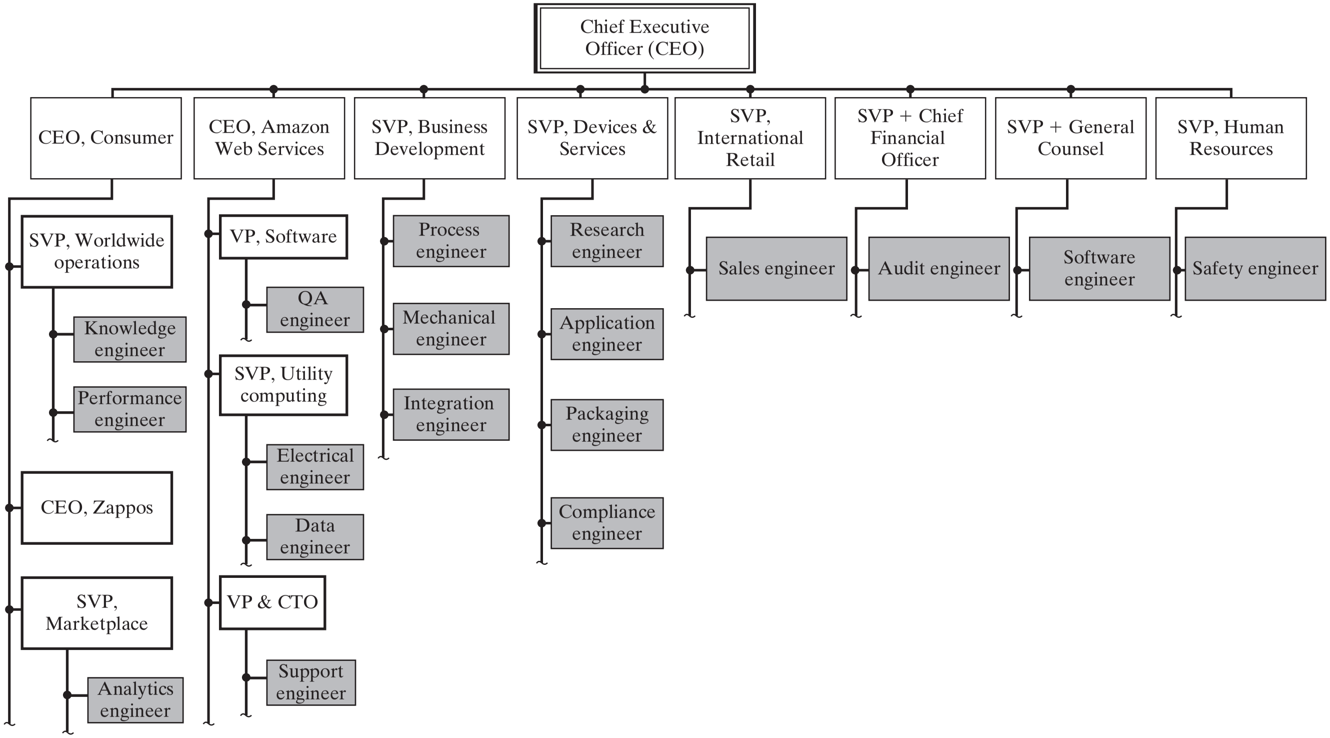

Figure 1-1 Selection of engineering roles in the organization of Amazon.com.

McFarland traces the meaning of the words *manage* and *management* as follows:

> The word *manage* seems to have come into English usage directly from the Italian *maneggiare*, meaning "to handle," especially to handle or train horses. It traces back to the Latin word *manus*, "hand." In the early sixteenth century *manage* was gradually extended to the operations of war and used in the general sense of taking control, taking charge, or directing. . . . *Management* was originally a noun used to indicate the process for managing, training, or directing. It was first applied to sports, then to housekeeping, and only later to government and business.

McFarland continues by identifying "four important uses of the word *management*, as (1) an organizational or administrative process; (2) a science, discipline, or art; (3) the group of people running an organization; and (4) an occupational career." Sentences illustrating each of these in turn might be (1) "He practices good management"; (2) "She is a management student"; (3) "Management *doesn't really believe* in quality"; and (4) (heard from innumerable college freshmen) "I want to get into management." Of these four, most authors of management textbooks are referring to the first meaning (the *process*) when they define "management." According to some of these authors, management is defined in the following ways:

- The work of creating and maintaining environments in which people can accomplish goals efficiently and effectively (Albanese)
- The process of achieving desired results through efficient utilization of human and material resources (Bedeian)
- The process of reaching organizational goals by working with and through people and other organizational resources (Certo)
- A set of activities (including planning and decision making, organizing, leading, and controlling) directed at an organization's resources (human, financial, physical, and information) with the aim of achieving organizational goals in an efficient and effective manner (Griffin)
- The process by which managers create, direct, maintain, and operate purposive organizations through coordinated, cooperative human effort (McFarland)
- The process of acquiring and combining human, financial, informational, and physical resources to attain the organization's primary goal of producing a product or service desired by some segment of society (Pringle, Jennings, and Longnecker)

Albanese provides a set of definitions of the word *management* suggested by a sample of business executives:

- Being a respected and responsible representative of the company to your subordinates
- The ability to achieve willing and effective accomplishments from others toward a common business objective
- Organizing and coordinating a profitable effort through good decision making and people motivation
- Getting things done through people
- The means by which an organization grows or dies
- The overall planning, evaluating, and enforcement that goes into bringing about "the name of the game"—profit
- Keeping your customers happy by delivering a quality product at a reasonable cost
- Directing the actions of a group to accomplish a desired goal or objective in the most efficient manner

Management Levels

Ensign or admiral, college president or department chair, maintenance foreman, plant manager, or company president—all are managers. What skills must they have, what roles do they play, what functions do they carry out, and how are these affected by the level at which they operate? Let us look at each of these questions in order.

Management is normally classified into three levels: first-line, middle, and top. Managers at these three levels need many of the same skills, but they use them in different proportions. The higher the management level is, the further into the future a manager's decisions reach, and more resources placed at risk.

First-line managers directly supervise nonmanagers. They hold titles such as foreman, supervisor, or section chief. Generally, they are responsible for carrying out the plans and objectives of higher management, using the personnel and other resources assigned to them. They make short-range operating plans governing what will be done tomorrow or next week, assign tasks to their workers, supervise the work that is done, and evaluate the performance of individual workers. First-line managers may only recently have been appointed from among the ranks of people they are now supervising. They may feel caught in the middle between their former coworkers and upper management, each of which feels the supervisor should be representing them. Indeed, they must provide the *linking pin* between upper management and the working level, representing the needs and goals of each to the other.

Many engineers who go into a production or construction environment quickly find themselves assigned as a foreman or supervisor. The engineer may find such an assignment a satisfying chance to make things happen through their own actions and decisions. Doing so effectively, while according the workers the courtesy and respect merited by their years of experience, requires tact and judgment. If the engineer can achieve this balance, they may be surprised to find that the team members are respectful in return and are helpful to the engineer in learning *their* job.

Middle managers carry titles such as plant manager, division head, chief engineer, or operations manager. Although there are more first-line managers than any other in most organizations, most of the *levels* in any large organization are those of middle management. Even the lowest middle manager (the second-line manager, who directly supervises first-line managers) is an *indirect manager* and has the fundamentally different job of managing the efforts of employees through other managers. Middle managers make intermediate range plans to achieve the long-range goals set by top management, establish departmental policies, and evaluate the performance of the units and people in their organization. Middle managers also integrate and coordinate the short-range decisions and activities of first-line supervisory groups to achieve the long-range goals of the enterprise. Over the last two generations, middle management positions have decreased as organizations became "flatter" in an effort to become more competitive and get closer to their customers.

Top managers bear titles such as chairman of the board, president, or executive vice president; the top one of these will normally be designated *chief executive officer* (CEO). In government, the top manager may be the administrator (of NASA), secretary (of state or commerce), governor, or mayor. While top managers may report to some policymaking group (the board of directors, legislature, or council), they have no full-time manager above them.

Top managers are responsible for defining the character, mission, and objectives of the enterprise. They must establish criteria for and review long-range plans. They evaluate the performance of major departments, and evaluate leading management personnel to gauge their readiness for promotion to key executive positions. Bedeian paints a picture of the typical top manager: a college graduate (85 percent), probably with some postgraduate work (58 percent) and often a graduate degree (40 percent); usually from a middle-class background, often born to parents in business or a profession; age 50 to 65, with work experience concentrated in one, two, or three companies; and with a work week of 55 to 65 hours. Often, an organization will look for a top manager with particular strength in the functional area in which the enterprise is currently facing a challenge.

Managerial Skills

Katz suggests that managers need three types of skills: technical, interpersonal, and conceptual. *Technical skills* are skills (such as engineering, accounting, machining, or word processing) practiced by the group supervised. Figure 1-2 shows that the lowest level managers have the greatest need for technical skills, since they are directly supervising the people who are doing the technical work, but even top managers must understand the underlying technology on which their industry is based. *Interpersonal skills*, on the other hand, are important at every management level, since every manager achieves results through the efforts of other people. *Conceptual skills* represent the ability to "see the forest for the trees"—to discern the critical factors that will determine an organization's success or failure. This ability is essential to the top manager's responsibility for setting long-term objectives for the enterprise, although it is necessary at every level.

Managerial Roles—What Managers Do

Henry Mintzberg gives us another way to view the manager's job by examining the varied *roles* a manager plays in the enterprise. He divides them into three types: *interpersonal*, *informational*, and *decisional* roles, further described as follows:

- *Interpersonal* roles are primarily concerned with the manager's interactions with other people. This role can be as figurehead, focused on appearances and outward relationships; leader, focused on people below them in the organization; and liaison, focused on horizontal relationships and networking.

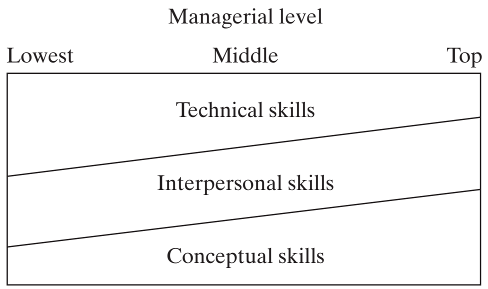

Figure 1-2 Blend of skills required at different management levels.

