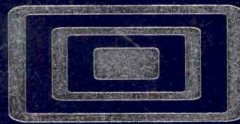
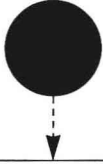


Second Edition

MANAGING  
ENGINEERING  
— AND —  
TECHNOLOGY



Daniel L. Babcock



# ***Managing Engineering and Technology***

***An Introduction to Management for Engineers***

***Second Edition***

**DANIEL L. BABCOCK**

***Professor Emeritus  
University of Missouri–Rolla***



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This book is dedicated to the current generation of  
practicing engineers, especially my children Jean, Bethany, and Sterling,  
my stepson Jim, and now *his* son Chris; the engineering students  
who will join them soon; and my late wife Bettie, whose unfailing love  
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*W.J. Fabrycky and J. H. Mize, Editors*



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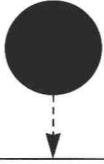
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## ***Preface***

For twenty years after I began teaching engineering management in 1970 I searched for a textbook to use in teaching management principles to young engineers, both upper level undergraduates and young professionals in graduate degree programs or noncredit courses. Certainly there was (and is) no shortage of excellent introductory textbooks in business management. I had several shelves full—generally well written, printed attractively in multiple colors, and accompanied by stacks of supplemental instructors' aids. However, I had been looking for something different—a book that would help introduce the engineer and applied scientist to the ways in which management principles are applied in the kinds of work they are most likely to encounter. And I'd found that young engineering and science students and beginning technical professionals have little understanding of the environment and the profession they are entering. For a limited group of engineers there were solutions. There were several books on construction management suitable for civil engineers interested in that aspect of management. For manufacturing engineers, or for mechanical engineers interested in manufacturing, there were several suitable books on manufacturing management. And a variety of books on project management were available for use in credit and noncredit classes and personal study in this area. Finally, there were several books on various aspects of engineering management, but none seemed to have the breadth and content I was looking for.

In the late 1980s I began to prepare handout materials that supplemented the management textbook I was then using. I incorporated them into an outline of the book I really wished were available. Prentice-Hall liked the outline, so I fleshed it out, and the first edition, appearing in late 1990, was the result. I've been pleased by the reception the book received from my colleagues in engineering management education and related fields. It was adopted for use in more than fifty U.S. institutions, as well as in several other countries (especially in Australia).

However, we live in a fast-moving world. American industry, portrayed in the first edition as being in serious difficulty, is now much more competitive worldwide. Our better companies have been "reengineered" by reducing layers of middle management, motivating and empowering employee teams to continually improve quality and productivity,

emphasizing customer satisfaction, and eliminating activities that are not essential. New methods and tools such as concurrent engineering, strategic management of technology, activity-based costing, and total productive maintenance have seen increasing use. International trade is increasingly important in the era of NAFTA, the expansion of GATT, and the collapse of the Soviet empire. These considerations, plus updating of statistical information and increasing end-of-chapter discussion questions, have been incorporated into this second edition.

As in the first edition, I begin this book with a chapter on the profession of engineering, the art and science of management, and their integration. This is followed by a chapter on the history of management from the engineer's perspective. Chapters 3 through 8 concern themselves with the management functions of planning, organizing, motivating, and controlling as they might appear in a more conventional management text, but somewhat condensed and written with an emphasis on the management of technology. The next chapters then apply these basics of management to the working environments the engineer is most likely to see, organized into chapters on research, design, production, and technical sales and service. Then two chapters on project management treat the application of management principles to this common type of engineering practice. Chapters 16 and 17 consider the early career development of the engineer—in getting off to the right start, maintaining technical competence, and considering the transition to management. Chapter 18 closes with supporting topics of interest to the engineer—the position of women and minorities in engineering, using time effectively, and the importance of professional ethics.

Instructors adopting this book may wish to tailor the content to their specific needs. For industrial and manufacturing engineering classes, Chapters 11 and 12 may be redundant to similar material covered in more detail in other classes. Chapter 16, dealing with the beginning of the engineering career, may be unnecessary for graduate classes of practicing engineers. Discussion questions at the end of each chapter include some that ask working engineers for application of chapter content to their own professional experience, and others more appropriate to undergraduates. Adopters have confirmed my experience that the book has more than enough breadth of material, even when selectively pruned in this manner, for use in a 45-contact-hour, 3-semester-hour program.

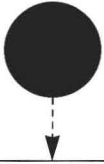
Suggestions for improvement or identification of errors are welcomed.

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*Daniel L. Babcock, PhD, P.E.*  
Rolla, Missouri





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## Introduction to Engineering Management

### CHAPTER

### 1

## *Engineering and Management*

### PREVIEW

We begin this chapter 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, we define *management* and characterize managerial jobs and functions. Finally, these topics are synthesized by defining *engineering management* and discussing the expectation of managerial responsibilities in the typical engineering career.