- *Informational* roles encompass how a manager exchanges and processes information. This role can be viewed as monitor, who collects information from inside and outside the organization; disseminator, who provides information to others within the organization; and spokesperson, who provides information to those outside the organization.
- *Decisional* roles describe how a manager uses information to make decisions. This role includes the entrepreneur, who initiates change and assumes risk; disturbance handler, who works to resolve problems or crises; resource allocator, who determines how the organization's resources of time and money are distributed; and negotiator, who handles bargaining and agreements inside and outside the organization.

Functions of Managers

Henri Fayol, the famous French mining engineer and executive, divided managerial activities into five elements: planning, organizing, command, coordination, and control. These elements, now called **functions of managers**, have proven remarkably useful and durable over the decades. Although each management author has their favored set of functions, almost all include planning, organizing, and controlling on their list. Command has become too authoritative a word in today's participative society and has been replaced by leading, motivating, or actuating. Few authors treat coordinating as a separate function. Nonetheless, as the late management author Harold Koontz concluded, "There have been no new ideas, research findings, or techniques that cannot readily be placed in these classifications." Koontz chose and (with coauthor Heinz Weihrich) defined his favored list of the functions of managers as follows:

- **Planning** involves selecting missions and objectives and the actions to achieve them; it requires decision making—choosing future courses of action from among alternatives.
- **Organizing** is that part of managing that involves establishing an intentional structure of roles for people to fill in an enterprise.
- **Staffing** [included with *organizing* by most authors] involves filling, and keeping filled, the positions in the organizational structure.
- **Leading** is influencing people to strive willingly and enthusiastically toward the achievement of organization and group goals. It has to do predominantly with the interpersonal aspect of managing.
- **Controlling** is the measuring and correcting of activities of subordinates to ensure that events conform to plans.

Engineering managers need to understand the body of knowledge that has been developed by management theorists and practitioners and organized under this framework, and this is the purpose of Part II of this book. Today the accepted functions of management are planning, organizing, leading, and controlling. Leading and motivating are treated in Chapter 3, planning and the associated subfunction of decision making are treated in Chapters 4 and 5, organizing in Chapters 6 and 7, and controlling in Chapter 8. Wherever possible, the particular implications of these functions for the technical employee and the technology-affected organization are emphasized.

The engineering manager also needs to understand the particular problems involved in managing research, development, design, production/operations, projects, and related technical environments. Parts III and IV treat the application of these management functions to the specific environments in which most engineers and engineering managers will work.

Management: Art or Science?

Earlier in this chapter the characteristics of a profession were discussed, and engineering was shown to meet all the criteria of a profession. Management also has a body of *specialized knowledge*, which is introduced in Part II. Many managers will have first completed bachelor's or master's degree programs in business administration, public administration, or engineering management, but the following applies, as Babcock has observed elsewhere:

> The knowledge need not be obtained only in such formal programs. It may be acquired by personal study, in-house employee education programs, seminars by all kinds of consultant entrepreneurs, or programs of many professional societies. Sometimes this formal or informal education is obtained before promotion [into] the management hierarchy, but often it occurs after promotion.
>
> A very small proportion of the broad range of managers belong to management-specific organizations such as the American Management Association, the Academy of Management, or (for engineers) the American Society for Engineering Management. They are more likely (especially in technical areas) to belong to management divisions or institutes within discipline-oriented professional societies. Considerations of standards, ethics, certification, and the like become those of the parent societies, not the management subset.

ENGINEERING MANAGEMENT: A SYNTHESIS

What Is Engineering Management?

Some writers would use a narrow definition of "engineering management," confining it to the direct supervision of engineers or of engineering functions. This would include, for example, supervision of engineering research or design activities. Others would add an activity we might consider the *engineering of management*—the application of quantitative methods and techniques to the practice of management (often called *management science*). However, these narrow definitions fail to include many of the management activities engineers actually perform in modern enterprises.

If engineering management is broadly defined to include the general management responsibilities engineers can grow into, one might well ask how it differs from *ordinary* management.

> The engineering manager is distinguished from other managers because they possesses both an ability to apply engineering principles and a skill in organizing and directing people and projects. They are uniquely qualified for two types of jobs: the management of *technical functions* (such as design or production) in almost any enterprise, or the management of broader functions (such as marketing or top management) in a *high-technology enterprise*.

Other Engineering Management Definitions

Engineering management is the art and science of planning, organizing, allocating resources, and directing and controlling activities that have a technological component.	American Society for Engineering Management
Engineering management is designing, operating, and continuously improving purposeful systems of people, machines, money, time, information, and energy by integrating engineering and management knowledge, techniques, and skills to achieve desired goals in technological enterprise through concern for the environment, quality, and ethics.	Omurtag (1988)
Engineering management is the discipline addressed to making and implementing decisions for strategic and operational leadership in current and emerging technologies and their impacts on interrelated systems.	IEEE (1990) and Kocaoglu (1991)

Source: Timothy Kotnour and John V. Farr, "Engineering Management: Past, Present, and Future," *Engineering Management Journal*, vol. 17, no. 1, March 2005.

Need for Engineers in Management

Herbert Hoover, a very successful mining engineer and manager, recognized the importance of the American engineering manager in an address to engineers the year he was elected president of the United States:

> Three great forces contributed to the development of the engineering profession. The first was the era of intense development of minerals, metallurgy, and transportation in our great West. . . . Moreover, the skill of our engineers of that period owes a great debt to American educators. The leaders of our universities were the first of all the educators of the world to recognize that upon them rested the responsibility to provide fundamental training in the application of science to engineering under the broadening influence and cultivation of university life. They were the first to realize that engineering must be transformed into a practice in the highest sense, not only in the training and character but that the essential quality of a profession is the installation of ethics. . . . A third distinction that grew in American engineering was the transformation from solely a technical profession to a profession of administrators—the business manager with technical training.

There are several reasons engineers can be especially effective in the general management, especially in technically oriented organizations. High-technology enterprises make a business of doing things that have never been done before. Therefore, extensive planning is needed to make sure that everything is done right the first time—there may not be a second chance. Planning must emphasize recognizing and resolving the uncertainties that determine whether the desired product or outcome is feasible. Since these critical factors are often technical, the engineer is best capable of recognizing them and managing their resolution. In staffing a technically based enterprise, engineering managers can best evaluate the capability of technical personnel when they apply for positions and rate their later performance. Further, they will better understand the nature and motivation of the technical specialist and can more easily gain their respect, confidence, and loyalty. George H. Heilmeier, president and CEO of Bellcore (and an electrical engineer), makes clear the advantages of an understanding of technology in top management:

Competition is global, and the ability to compete successfully on this scale is fostered by corporate leaders who can do the following:

- Understand the business at a deep level.
- Understand both the technology that is driving the business today and the technology that will change the business in the future.
- Treat research and development as an investment to be nurtured, rather than an expense to be minimized.
- Spend more time on strategic thinking about the future as they rise higher in the corporation.
- Be dedicated to solving a customer's problem or satisfying a need.
- Place a premium on innovation.

Management and the Engineering Career

It is common for engineers to move into a management role or pursue management-related advanced degrees. A 2006 study by the National Science Foundation found over 15 percent of those employed 10 years after earning an engineering degree hold a management role. That percentage grows to over 20 percent about 10 years later. The Bureau of Labor Statistics currently records the total employment for engineering managers to be over 180,000, with a 5.5 percent increase expected by 2026. Despite this, undergraduate engineering education offers little preparation for such a possibility. To meet this need, many engineering schools now provide degree programs and courses in engineering management. These courses and programs blend business and engineering, as shown in Figure 1-3. Professional societies are an additional way engineers may improve their managerial skills with many providing a variety of educational opportunities. Many engineering related professional socities (e.g. the American Society of Mechanical Engineers, the Institute of Industrial and Systems Engineers, etc.) have subgroups for engineering management. In addition, the American Society for Engineering Management (ASEM) is solely dedicated to development of Engineering Management professionals.

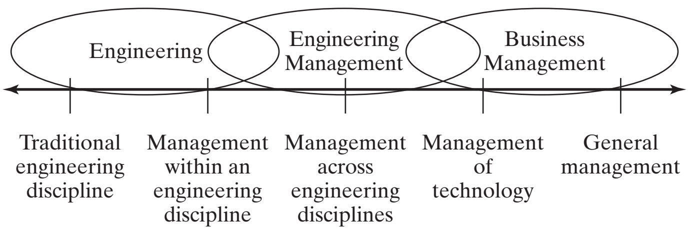

Figure 1-3 The field of engineering management.

Tim Cook: Picture of the Successful Engineering Manager

As CEO of Apple, Tim Cook is one of the most famous business leaders in the world and almost every profile of him makes prominent mention of his background in engineering. Cook graduated from Auburn University in 1982 with a Bachelor of Science in Industrial Engineering and later earned an MBA from Duke University. The skills developed in his industrial engineering education and how he used those skills at IBM and Compaq are prominent reasons that Steve Jobs recruited Cook to join Apple in 1998 where his first position was Senior Vice President of Worldwide Operations.[1] Tasked with improving Apple's complex supply chain, at that time a severe drag on the company's performance—Apple lost nearly 33 percent of its market value in the two years prior to him joining—Cook developed a system that continues to enable the company's product innovation. The results were almost immediate, and two years after Cook's arrival, Apple's value had increased over 460 percent and today it is commonly the most valuable company in the world and the first to reach $1 trillion in valuation. Cook recognizes the importance of blending both engineering and management skills and as an advisor at his alma mater has pushed for both excellence in technical education and well-rounded engineers.[2] He has noted that as "an engineer, you want to analyze things a lot. But if you believe that the most important data points are people, then you have to make conclusions in relatively short order."[3] As CEO, Cook has exemplified the tenants of the engineering profession to serve society and engineering ethics (see Chapter 16), dramatically increasing the company's charitable giving, social outreach, and recently stating "Whatever you do in your life, and whatever we do at Apple, we must infuse it with the humanity that each of us is born with."[4]

Source: Tobias Hase/dpa picture alliance/Alamy Stock Photo

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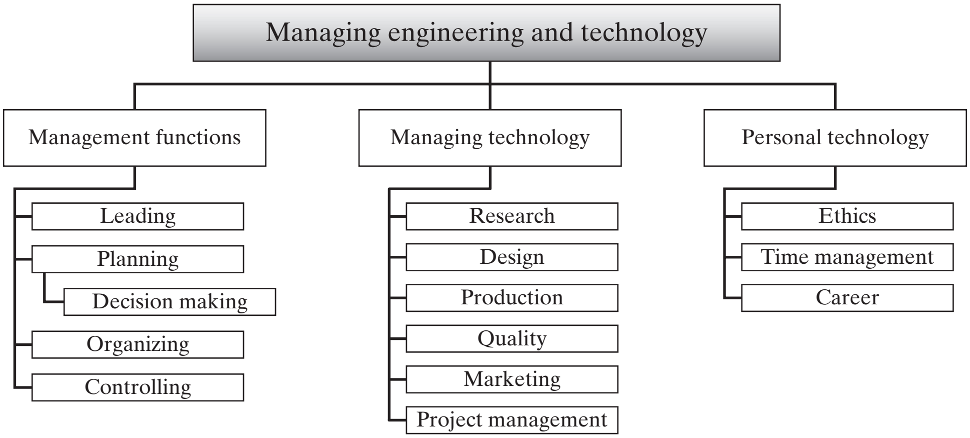

Figure 1-4 Managing engineering and technology text organization.