### ENGINEERING

#### Origins of Engineering

The words *engineer* and *ingenious* both stem from the Latin *ingenium*, which meant 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,”<sup>22</sup> and the following stems both from that and from my own writings. In 1716 the French government, under Louis XV, formed a civilian engineering corps, the *Corps des Ponts et Chaussées*, to oversee design and construction of roads and bridges, and in 1747 founded the *École des Ponts et Chaussées* 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 *École 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 “Knowledge was gained pragmatically, in the workshop and on construction sites, and engineers learned their craft—and such science as seemed useful, by apprenticeship.”

America was heir to both traditions. Harvard and other early colleges followed the British classical tradition, and in the Revolutionary War we had to borrow engineers from France and elsewhere to help us 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.’”<sup>23</sup>

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 the *École 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

he 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

Given the preceding, is engineering *really* a profession? “Profession” has been defined (in *Webster’s Third International Dictionary*) as:

2 a calling requiring *specialized knowledge* and often long and *intensive preparation*, including instruction in *skills and methods* as well as in the scientific, *historical or scholarly principles underlying such skills and methods, maintaining* by force of *organization* or concerted opinion *high standards of achievement and conduct*, and committing its members to *continued study* and to a kind of work which has for its prime purpose the rendering of a *public service*. [emphasis added]

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

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

A more modern and complete definition was created in 1979 by American engineering societies, acting together through the Engineers’ Council for Professional Development (ECPD, the precursor to ABET, the Accrediting Board for Engineering and Technology). ECPD defined *engineering* as

2 the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.<sup>5</sup>

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 life-long learning to keep up with the march of technology. In Part 5 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 work.** The U.S. Bureau of Labor Statistics defines the nature and variety of engineering work as follows:

Engineers apply the theories and principles of science and mathematics to the economical solution of practical technical problems. Often their work is the link between a scientific discovery and its application. Engineers design machinery, products, systems, and processes for efficient and economical performance. They design industrial machinery and equipment for manufacturing goods; design defense and weapons systems for the Armed Forces; and design, plan, and supervise the construction of buildings, highways, and rapid transit systems. They also design and develop consumer products and systems for control and automation of manufacturing, business, and management process.<sup>6</sup>

**Numbers of engineers.** To identify the number of engineers in the United States at any specific date, one must first specify carefully what is meant by an engineer. For example, the U.S. Bureau of Labor Statistics (BLS) included in their totals of “employed civilians” taken from January *Employment and Earnings* data a total of 1,572,000 engineers for 1983 and 1,716,000 for 1993 (Table 1-1). However, BLS also lists from *Monthly Labor Review* data 1,353,800 engineers and 666,200 “computer systems analysts, engineers, and scientists,” for a total of 2.02 million in 1992 (Table 1-2); the comparable table for 1990 data,<sup>7</sup> using earlier category definitions, listed 1,519,000 engineers but only 463,200 “system analysts, EDP,” for a comparable total of 1.98 million. Moreover, the National Science Foundation (NSF) reported the U.S. engineering population in the labor force in **1986** as 2.47 million!<sup>8</sup> Only a small portion of the excess reported by NSF can be accounted for by engineers in military uniform, excluded from the BLS total. A National Research Council study sums up the difficulty:

There is considerable diversity of opinion among individuals, groups, and organizations on what constitutes engineering. . . . In fact, the engineering community contains significant numbers of

- individuals with baccalaureate or higher degrees in science or mathematics who have acquired status as engineers;
- people whose highest degree is an associate engineering [technician] or technologist degree and who have acquired status through experience as engineers or as engineering technicians or technologists; and
- individuals who over years of experience and/or noncollegiate training have acquired the skills and knowledge to do bona fide engineering work.<sup>9</sup>

There also appears to be a large “strategic reserve” represented by those who have qualified as members of the engineering community in the past but who either left the profession entirely or, more likely, are currently engaged in managerial and engineering support activities.<sup>10</sup>

**TABLE 1-1** U.S. Civilian Employment of Engineers by Type

Type of Engineer	Number in Thousands (percent)			
	1983		1993	
Electrical & electronic	450	(28.6)	533	(31.1)
Mechanical	259	(16.5)	296	(17.2)
Civil	211	(13.4)	221	(12.9)
Industrial	210	(13.3)	201	(11.7)
Aerospace	80	(5.1)	83	(4.8)
Chemical	67	(4.3)	58	(3.4)
Other types of engineers	295	(18.8)	324	(18.9)
Total Engineers	1572	(100.0)	1716	(100.0)

Source: *Statistical Abstract of the United States 1994*, 114th ed., U.S. Department of Commerce, Bureau of the Census, Washington, DC, 1994, Table 637, taken from U.S. Bureau of Labor Statistics, *Employment and Earnings*, monthly, January issues.