This book provides some insight into the nature of management and the environments in which the engineer is most likely to encounter the need for an understanding of management as their career progresses. Chapters 3 through 8 examine the functions of technology management. Chapters 9 through 13 examine the management of technology through the product life cycle. In the last three chapters, the career implications for the engineer moving to management are considered. The organization of these concepts within the book is shown in Figure 1-4.

DISCUSSION QUESTIONS

1-1. The precursors of today's engineers listed in the quotation from Wickenden had no classes and few or no books from which to learn scientific principles. How can you explain their success?
1-2. Create your argument for why *engineering management* is different than *management*. Why is this field needed?
1-3. Why is it so difficult to answer the simple question "How many engineers are there in the United States?" Is the question "How many physicians are there in the United States?" any easier? Why or why not?
1-4. Compare and contrast the role of the engineer with the role of the manager. How are they similar and how are they different?
1-5. What are the similarities in the definitions of *management* quoted from authors of management textbooks? How do you define *management*?
1-6. How does the job of supervisor or first-line manager differ from that of a middle manager?
1-7. Engineers often move into management of their organizations. Explain the ways that an engineering degree prepares an individual for this transition? What are the problems with this path?
1-8. Identify the three types of skills needed by an effective manager, as conceived by Robert L. Katz, and describe how the relative need for them might vary with the level of management.

1-9. Defend the need for engineering management. Why should engineering management be considered a different profession than simply "management"?

1-10. Find the engineering management related sub group for the professional society of your undergraduate discipline (e.g. IEEE for electrical engineers). What are the offerings of this society vs. those of ASEM? Which do you think will better serve your career development? Why?

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2

Historical Development of Engineering Management

PREVIEW

The story of the development of management thought and of our ability to organize and control complex activities has already been documented. Two excellent books on this subject are by Claude George and Daniel Wren. In this chapter, only a small part of this history is introduced, concentrating on the people and situations of greatest significance to the engineer in management. First, the great construction projects of ancient civilizations are considered, and then the medieval production facility that was the Arsenal of Venice is discussed. Discussion of the Industrial Revolution examines its changes to manufacturing and society, first in England, and then in America.

As the nineteenth century ended and the twentieth century began, the United States led the world in finding better, more efficient ways to do things, in a movement that became known as **scientific management**, while Europeans such as Max Weber and Henri Fayol were developing philosophies of management at the top level. Around 1930, a series of experiments at the Hawthorne Works near Chicago led to studies on the impact of individual and group behavior on the effectiveness of managing. Engineering management continues to evolve, with the development in the second half of the twentieth century of methods for managing large projects such as the Apollo program, customer-centered organizations, globalization, and the information revolution.

LEARNING OBJECTIVES

When you have finished studying this chapter, you should be able to do the following:

- Describe the origins of engineering management.
- Identify the different basic management philosophies.
- Discuss the future issues that will affect the continued development of engineering management.

ORIGINS

Ancient Civilizations

Even the earliest civilizations required management skills wherever groups of people shared a common purpose: tribal activities, estates of the rich, military ventures, governments, or organized religion. Indeed, the prototypes of civil engineering and construction management became necessary as soon as "plants and animals were domesticated and people began living in communities. By 6000 B.C. these communities sometimes contained over 1,000 people, and Jericho is known to have had a wall and defensive towers." according to Davey, by 4500 B.C. the first canals diverted water from a river in eastern Iraq for crop irrigation. As canals proliferated, it became possible to store crops for commerce, and written records as well as management organization became necessary. According to Wren:

> In ancient Mesopotamia, lying just north and west of Babylon, the temples developed an early concept of a "corporation," or a group of temples under a common body of management. Flourishing as early as 3000 B.C., temple management operated under a dual control system: one high priest was responsible for ceremonial and religious activities, while an administrative high priest coordinated the secular activities of the organization. Records were kept on clay tablets, plans made, labor divided, and work supervised by a hierarchy of officials.

Many ancient civilizations left behind great stone structures that leave us wondering how they could have been created with the few tools then available. Examples include the Great Wall of China, the monoliths on Easter Island, Mayan temples in South America, and Stonehenge in England. Especially impressive are the pyramids of Egypt. The great pyramid of Cheops, built about 4,500 years ago, covers 13 acres and contains 2,300,000 stone blocks weighing an average of 5,000 pounds apiece. Estimates are that it took 100,000 men and 20 to 30 years to complete the pyramid—about the same effort in worker-years as it later took the United States to put a man on the moon. The only construction tools available were levers, rollers, and immense earthen ramps. Yet the difference in height of opposite corners of the base is only $\frac{1}{2}$ inch!

Hammurabi (2123–2081 B.C.) of Babylon "issued a unique code of 282 laws which governed business dealings....and a host of other societal matters." One law that should interest the civil engineer is the following:

> If a builder builds a house for a man and does not make its construction firm, and the house which he has built collapses, and causes the death of the owner of the house, that builder shall be put to death.

Today's engineer should be thankful that, while penalties for faulty design can be expensive and damaging to one's career, they are not terminal!

Problems of controlling military operations and dispersed empires have made necessary the development of new management methods since ancient times. Alexander the Great (356–323 B.C.) is generally credited with the first documented use of the staff system in the Western world. He developed an informal council whose members were each entrusted with a specific function (supply, provost marshal, and engineer).

Imperial Rome governed an estimated 50 million people spread from England to Syria and from Europe to North Africa by dividing the empire in turn into four major regions, 13 dioceses, and 110 provinces for civil government, with a separate structure for the military forces garrisoned throughout the provinces to maintain control. The great Roman roads that made it possible to move messages and Roman legions quickly from place to place were an impressive engineering achievement that enabled the empire's growth and helped it survive as long as it did.

It should not be inferred that early management skills were confined to Western civilization as it developed around the Mediterranean Sea (see Management Philosophies Outside Western Culture). George describes the consistent use of advisory staff by Chinese emperors as early as 2350 B.C., and "ancient records of Mencius and Chow (1100 to about 500 B.C.) indicate that the Chinese were utilizing principles of organizing, planning, directing, and controlling." In India, one Brahman Kautilya described in *Arthashastra* in 321 B.C. a wide range of topics on government, commerce, and customs. Because he analyzed objectively rather than morally the political practices that brought success in the past, his name *has become synonymous with sinister and unscrupulous management* in India (just as has Niccolo Machiavelli's name for his similar analysis in *The Prince* in the early seventeenth century in Italy).

The Arsenal of Venice

George abstracts from Lane a fascinating story of "what was perhaps the largest industrial plant of the [medieval] world." As Venice's maritime power grew, the city needed an armed fleet to protect her trade, and by 1436 it was operating its own government shipyard, the Arsenal. The Arsenal "had a threefold task: (1) the *manufacture* of galleys, arms, and equipment; (2) the *storage* of the equipment until needed; and (3) the *assembly and refitting* of the ships on reserve."

Most impressive was the assembly line used to outfit ships. A Spanish traveler, Pero Tafur, wrote in 1436:

> And as one enters the gate there is a great street on either hand with the sea in the middle, and on the one side are windows opening out of the houses of the Arsenal, and the same on the other side, and out came the galley towed by a boat, and from the windows they handed out to them from one the cordage, from another the bread, from another the arms, and from another the balistas and mortars, and so from all sides everything which was required, and when the galley had reached the end of the street, all the men required were on board, together with the complement of oars, and she was equipped from end to end. In this manner there came out ten galleys, fully armed, between the hours of three and nine.

George identifies several other industrial management practices of the Arsenal that were ahead of their time:

1. Systematic warehousing and inventory control of the hundreds of masts, spars, and rudders, and thousands of benches, footbraces, and oars needed to make the assembly line work
2. Well-developed personnel policies, including piecework pay for some work (making oars) and day wages for both menial labor and artisans (the latter with semiannual merit reviews and raises)
3. Standardization, so that any rudder would meet any sternpost, and all ships were handled the same way

4. Meticulous accounting in two journals and one ledger, with annual auditing
5. Cost control. As an example, one accountant discovered that lumber was stored casually in piles, and the process of searching through the piles to find a suitable log was costing three times as much as it did to buy the log in the first place; as a result of this early industrial engineering study an orderly lumberyard was established, which not only saved time and money but also permitted accurate inventory of lumber on hand.

An important innovation developed in Venice during this period was *double-entry bookkeeping*. Luca Pacioli published an instruction manual (*Summa de arithmetica, geometria, proportioni et proportionalia*) in 1494 describing the system then in use and recommending it. His discussion of the use of memorandum, journal, and ledger, supporting documents, and internal checks through periodic audits were so modern that *[m]any excerpts from Pacioli's writing could be inserted into our current accounting textbooks with virtually no change in wording*. Pacioli's work was translated into English about 50 years later and was in widespread use by the early eighteenth century.

THE INDUSTRIAL REVOLUTION

End of Cottage Industry

Before the late eighteenth century, farm families would spin cotton, wool, or flax to yarn or thread on a spinning wheel, weave it on a hand loom, wet the goods with mild alkali, and spread them on the ground for months to bleach in the sun before selling these *gray goods* at a local fair for whatever price they could get. Even when under the "putting out" system, where merchants at the fairs would provide the family with materials and buy their output at a negotiated rate, the work could be done in the farm cottage.

In the last third of the eighteenth century, a series of eight inventions (six British and two French) changed society irretrievably. Summarized from Amrine et al., they are the following:

1. The *spinning jenny*, invented by James Hargreaves in 1764, which could spin eight threads of yarn (later, 80) at once instead of one
2. The *water frame*, a spinning machine driven by water power, patented by Richard Arkwright and incorporated by him in 1771 in the first of many successful mills
3. The *mule*, a combination of the spinning jenny and water frame invented by Samuel Crompton in 1779, which enormously increased productivity and eliminated hand spinning
4. The *power loom*, a weaving machine patented in 1785 by Edmund Cartwright, which with time and improvements ended the ancient system of making cloth in the home
5. *Chlorine bleach*, discovered in 1785 by the French chemist Claude Louis Berthollet (and bleaching powder in 1798 by Charles Tennant), which provided quick bleaching without the need for large open areas or constant sunlight
6. The *steam engine*, patented by James Watt in 1769 and used in place of water power in factories beginning about 1785
7. The *screw-cutting lathe*, developed in 1797 by Henry Maudslay, which made possible more durable metal (rather than wood) machines
8. *Interchangeable manufacture*, commonly attributed to the American Eli Whitney in carrying out a 1798 contract for 10,000 muskets, but perhaps adopted by him as a result of a letter dated May 30,

1785, from Thomas Jefferson (while in France) to John Jay, describing the approach of Leblanc at the *manufacture de Versailles*:

> An improvement is made here in the Construction of muskets, which it may be interesting to Congress to know....It consists in the making of every part of them so exactly alike, that what belongs to any one, may be used for every other musket in the magazine.... [Leblanc] presented me the parts of fifty locks, taken to pieces, and arranged in compartments. I put several together myself, taking pieces at hazard as they came to hand, and they fitted in the most perfect manner. The advantage of this when arms are out of repair [is] evident.

Problems of the Factory System

The innovations of the late eighteenth century just described caused major upheavals in England's society as well as its economy. Cottage industry could not compete with factories powered first by water and then by steam. Underground coal mines provided fuel for the steam engine, and the steam engine powered the pumps that removed water seepage from the mines. A mass movement of workers from the farms and villages to the new industrial centers was required.

The new factory managers had problems of recruiting workers, training the largely illiterate workforce, and providing discipline and motivation to workers who had never developed the habits of industry. Wren quotes Powell: "If a person can get sufficient [income] in four days to support himself for seven days, he will keep holiday for the other three." Wren adds, "Some workers took a weekly holiday they called 'Saint Monday' which meant either not working or working very slowly at the beginning of the week." Today, plant managers who hire the chronically unemployed can face exactly this same problem with workers who have neither personal experience nor family tradition with the *habits of industry,* such as regular attendance and punctuality.

Explosive growth of the English mill towns led to filthy, overcrowded living conditions, widespread child labor, crime, and brutality. Falling wages, rampant unemployment, and rising food prices led to a rash of smashing of textile machinery by the Luddites, peaking between 1811 and 1812. This movement soon died for lack of leadership by dint of hanging Luddites in at least four cities.

England's agrarian history provided no source of professional managers. Supervisors often were illiterate workers who rose from the ranks and were paid little more than the workers they supervised, and there was no common body of knowledge about how to manage. Upper management often consisted of the sons and relatives of the founders, a condition that persists today in many areas. Gradually, the forerunners of modern factory management began to develop. One early firm was Boulton and Watt, founded by Matthew Boulton and James Watt to manufacture Watt's steam engine. By 1800, their sons inherited the firm and instituted innovations at their Soho Engineering Foundry such as factory layout planning, inventory control, production planning, work-flow study, sophisticated analysis of piecework rates, and paid overtime.

Another pioneer was Robert Owen, part owner of a mill complex in New Lanark, Scotland. Owen was ahead of his time in proposing that as much attention be paid to vital "human machines" as to inanimate ones. He told a group of factory owners the following:

> Your living machines may be easily trained and directed to procure a large increase of pecuniary gain. Money spent on employees might give a 50 to 100 percent return as opposed to a 15 percent return on machinery. The economy of living machinery is to keep it neat and clean, treat it with kindness that its mental movements might not experience too much irritating friction.

Owen was ahead of his time in adopting practices that treated workers well. He reshaped the whole village of New Lanark, improving housing, streets, sanitation, and education. Although he continued to employ children, he lobbied for legislation that ultimately forbade employing children under the age of nine, limited the workday to $10\frac{1}{2}$ hours, and forbade night work for children.

Industrial Development in America

England regarded her colonies as markets for English factories; as early as 1663, all manufactured goods were required to be purchased in England (even if made elsewhere in Europe), and the 1750 English Iron Act made it illegal to set up in the Colonies mills and furnaces for the manufacture of finished products. Although emigration of skilled labor to America was prohibited after the American Revolution, an experienced textile machinery builder and mechanic named Samuel Slater emigrated from England as a *farmer* and joined with three prosperous Rhode Island merchants to build the first technically advanced American textile mill at Pawtucket, Rhode Island, in 1790; by 1810 the census listed 269 mills in operation. Although growth of American industry was accelerated by the War of 1812 with England, most American firms before 1835 were small, family owned, and water powered. Only 36 firms employed more than 250 workers: 31 textile firms, three in iron, and two in nails and axes. The greatest sophistication in manufacturing was at the government-owned Springfield, Massachusetts, Armory, and this knowledge provided the basis for the later manufacture of axes, shovels, sewing machines, clocks, locks, watches, steam engines, reapers, and other products in the 1840s and 1850s.

Canals provided the first construction challenge for the new nation. Although the Middlesex Canal Company obtained the rights to build a canal from Boston to Lowell, Massachusetts, in 1793, they experienced great difficulty until they called in an immigrant engineer, William Weston, who had worked under a canal builder in England. Weston went on to provide know-how for all the major projects of that period in New England. This experience was available when the Erie Canal was built, 363 miles from Albany to Buffalo, New York between 1816 and 1825, a project that provided the training for many of early American civil engineers.

Railroads and steel were the high-technology growth industries of the nineteenth century. Colonel John Stevens, dubbed the *father of American engineering,* built the first rail line—the 23-mile Camden and Amboy Railroad—in 1830; by 1850 there were 9,000 miles of track extending west to Ohio. Morse's first experimental telegraph line was built in 1844; by 1860 there were 50,000 miles of telegraph line—much of it along railroad right of way and used in part to facilitate rail shipment.

The railroads presented management problems of a dimension not seen before, and the men who mastered these challenges became the leaders of the American industrial explosion. One such person was Andrew Carnegie (1835–1919), who at age 24 became superintendent of the largest division of the nation's largest railroad (the Pennsylvania). In 1872, attracted by Sir Henry Bessemer's new process, he moved into steelmaking—integrating operations, increasing volume, and selling aggressively. In 1868 the United States produced 8,500 tons of steel while England produced 110,000 tons; by 1902, thanks to Carnegie and others, America produced 9,100,000 tons to England's 1,800,000 tons.

The large industrial firms of the nineteenth century were precursors of the industrial giants of the twentieth century, headquartered primarily in Europe, the United States, or Japan, but manufacturing and selling all over the world. The nature of these *multinational corporations* and the opportunities they offer engineers are discussed in Chapters 17 and 18.

Development of Engineering Education

Most engineering skills through the eighteenth century were gained through apprenticeship to a practitioner. This is described by John Mihalasky:

> The first engineering school was probably established in France in 1747 when [Jean Rodolphe] Perronet, engineer to King Louis XV, set up his staff as a school. This group was later chartered in 1775 under the official name Ecole des Ponts et Chaussées [School of Bridges and Roads]. Other early schools were the Bergakadamie at Freiburg in Saxony (1766), Ecole Polytechnic in Paris (1794), Polytechnic Institute in Vienna (1815), Royal Polytechnic of Berlin (1821), and University College of London (1840).

When the American colonies revolted in 1776, they did not have the engineering resources needed to build (or destroy) fortifications, roads, and bridges, and they had to rely on French, Prussian, and Polish assistance. At the urging of Thomas Jefferson and others, the new nation quickly established the U.S. Military Academy at West Point, New York, in 1802 to provide training in, among other things, practical science. Graduates did not acquit themselves as well as hoped in the War of 1812 with England, so Sylvanus Thayer, assistant professor of mathematics at the Academy (1810–1812), and Lt. Colonel William McRee were sent to Europe to examine the curricula at Ecole Polytechnic, the most famous scientific military school in the world. On their return in 1817, Thayer was appointed Superintendent at West Point. He collected the best teachers of physics, engineering, and mathematics available and set up a four-year civil engineering program. Ross emphasizes the importance of this program:

> The influence of the Academy extended far beyond the institution's cadets. "Every engineering school in the United States founded during the nineteenth century copied West Point, and most found their first professors and president among academy graduates." Many of the great canals, railroads, and bridges constructed during the nineteenth century were built by West Point graduates. The faculty, recruited by Thayer, wrote textbooks that dominated the subjects of mathematics, chemistry, and engineering during the 1800s.

For example, Mihalasky reports that Captain Partridge, an early Academy superintendent, founded the first civilian engineering school in the country in 1819, which later became known as Norwich University, followed by Rensselear (New York) Polytechnic Institute in 1823 with *a practical school of science,* and 12 years later a school of civil engineering. Other early engineering schools were Union College (1845), Harvard, Yale, and Michigan (1847). Mihalasky reports that only these six engineering schools existed in the United States when the Civil War opened, although Reynolds and Seely *have identified at least 50 institutions that at one time or another offered instruction in engineering before 1860* (although not necessarily as full curricula).

As reported elsewhere, "the event that had the greatest influence on engineering education was passage of the Morrill Land Grant Act in 1862. This act gave federal land (ultimately [totaling] 13,000,000 acres, an area 46 percent greater than Taiwan) to each state to support 'at least one college where the leading object shall be...scientific and classical studies...agriculture and mechanic arts.'" This made education in the "mechanic arts" (which became engineering) available and affordable throughout the country. By 1928, president-elect Herbert Hoover (himself a distinguished engineer and manager) could say the following:

> The leaders of our universities were the first of all the educators of the world to … provide fundamental training in the application of science to engineering under the broadening influence and cultivation of

> university life.... [Another] dimension that grew in American engineering was the transformation from solely a technical profession to a profession of administrators—the business manager with technical training.

An International Engineering Congress, with one division of the meetings on engineering education, was held as part of the 1893 Columbian Exposition in Chicago. Since there were then more than 100 engineering schools in the country, the engineering education sessions were well attended. Interest there led to the 1893 formation of the Society for the Promotion of Engineering Education, which became the American Society for Engineering Education (ASEE). In the century since, the meetings, journals, and studies of the ASEE have represented another major factor improving the quality of American engineering education.

MANAGEMENT PHILOSOPHIES

Over time, the number of management philosophies has been numerous. All have had, as their goal, to obtain optimal organizational performance, with the overall business environment guiding the selection of a particular style of management. Some theories have been fads that have not influenced a company's performance in the long term, while others have enhanced quality and productivity. Each theory has had its merits and drawbacks. These philosophies may be grouped into general categories of scientific, administrative, and behavioral.

SCIENTIFIC MANAGEMENT

Charles Babbage

Babbage (1792–1871) lived in England during the Industrial Revolution. His work was far ahead of its time: Wren calls him both *patron saint of operations research and management science* and *grandfather of scientific management*; and so, he will be discussed here, out of chronological sequence. Wren continues by describing the work for which Babbage is popularly known:

> He demonstrated the world's first practical mechanical calculator, his difference engine, in 1822. Ninety-one years later its basic principles were being employed in Burroughs' accounting machines. Babbage had governmental support in his work on the difference engine, but his irascibility cost him the support of government bureaucrats for his analytical engine, a versatile computer that would follow instructions automatically. In concept, Babbage's computer had all the elements of a more modern version. It had a store or memory device, a mill or arithmetic unit, a punch card input system, an external memory store, and conditional transfer [the modern "if statement"].

Babbage's engines never became a commercial reality, largely because of the difficulty in producing parts to the necessary precision and reliability. This frustration led him to visit a wide variety of English factories, and his fascination with what he observed there led to the publication of his very successful book *On the Economy of Machinery and Manufactures*, in 1832. In this he described at length his ideas on division of labor, his *method of observing manufacturies,* and methods of optimizing factory size and location, and he proposed a profit-sharing scheme. He showed a sophisticated understanding of effective time-study methods:

> If the observer stands with his watch in his hand before a person heading a pin, the workman will almost certainly increase his speed, and the estimate will be too large. A much better average will result from inquiring what quantity is considered a fair day's work. When this cannot be ascertained, the number of operations performed in a given time may frequently be counted when the workman is quite unconscious that any person is observing him. Thus, the sound made by...a loom may enable the observer to count the number of strokes per minute...though he is outside the building.

Henry Towne and the American Society of Mechanical Engineers

From the first large-scale human endeavors, the science of management made little progress over the centuries, largely because almost no one considered management as a legitimate subject for study and discussion. Although engineers frequently became enterprise managers, the first American engineering societies (the American Society of Civil Engineers, founded in 1852, and the American Institute of Mining Engineers, founded in 1871) were not interested in machine shop operation and management. Wren believes that the first American forum for those interested in factory management was the *American Machinist*, an illustrated journal of practical mechanics and engineering founded in 1877, which soon began including a series of letters to the editor from James Waring See on machine shop management. The *Machinist* was instrumental in the formation of the American Society of Mechanical Engineers (ASME), which elected its first officers on April 7, 1880, at the Stevens Institute of Technology in Hoboken, New Jersey; ASME was formed to address itself to *those issues of factory operation and management that the other groups had neglected.* Speaking in this vein before the May 1886 ASME meeting in Chicago was an engineer named Henry R. Towne, who was cofounder of Yale Lock Company and president of Yale & Towne Manufacturing Company. Towne began his famous paper *The Engineer as Economist* with the following passage:

> The monogram of our national initials, which is the symbol of our monetary unit, the dollar, is almost as frequently conjoined to the figures of an engineer's calculations as are the symbols indicating feet, minutes, pounds, or gallons. The final issue of his work, in probably a majority of cases, resolves itself into an issue of dollars and cents, of relative or absolute values.

Towne then observed that

> although engineering had become a well-defined science, with a large and growing literature of its own,...the matter of shop management is of equal importance with that of engineering, as affecting the successful conduct of most, if not all, of our great industrial establishments, and that the *management of works* has become a matter of such great and far reaching importance as perhaps to justify its classification also as one of the modern arts.

Towne cited the need for a medium for the interchange of management experience *by the publication of papers and reports, and by meetings for the discussion of papers and interchange of opinions and* called for a new section of the ASME to carry this out. Although such a management section was not organized until 1920, consideration of matters of shop management became part of ASME meetings, and the ASME Management Division dates its official history from Towne's 1886 paper.

Frederick W. Taylor

Frederick Winslow Taylor (1856–1915), called the *father of scientific management,* was born in 1856 to a well-to-do family in Germantown (Philadelphia) and completed a four-year apprenticeship as a machinist. In 1878, he joined Midvale Steel Company as a laborer, and was promoted to time clerk and then foreman of a machine shop.

As foreman, he was frustrated because his machinists were producing only about a third of what Taylor (as a machinist himself) knew and demonstrated they should be producing. Even on piecework pay, production did not improve because the workers knew that as soon as they increased production, the rate paid per piece would be decreased, and they would be no better off. With permission of the president of Midvale Steel, Taylor began a series of experiments in which work was broken down into its "elements" and the elements timed to establish what represented a fair day's work.

During this period, he was a mechanical engineering student at Stevens Institute, where the ASME held its first meeting, graduating in 1883. The next year, at the age of 28, Taylor became chief engineer at Midvale Steel; a year later he joined the ASME, and in May 1886 attended its meeting in Chicago. Biographers report that Taylor was encouraged there to continue his studies of work methods and shop management by Henry Towne's paper (described previously). Another paper at that meeting was by Captain Henry Metcalf, describing a *shop-order system of accounts* he established at the Frankford (Pennsylvania) and Watervliet (New York) Arsenals in 1881 that helped management determine direct and indirect costs of work activity. In the extensive discussion that followed, Taylor reported on a similar system Midvale had been using for 10 years. For the first time in recorded history, engineers now had a medium for sharing their management problems and solutions. Taylor contributed further to this interchange with papers presented to the ASME in 1895 (*A Piece Rate System*) and in 1903 (*Shop Management*), and became president of ASME in 1906. Today, many of the engineering societies have active management divisions, with the American Society for Engineering Management totally devoted to such concerns.

Taylor's *piece rate system* involved breaking a job into elementary motions, discarding unnecessary motions, examining the remaining motions (usually through stopwatch studies) to find the most efficient method and sequence of elements, and teaching the resulting method to workers. The workers would be paid according to the quantity of work produced. Taylor went further in his *differential piecework* method by establishing one piece rate if the worker produced the standard number of pieces, and a higher rate for all work if the worker produced more. For example, if three pieces were deemed a standard day's work and the two rates were 50 and 60 cents per piece, the worker would earn $1.50 for making three pieces a day, but $2.40 for four.

The best-known examples of Taylor's studies occurred after he became a consultant to Bethlehem Iron (later Bethlehem Steel) Company in 1898. One was a study of a crew of pig-iron handlers: workers who picked up 92-pound *pigs* of iron, carried them up an inclined plank, and loaded them onto railroad flat cars. By developing a method that involved frequent rest periods to combat the cumulative fatigue resulting from such drudgery, Taylor was able to increase the number of long tons loaded by a worker in a day from 12.5 to 47.5.

In another example, Taylor examined the work of shoveling at Bethlehem:

> Operation of the three blast furnaces and seven large open-hearth furnaces required a steady intake of raw materials—sand, limestone, coke, rice coal, iron ore, and so forth. Depending on the season, 400 to 600 men were employed as shovelers in the 2-mile-long and a half-mile wide Bethlehem yard. Taylor noted that the shovelers were organized into work gangs of 50 to 60 men under the direction of a single foreman. Each owned his own shovel and used it to shovel whatever he was assigned....Taylor's analysis revealed that a shovel-load (depending on the shovel and the substance shoveled) varied in weight from 3.5 to 38.0 pounds, and that a shovel-load of 21.5 pounds yielded the maximum day's work. As a result, instead of permitting workers to use the same shovel regardless of the material they were handling, Taylor designed new shovels so that for each substance being shoveled the load would equal 21.5 pounds.

In the latter example, the average amount shoveled per day increased from 16 to 59 tons. In both of these cases the savings produced were shared. Workers' earnings increased from $1.15 to about $1.85 a day, while management's cost per ton handled was reduced by 55 percent or more.

Taylor summarized his methods in his 1911 book *Principles of Scientific Management* as a combination of four principles:

> *First.* Develop a science for each element of a man's work, which replaces the old rule-of-thumb method.
> *Second.* Scientifically select, then train, teach, and develop the workmen, whereas in the past he chose his own work and trained himself as best he could.
>
> *Third.* Heartily cooperate with the men so as to insure all of the work being done in accordance with the principles of the science which has been developed.
>
> *Fourth.* There is an almost equal division of the work and the responsibility between the management and the workmen. The management take over all work for which they are better fitted than the workmen [defining *how* work is to be done], while in the past almost all of the work and the greater part of the responsibility were thrown upon the men.

The Gilbreths

Frank B. Gilbreth (1868–1924) passed the entrance exams for the Massachusetts Institute of Technology, but he chose instead to apprentice himself as a bricklayer. Trying to learn the trade, he found that bricklayers used three sets of motions: one when working deliberately but slowly, another when working rapidly, and a third when trying to teach their helpers. Gilbreth resolved to find the *one best way.* He described it later in a testimony before the U.S. Interstate Commerce Commission:

> Bricks have been laid the same way for 4,000 years. The first thing a man does is to bend down and pick up a brick. Taylor pointed out that the average brick weighs ten pounds, the average weight of a man above his waist is 100 pounds. Instead of bending down and raising this double load, the bricklayer could have an adjustable shelf built so that the bricks would be ready to his hand. A boy could keep these shelves at the right height. When the man gets the brick in his hand, he tests it with his trowel. If anything, this is more stupid than stooping to pick up his material. If the brick is bad he discards it, but in the process, it has been carried up perhaps six stories, and must be carted down again. Moreover, it consumes

> the time of a $5-a-day man when a $6-a-week boy could do the testing on the ground. The next thing the bricklayer does is to turn it over to get its face. More waste: more work for the $6 boy. Next what does the bricklayer do? He puts the brick down on the mortar and begins to tap it with his trowel. What does his tapping do? It gives the brick a little additional weight, so it will sink into the mortar. If anything, this is more stupid than any of the others. For we know the weight of the brick and it would be a simple matter in industrial physics to have the mortar mixed so that just that weight will press it down into the right layer. And the result? Instead of having eighteen motions in the laying of a brick, we have only six. And the men put to work to try it lay 2,700 with no more effort than they laid a thousand before.

By 1895 Gilbreth had his own construction firm based on *speed work.* He analyzed each job to eliminate unnecessary motions, devising a system of classifying hand motions into 17 basic divisions (which he called *therbligs* from his last name) such as *search*, *select*, *transport loaded*, *position*, and *hold*. He soon became one of the best-known building contractors in the world, but by 1912 had given up the construction business and was devoting full time to management consulting.

Lillian Moller Gilbreth (1878–1972) earned a bachelor's and master's degree in English at the University of California (and qualified for Phi Beta Kappa, although as a woman she was not included on the official list of recipients). She interrupted her Ph.D. studies for a trip to Europe by way of the port of Boston, where she met Frank Gilbreth on the outgoing leg and married him on her return. She later completed her Ph.D. at Brown University.

Lilian's contributions to both the fields of management and industrial psychology are significant. However, what is often missed in discussions of Lillian is how she helped others in her era achieve impact. In a presentation on the contributions of scientific management pioneers, Lyndall Urwick, a noted management scholar discussed later in this chapter, stated that the marriage of Frank and Lillian was providential. For without Lillian's deep understanding of human beings, the three engineers who led the scientific management revolution – Taylor, Gannt, and Gilbreth – might not have overcome the struggle to achieve wide-spread adoption of their techniques. It was Lillian's ability to bring the human element into the field that led to recognition that management could be learned and was not available only to those born with the ability. These are some of the reasons Wren called Lillian the "First Lady of Management."

Lillian quickly became interested in Frank's work and assisted him in preparation of six books published between 1908 and 1917 (*Field System*, *Concrete System*, *Bricklaying System*, *Motion Study*, *Fatigue Study*, and *Applied Motion Study*). Meanwhile, she continued work on her Ph.D. thesis, *The Psychology of Management*, one of the earliest contributions to understanding the human factor in industry, and submitted it in 1912. The work was serialized in *Industrial Engineering Magazine* and finally published as a book (the latter with the proviso that the author be listed as *L. M. Gilbreth* without identifying her as a woman, so that it might have some credibility).

Frank prepared an invited paper for the 1925 International Management Conference in Prague, but he died suddenly of a heart attack on June 14, 1924. Lillian presented the paper in his place, then continued Frank's work and established a strong reputation of her own as one of the creators of industrial psychology. She was the first woman admitted to the Society of Industrial Engineers (now the Institute of Industrial and Systems Engineers) and the ASME, the first woman professor of management at an engineering school (Purdue University and later the Newark College of Engineering), and the only woman to date to be awarded the Gilbreth Medal, the Gantt Gold Medal, or the CIOS Gold Medal. She has understandably been called the *first lady of management*. Many scholars have noted the signs of Lillian in Frank's earlier work, noting that her contributions to management are probably even greater than she was credited. Her life was so long (she outlived Frank by 48 years) and distinctive that many women engineers throughout the 20th century spoke of her as an inspiration that led them into engineering.

Growth and Implications of Scientific Management

Taylor's work attracted many disciples who propagated the scientific management method. Carl Barth, a mathematics teacher, was recruited by Taylor to help Henry Laurence Gantt solve the speed and feed problems in metal-cutting studies conducted at Bethlehem. Barth later helped Taylor apply scientific management to the problems of Link Belt, Fairbanks Scale, and Yale & Towne companies, and then helped George D. Babcock install scientific management at the Franklin Motor Car Company (1908–1912).

Gantt (1861–1919) earned degrees from Johns Hopkins University and Stevens Institute of Technology (in mechanical engineering in 1884, a year after Taylor). He joined Taylor at Midvale Steel in 1887, followed him to Simond's Rolling Machine Company and then to Bethlehem Steel, and became an independent consulting industrial engineer in 1901. Gantt modified Taylor's *differential piece rate* by providing a standard day rate regardless of performance, which provided security to workers during training and work delays due to materials not being available; workers who accomplished the specified daily production received an additional bonus, as did their foremen. Gantt is also noted for his work in developing charts that graphed function of performance against time; their application to project management is discussed in Chapter 14.

Another protégé of Taylor was Morris L. Cooke (1872–1960), a mechanical engineer (Lehigh University, 1895) who began *applying a questioning method to the wastes of industry long before he met or heard of Taylor*, then started reading Taylor's writings, and met him. Taylor funded Cooke to study the administrative effectiveness of ASME, sent him to perform an "economic study" of administration in educational organizations for the Carnegie Foundation for the Advancement of Teaching, and then sent him to help the newly elected reform mayor of Philadelphia improve the efficiency and effectiveness of municipal government (1911–1915). Cooke later advised the president of the American Federation of Labor (Samuel Gompers) and coauthored a book with the president of the Congress of Industrial Organizations (Phillip Murray), emphasizing that labor was as important for production as management. Later, he headed the Rural Electrification Administration, which brought inexpensive electric power to rural America.

Taylor's system received extensive publicity in the 1911 Eastern Rate case. The Eastern-railroads petitioned the Interstate Commerce Commission for an increase in rates, but Boston lawyer (and later Supreme Court justice) Louis D. Brandeis took up the cause of shippers with the theme that no increase would be necessary if railroads would only apply *scientific management* (the name adopted instead of the *Taylor system* in a meeting of Brandeis, Gilbreth, Gantt, and others in preparation for this case). The parade of witnesses supporting this view included Taylor, Gilbreth (as quoted above), Henry Towne, and others. Harrington Emerson (1853–1931), who had been very successful as a troubleshooter on the Burlington Railroad and then a consultant to the Santa Fe Railroad, testified that preventable labor and material waste was costing the railroad industry a million dollars a day. Scientific management spread rapidly because media and institutions for the sharing of knowledge and experience were becoming available in an unprecedented way. Many of the practitioners were active in ASME; they presented and critiqued papers at their meetings. Industrial and popular journals were increasing in number, and they reported on progress in scientific management and even serialized books by Taylor and Lillian Gilbreth. Most of the major participants authored several books each, many of which were widely read. Universities increasingly decided management was, after all, worthy of study. Taylor was persuaded to lecture at what would become the Harvard Business School, Lillian Gilbreth and Carl Barth each lectured at two universities, and Henry Gantt lectured at four. Bachelor's degree programs that combined engineering and business were founded at Stevens in 1902, Yale in 1911, and MIT in 1913. The discipline of industrial engineering (and the Institute of Industrial and Systems Engineers) originated from the work of scientific management, and the newer discipline of engineering management owes a great debt to it as well.

Scientific management did, however, have some negative impacts, which still affect us today. Taylor divided work into planning and training (a management responsibility) and rote execution (by the uneducated laborer of the day). Only in the last four decades have executives in mass production industries such as General Motors realized how much they were losing by only hiring workers for their physical labor rather than encouraging them to participate in improving work methods. This realization has led many modern companies to seek to eliminate what Konosuke Matsushita, founder of Matsushita Electric Industrial Company, termed "Taylorized heads"—situations where workers are not contributing their thoughts, just their labor. Efforts to eliminate the idea that "managers manage and workers work" are widespread in most Western service and technology companies today. In Chapter 2 some of the theories of human motivation are examined, and Chapter 12 looks at their application to production operations using techniques of total quality management and empowered teams.

ADMINISTRATIVE MANAGEMENT

As we have seen, initial American management study emphasized management at the production-shop level. In the meantime, two Europeans, Henri Fayol and Max Weber, were making significant contributions to general management theory.

Henri Fayol

Fayol (1841–1925) was an 1860 graduate of the National School of Mines at St. Etienne, France. His distinguished career is described in Urwick's foreword to the 1949 English translation of his most noted work, *Administration Industrielle et Générale* (General and Industrial Management). He believed that the activities of industrial undertakings could be divided into six groups: technical (production), commercial (marketing), financial, security, accounting, and administrative activities. The first five he considered well known, but the last, administrative (French has no exact equivalent of the word *management*), he considered most important above the first two levels of management, yet least understood. Fayol divided administration into planning/forecasting (*prevoyance*), organization, command, coordination, and control. He decried the absence of management teaching in technical schools, but stated that without a body of theory, no teaching is possible. He then proceeded to develop a set of 14 "general principles of administration," most of which have meaning to this day.

Today's critics of engineering education would agree with Fayol that:

> [o]ur young engineers are, for the most part, incapable of turning the technical knowledge received to good account because of their inability to set forth their ideas in clear, well-written reports, so compiled as to permit a clear grasp of the results of their research or the conclusions to which their observations have led them.

Engineering educators today would be less comfortable with his observation that "[l]ong personal experience has taught me that the use of higher mathematics counts for nothing in managing businesses and that engineers, mining or metallurgical, scarcely ever refer to them." However, every engineering student should consider his advice to future engineers:

> You are not ready to take over the management of a business, even a small one. College has given you no conceptions of management, nor of commerce, nor of accounting, which are requisite for a manager. Even if it had given you them, you would still be lacking in what is known as practical experience, and which is acquired only by contact with [people] and with things....Your future will rest much on your technical ability, but much more on your managerial ability. Even for a beginner, knowledge of how to plan, organize, and control is the indispensable complement of technical knowledge. You will be judged not on what you know but on what you do, and the engineer accomplishes but little without other people's assistance, even when [they] start out. To know how to handle [people] is a pressing necessity.

Max Weber and Bureaucracy

A contemporary of Fayol, the German sociologist Max Weber (1864–1920) influenced classical organization theory more than any other person. Weber developed a model for a rational and efficient large organization, which he termed a bureaucracy. Weber described the following as characteristics of *legal authority with a bureaucratic administrative staff*:

- The basic organizational unit is the *office* or position, which is designated a specific set of functions (based on division of labor), with clearly defined authority and responsibility.
- Members of the organization owe loyalty to the office, not (as with traditional authority or charismatic authority) to the individual.
- Candidates for offices are selected and appointed (not elected) based on their technical capability.
- Offices are organized in a clearly defined hierarchy: each lower office is under the control and supervision of a higher office.
- Officials (office holders) are *subject to strict and systematic discipline and control in the conduct of the office*, and subordinates have a right of appeal.
- Administrative acts, decisions, and rules must be reduced to writing.
- The office is the primary occupation of the incumbent, who is reimbursed by a fixed salary.
- Promotion is based on the judgment of superiors.
- Officials are not the owners of the organization.

The term *bureaucracy* need not imply an organization that is mired in red tape, delay, and inefficiency, with no concern for the human dimension. Most of Weber's elements are necessary in any large organization to assure consistent and reasonably efficient operation. The U.S. Postal Service or Internal

Revenue Service must have the same rules of operation at every local office; an army must have common procedures so that replacement officers and men can function quickly on assuming new positions; General Motors, or a large university or hospital, or the Boy Scouts of America must have fairly uniform structures and rules among their divisions to function smoothly. The challenge of a large organization is to incorporate into this necessary structure some flexibility to handle exceptions and an ability to recognize and reward individual contributions.

Russell Robb

Robb (1864–1927) was an American electrical engineer and manager whose original contributions on organization theory have not received the attention they deserve. After graduating from MIT, Robb spent most of his career as an executive in the Stone and Webster Engineering Corporation. He expressed his views on organization in three lectures presented to the Harvard University Graduate School of Business Administration in 1909 and later published. Young summarizes their import:

> These three lectures...contain more practical observations on organizations and concepts of organization theory than Weber. He was a practising engineer manager, whereas Weber was a sociologist. . . . His penetrating observation of organizations as “only a means to ends—it provides a method” and analysis of principles and concepts make him more a “pioneer of organization theory” than Weber.

Lyndall Urwick

Urwick was an Englishman who majored in history at Oxford. His contribution lay not in creating concepts of management, but in being the first to try to develop a unified body of knowledge. Using Fayol’s management functions as a framework, he analyzed the writings of Fayol, Taylor, Mary Parker Follett, James Mooney, and others, and attempted to correlate them with some of his own views into a consistent system of management thought. His 1943 book, *The Elements of Administration*, can therefore be viewed as the first general textbook on, as opposed to personal observations about, management. Toward the end of his long career he summarized his observations on the contribution of engineers to management:

> The study of management, as we all know, started with engineers. It was the sciences underlying engineering practice—mathematics, physics, mechanics, and so on—which were first applied by Frederick Winslow Taylor to analyzing and measuring the tasks assigned to individuals. That is where the science of management started.

BEHAVIORAL MANAGEMENT

Hawthorne Studies

What was arguably the single biggest direction change in early management thinking grew out of a series of studies conducted in the 1920s and early 1930s at the Hawthorne Works (near Cicero, Illinois) of the Western Electric Company (eventually becoming Lucent Technologies before being sold as pieces to other companies including Avaya and Nokia). The first phase of the studies, known as the Illumination Experiments, was conducted between 1924 and 1927 under the direction of Vannevar Bush, an electrical engineer from MIT who later developed systems that made the modern computer possible. The original intent was to find the level of illumination that made the work of female coil winders, relay assemblers, and small parts inspectors most efficient. Workers were divided into test and control groups, and lighting for the test group was increased from 24 to 46 to 70 foot-candles. Production of the test group increased as expected, *but production of the control group increased roughly the same amount*. Again, when lighting for the test group was decreased to 10, and then three foot-candles, their output *increased*, as did that of the control group. Production did not drop appreciably until illumination was lowered to that of moonlight (0.06 foot-candle).

To try to understand these unexpected results, Australian-born Harvard professor Elton Mayo and his colleague Fritz Roethlisberger conducted a second phase (1927–1932), known as the Relay Assembly Test Room Experiments. A large number of women were employed in assembling about 40 parts into the mechanical relays that were needed for telephone switching in the days before solid-state electronics. Six women whose prior production rates were known were moved from the large assembly room to a special test room to test the effects of changes in length and frequency of rest periods and hours worked. The women were given regular physical examinations (with free ice cream), their sleep each night and food eaten were carefully recorded, and room temperature and humidity were controlled. The room had an observer who recorded events as they happened and maintained a friendly atmosphere. The women had no supervisor, but they increasingly assumed responsibility for their own work and were allowed to share in decisions about changes in their work (a precursor of today's emphasis on *empowered teams*). Birthdays were regularly celebrated at work, and the women became fast friends after hours as well. Incentive pay had been used in the main workroom based on overall production of a large number of workers, but in the test room incentive pay was based just on production of the group of six.

After production rates had been stabilized in the new room, rest periods were added and maintained for periods of four or five weeks each at levels of (1) two five-minute periods, (2) two 10-minute periods, (3) six-five minute periods, and (4) two 10-or 15-minute periods with light snacks. Shorter workdays and elimination of Saturday work were also tried. Throughout this period daily production continued to increase, as it also did in a subsequent 12-week period when *rest periods, refreshments, and shortened workdays were eliminated*, and again when they were reinstated. Absenteeism among the six was only a third of that in the main room.

A third phase of study (the Bank Wiring Observation Room Experiment of 1931–1932) involved a group of 11 wiremen, soldermen, and inspectors who assembled terminal banks used in telephone exchanges. It became clear that the men formed a complex social group, had established their own standard of a fair day's work, and despite the piecework pay that existed, ridiculed and abused any worker who tried to work faster (or slower) than the group norm.

Mayo and others have attributed the surprising results in the first two phases to the pride of the women in being part of something important, the *esprit de corps* developed in the work group, and the satisfaction of having some control over their own destiny; the behavior of the men was attributed to the need for affection from the group (and the fear that management would lower pay rates if productivity improved). Later analysts such as Rice have criticized the studies as lacking the rigorous controls

Summary of Engineering and Management History

Ancient Civilizations	Egyptian pyramids
	China—Great Wall
	Mayan temples
	England—Stonehenge
	Alexander the Great—staffing system
	Romans—roads and aqueducts
Medieval Period	Four centuries of Dark Ages
Renaissance	Arsenal of Venice
Industrial Revolution, Eighteenth and Nineteenth Centuries	Factories
	Steam engine
Industrial Development in the United States, Nineteenth Century	Railroads, canals, steel mills
	West Point Military Academy
	Morrill Land Grant Act
	American Society for Engineering Education
Management Philosophies, Twentieth Century Scientific Management	Frederick Taylor
	Frank Gilbreth
	Lillian Gilbreth
	Henry Gantt
Administrative Management	Henry Fayol
	Max Weber
Behavioral Management	Abraham Maslow
	Hawthorne Studies
	Abilene Paradox
	Theory X and Theory Y

now demanded in scientific experiments. These studies focused the attention of an army of behavioral scientists—psychologists, sociologists, and even anthropologists (who turned their attention from the culture of remote tribes to the culture of General Motors and IBM)—on the behavior of workers individually and in groups; their work over the ensuing decades has added immeasurably to our knowledge of the art of management. The results of these studies are referred to as the Hawthorne effect, which is the tendency of persons singled out for special attention to perform as expected. While widely quoted, the legitimacy of this effect remains in question to this day.

Management Philosophies outside Western Culture

After discussion of the ancient roots of management, most of this text will focus on effective Western approaches to management. This is because we assume most of our readers are students in Western Universities seeking employment in Western companies. However, given the global nature of today's work environment (see Chapter 18), it is important that future engineering managers understand that Western management philosophies are not the only ones, and many successful management approaches have their roots in Eastern philosophies.[1]

Perhaps the two most famous examples of successful Eastern management philosophies are the dramatic rise of the Japanese economy following World War II and the current rise of the Chinese economy. Both of these changes were enabled by a fundamental difference between Eastern and Western approaches: focus on the success of the collective vs. focus on the success of the individual. In other words, the success of the Japanese rebuild was enabled by the norm of Japanese culture to focus on mutual benefit. This is further evidenced by the Toyota Production System's famous empowering any member of the factory to pull the Andon cord and stop the line when they see a problem.

At the same time that focus is transferred to the greater good, many Eastern management approaches look at the manager as nearly all powerful (notably China and India). In fact, during the author's time in India, colleagues would often explain that even middle-managers were "like a god" within the company. This view of managers as all powerful, stems from a cultural norm that seeks to save face and avoid conflicts, especially with those in authority. Bendixen and Burger note this norm is "characterized by idealism where mind and spirit are of central importance and where a state of highest perfection exists."[2] That perfection is often defined by the manager, and generally is defined in their image. The engineer working in a global setting is advised to not only be aware of these differences, but study them carefully—just because something works in one culture does not mean it will work in another!

Source: Akkaradech Maked/123RF

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Abilene Paradox

The Abilene paradox is the situation that results when groups take an action that contradicts what the members of the group silently agree they want or need to do. Stated another way, it is the inability of a group to agree to disagree. This is based on a story set in Abilene, Texas, by Dr. Jerry Harvey.

> Four adults are sitting on a porch in 104-degree heat in the small town of Coleman, Texas, some 53 miles from Abilene. They are engaging in as little motion as possible, drinking lemonade, watching the fan spin, and occasionally playing dominoes. The characters are a married couple and the wife's parents. At some point, the wife's father suggests they drive to Abilene to eat at a cafeteria there. The son-in-law thinks this is a crazy idea but does not see any need to upset the apple cart, so he goes along with it, as do the two women. They get in their Buick with no air-conditioning and drive through a dust storm to Abilene. They eat a mediocre lunch at the cafeteria and return to Coleman exhausted, hot, and generally unhappy with the experience. It is not until they return home that it is revealed that *none* of them really wanted to go to Abilene—they were just going along because they thought the others were eager to go.

The paradox is that not all group members are in agreement, but go along with decisions because they think the rest of the group agrees. The Abilene paradox occurs in group decision making and may happen in the workplace, with a family, or with friends.

More on behavioral management may be found in the contributions of McGregor and his Theory X and Theory Y, and Maslow's hierarchy of needs, which are discussed with leadership and human motivation in Chapter 7.

CONTEMPORARY CONTRIBUTIONS

Quality Management

Quality management (QM) is a management approach that originated in the 1950s and has steadily become more popular since the early 1980s. Quality is a description of the culture, attitude, and organization of a company that strives to provide customers with products and services that satisfy their needs. The culture requires quality in all aspects of the company's operations, with processes being done right the first time and defects and waste eradicated from operations. QM is a management philosophy that seeks to integrate all organizational functions (marketing, finance, design, engineering, production, customer service, etc.) to focus on meeting customer needs and organizational objectives. Specific topics in QM are discussed in Chapter 12. The following outline part of the quality approach:

- Meeting customer requirements
- Commitment by senior management and all employees
- Focus on processes/continuous improvement plans
- Planning quality into products and processes
- Teams
- Systems to facilitate quality control and improvement
- Employee involvement and empowerment
- Recognition and celebration
- Reducing development cycle times
- Benchmarking one's own performance and practices against others
- Six Sigma

Customer Focus

Quality and performance are judged by an organization's customers. The term **customer** refers to actual and potential users of an organization's products or services. Customers include the end users of products or services. The role of an organization's mission and vision is to align work toward meeting customer expectations. Marketing, design, manufacturing, and support must be aligned to meet customer needs. Customer-driven excellence has both current and future components: understanding the customer of today and anticipating future customer desires and needs.

Project Management

Many of the most difficult management challenges of recent decades have been to design, develop, and produce very complex systems of a type that has never been created before. Examples include the establishment of vast petroleum production systems in the waters of the North Sea or the deserts of Saudi Arabia, the collaboration of 400,000 people in the Apollo program to place people on the moon, development of complex jet aircraft, the International Space Station, the systems design for the Mission to Mars project, and software development. To create these systems with performance capabilities not previously available, there are three essential considerations for a manager to keep in balance: time (project schedule), cost (in dollars and other resources), and performance (the extent to which the objectives are achieved). Chapters 14 and 15 are devoted to discussing project management.

Globalization

People around the globe are more connected to each other than ever before. This new international system of globalization, as defined by Thomas Friedman, "has its own unique logic, rules, pressures, and incentives and it deserved its own name: 'globalization.' Globalization is not just some economic fad, and it is not just a passing trend. It is an international system." Human societies around the globe have

Engineering and Information Technology

Engineering continues to experience transformative change in the way the engineers practice due to the explosive growth of information technology (IT) over the past two generations. Not since the Industrial Revolution employed the power of steam engines has the engineering world seen such advancements. These changes began with the availability of desktop and mainframe computing power over fifty years ago. These tools brought fundamental change to the way engineers performed many aspects of their job. An example can be seen in how drafting is done. The engineer's drafting table has been replaced with CAD (computer-aided drafting / design) software. Design drawings are no longer drawn with paper and pencil with velum overlays for changes. Instead the drawings are created within the software where they can be rapidly changed and instantly sent to all stakeholders.

Today, the connected economy and Internet of Things (IoT) continues to transform engineering practice. While we're all familiar with consumer connected devices like smart speakers, connected doorbells with video monitoring, and refrigerators that can monitor what food needs to be purchased during the next shopping trip, most are less familiar with how this technology is changing the world of engineering. These changes are wide ranging and pertain to essentially every field of engineering. For example, the world of civil engineering has been changed by connected devices with GPS technology, where companies like Trimble Navigation connect earth moving equipment directly to engineering plans, dramatically reducing the need for field survey work and accelerating construction projects. For industrial engineers, these same types of connections provide real time data on the use of vehicles and inbound or outbound freight, dramatically improving their ability to design and manage supply chains and optimize equipment utilization. For mechanical engineers, modeling technology dramatically shortens the design cycle and lowers prototype costs, while electrical and power engineers can receive real-time information about grid performance and issues. While we don't know how the next technological breakthrough will impact engineering, we can be confident that it will bring some type of change.

established progressively closer contacts over many centuries, but now the pace has dramatically increased. Information and money flow more quickly than ever. Goods and services produced in one part of the world are increasingly available in all parts of the world. Workplace teams are composed of members from different parts of the world connected seamlessly by technology. International travel is more frequent. As a result, laws, economies, and social movements are forming at the international level. Globalization and opportunities are addressed more fully in Chapter 18.

Management Theory and Leadership

Management theory owes a great deal to practical executives who took the time to set down the wisdom they had accumulated in a successful management career. Henri Fayol, discussed previously, was such a man, as were Chester Barnard, who summarized his findings about people in organizations in *The*

Functions of the Executive, and Alfred P. Sloan, who documented his development of the decentralized organization with central control in *My Years with General Motors*. Just as often, these contributions are related secondhand by management writers. Peter Drucker, widely considered to be "the father of modern management," wrote many books and countless scholarly and popular articles on leadership and management. Two of the books are *The Effective Executive: The Definitive Guide to Getting the Right Things Done* and *Managing in the Next Society.* Peters and Waterman highlighted in their book *In Search of Excellence* the following: the wisdom of Walt Disney in treating theme park customers as "guests"; the emphasis of Thomas Watson, Jr., of IBM on service and customer satisfaction; the revolution in the U.S. Navy by Admiral Zumwalt "based on the simple belief that people will respond well to being treated as grownups"; and the success of MBWA ("management by walking around") by Bill Hewlett and Dave Packard at HP.

Other contributions to management theory include: *The Seven Habits of Highly Effective People* by Stephen Covey; *The One Minute Manager* by Kenneth Blanchard and Spencer Johnson; *Reengineering the Corporation* by Michael Hammer and James Champy; *Good to Great: Why Some Companies Make the Leap . . . and Others Don't* by Jim Collins; *Leadership 101: What Every Leader Needs to Know* by John C. Maxwell; quality management (TQM) philosophies; and the management styles of Jack Welch, formerly of General Electric. This list of contributors to management theory in the last three decades is not meant to be inclusive, rather it shows that the businessperson of today has more access to advice, some good and some not so good, than at any other time in history. Business books are better than ever. Through organized mentoring and other efforts, organizations and management are trying to preserve the wisdom that resides only in employees' heads.

DISCUSSION QUESTIONS

2-1. The practice of management is ancient, but the formal study of the body of management knowledge is relatively new. Why is this?

2-2. Stones for the pyramids were quarried far to the south (upstream on the Nile River) and were brought downstream on rafts only during the spring flood of the Nile. Discuss some of the planning and organizational implications of this immense logistic effort.

2-3. You are the production manager for a new start-up where the production floor has been up and running for six months. Things are not going smoothly. Quality is not meeting expectations and productivity issues are leading to substantial overtime work and cost overruns. Explain how the work of the Gilbreths could be applied to understand and solve these problems.

2-4. The development of cotton and woolen mills in the mill cities of England, and later New England, caused tremendous sociological change as potential workers (especially women) swarmed from rural areas to the growing industrial cities. Cite examples of similar occurrences in more recent times in developing countries.

2-5. How did Henri Fayol's approach to management compare with Weber's? How did Fayol's solutions differ? Describe Fayol's assumptions and the components of his theory of management. What remnants of Fayol's ideas exist today in management practice?

2-6. Matsushita emphasized the residual disadvantages to the United States of the teachings of Frederick Taylor. Discuss the *positive* contributions made by Taylor and his contemporaries in the scientific management movement.

2-7. What was the positive value of Max Weber's model of "bureaucracy"?

2-8. The essence of the Relay Assembly Test Room Experiments at the Hawthorne Works was that expected correlations between productivity and physical factors such as rest periods were not demonstrated. What other factors could explain the regular productivity increases observed in these experiments?

2-9. Schermerhorn defines management as the activity which "performs certain functions in order to obtain the effective acquisition, allocation, and utilization of human efforts and physical resources in order to accomplish some goal." Provide some examples of how ancient cultures met this definition.

2-10. As made clear in this chapter, engineers and engineer managers have made strong contributions to management theory and practice. List the engineers and engineer managers identified in this chapter together with their contributions, and add any others you may know of.

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Part II

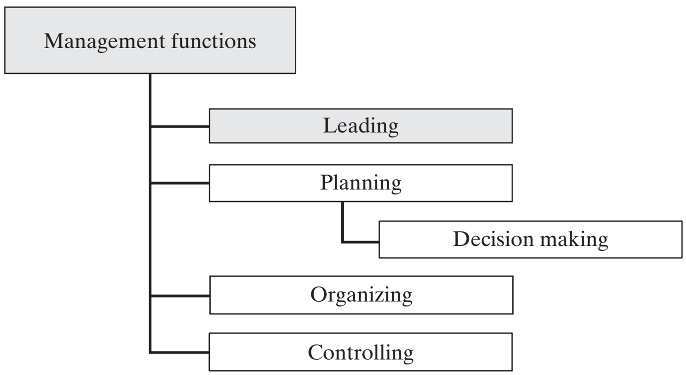
Functions of Technology Management

3

Leading Technical People

PREVIEW

There are four basic management functions defined by Fayol and discussed in Chapters 1 and 2, that are still accepted today. These basic functions of management are commonly identified as leading, planning, organizing, and controlling. Coordination ties all these functions together. President Harry S. Truman defined leadership as "the ability to get [people] to do what they don't want to do and like it." Even if you do not appreciate the sentiment of this statement, it makes clear that leadership is more than just directing others; it is getting others to engage in the work. Fortunately, leadership is truly an art form that can be learned. Just as in any other art form, there are multiple styles of leadership. Engineers need leadership skills even if not in a formal leadership role because they need to influence others to change, whether that is accepting a new product or work effectively on a project team. Engineers are trained to innovate, but many have not learned the skills to be the lead on projects, which they are often expected to do early in their careers.



The characteristics that make leadership effective in one company for a certain situation might be ineffective in another organization or another situation. All organizations and people are different and react differently. Different leadership studies have different theoretical approaches, but the same general factors are involved:

- Characteristics and behaviors of the leader
- Attitudes, needs, behaviors, and other characteristics of the followers
- Characteristics of the organization
- Social, economic, and political climate.

This chapter begins with an examination of nature of leadership and the perceived differences in managers and leaders. Next, the traditional trait theories and their application to the engineering leader are considered. Several additional approaches are explored. These include the leadership grid, situational leadership, transactional and transformation leadership, and servant leadership.

Motivation is a key component of the leadership model. McGregor's two contrasting viewpoints (Theories X and Y) on the nature of the individual who is to be motivated are considered. Then two approaches to understanding motivation are presented: content theories and process theories. The content theories include Maslow's hierarchy of needs, Herzberg's two-factor theory, and McClelland's acquired need theory. Process theories assume that behavior is determined by expected outcomes and include Adam's equity theory, Vroom's expectancy theory, and Skinner's behavior modification.

LEARNING OBJECTIVES

When you have finished studying this chapter, you should be able to do the following:

- Describe the role of leaders and what makes leaders effective.
- Describe the nature of leadership and its significance to an organization.
- Describe how motivation theories should be utilized when leading others.
- Address the application of servant leadership in current organizations.
- Describe the full-range leadership model and when different styles of leadership within this model are effective.

LEADERSHIP

Leadership and Management. The words *leadership* and *management* are often used interchangeably, yet they describe what many see as two different concepts. Just as there are conflicts in what the exact definition of leadership is, there exist conflicts in how leadership and management are or are not inter-related. In his seminal work, Sheldon developed a professional creed for managers to ensure that industry was run with the greatest efficiency possible. Included in this creed were key tenets regarding how management should be incorporated as a stabilizing influence on industry, one that safeguards against disruptive change. This tenet runs in conflict with the concept of leadership as the catalyst for managing and even promoting change in an organization to enable further growth and success discussed by many authors, including Collins' Level 5 leader.