**Types of engineers.** Since the first engineers were military, the term *civil engineer* was first used to refer to all other engineers. With the age of machinery came the *mechanical engineer*, and today there are many kinds of engineers. The relative number of engineers of the most common types in the United States in 1983 and 1993 is shown in Table 1-1 (taken from the BLS *Employment and Earnings* data previously cited). About 31% of all (1.716 million) engineers by 1993 were electrical (and electronic) engineers, and another 17% mechanical. This difference may decrease: from 1987 to 1992, U.S. undergraduate enrollment decreased from 104,000 to 72,000 for electrical engineers, while increasing slightly from 65,000 to 67,000 for mechanical engineers, perhaps due to changes in perceived demand.<sup>11</sup> The large proportion (19%) of engineers in categories “other” than the six listed shows the continuing diversification of the engineering profession and the formation of new and rapidly growing specialties. In developing countries where the major engineering emphasis is on building infrastructure, civil engineers make up a much greater proportion than the 13% shown for the United States.

**Employers of engineers.** In 1992, engineers not working primarily on computer systems held 1,353,800 civilian jobs. As shown in Table 1-2, almost half (640,700, or 47.3%) of them worked in manufacturing industries—mostly in electrical and electronic equipment, aircraft and parts, machinery, scientific instruments, chemicals, motor vehicles, fabricated metal products, and primary metals industries. They were not evenly distributed as a percentage of total employment across industry. According to the National Research Council<sup>12</sup>, in 1980 about 25.2% of engineering services, 15.7% of aircraft (aerospace), and 12.7% of commercial R&D personnel were engineers. Engineers then made up 9.6% of electronic computer, 7.1% of electrical machinery, and 4.8% of nonelectric machinery employment, but only about 4% in chemicals, communications, and motor vehicles and roughly 2.2% in primary and fabricated metals industries.

Another 302,200 (22.3%) of civilian engineers in 1992 worked in services, especially in engineering and architectural services and business and management consulting services, where firms designed construction projects or did other engineering work on a con-



**TABLE 1-2** U.S. Civilian Employment of Scientists, Engineers, and Technicians, by Occupation and Industry: 1992  
[In thousands. Based on sample and subject to sampling error. For details, see source]

Occupation	Total <sup>1</sup>	Wage and Salary Workers						Self-employed	
		Mining <sup>2</sup>	Construction	Manufacturing	Transportation <sup>3</sup>	Trade	FIRE <sup>4</sup>	Services	Government
<b>Scientists and engineers</b>	<b>2,673.7</b>	<b>41.6</b>	<b>27.1</b>	<b>913.5</b>	<b>108.4</b>	<b>86.8</b>	<b>99.3</b>	<b>761.1</b>	<b>461.6</b>
Scientists	1,319.8	19.5	1.2	272.8	33.1	30.8	88.0	458.9	271.7
Physical scientists	197.5	14.8	0.1	59.4	3.2	2.5	0.6	65.3	45.2
Life scientists	182.1	0.1	—	27.6	0.9	1.7	(NA)	57.7	72.9
Mathematical scientists	16.3	—	—	1.5	0.7	—	1.6	7.4	5.1
Social scientists	257.8	0.3	—	—	1.3	—	7.7	99.0	65.1
Computer systems analysts, engineers and scientists	666.2	4.2	1.1	184.4	26.9	26.5	78.1	229.5	83.3
Engineers <sup>5</sup>	1,353.8	22.2	25.9	640.7	75.4	56.0	11.3	302.2	189.9
Civil engineers	172.8	1.1	10.9	8.3	6.2	0.5	0.9	66.2	73.7
Electrical/electronics	369.9	0.9	5.8	167.6	34.5	35.5	1.1	78.7	39.8
Mechanical engineers	227.0	1.7	4.0	136.6	5.1	7.1	1.3	52.3	13.8
<b>Engineering and science technicians</b>	<b>1,253.1</b>	<b>19.2</b>	<b>25.5</b>	<b>449.5</b>	<b>74.0</b>	<b>84.4</b>	<b>5.1</b>	<b>400.3</b>	<b>160.8</b>
Electrical/electronics technicians	322.8	1.6	5.1	128.0	26.0	62.1	1.8	67.3	26.7
Engineering technicians	372.1	5.4	4.5	132.0	26.6	11.4	0.3	94.7	90.4
Drafters	314.2	2.7	15.9	100.1	17.5	6.6	1.1	144.9	11.3
Science technicians	244.1	9.5	—	89.3	3.9	4.3	1.9	93.4	32.4
<b>Surveyors</b>	<b>99.3</b>	<b>2.6</b>	<b>3.3</b>	<b>—</b>	<b>3.3</b>	<b>—</b>	<b>0.6</b>	<b>55.9</b>	<b>23.0</b>
<b>Computer programmers</b>	<b>554.7</b>	<b>3.4</b>	<b>1.3</b>	<b>80.8</b>	<b>24.1</b>	<b>57.0</b>	<b>75.4</b>	<b>246.1</b>	<b>50.1</b>

— Represents or rounds to zero. NA Not available. <sup>1</sup>Includes agriculture, forestry, and fishing not shown separately. <sup>2</sup>Includes oil and gas extraction. <sup>3</sup>Includes communications and public utilities. <sup>4</sup>Finance, insurance, and real estate. <sup>5</sup>Includes kinds of engineers and technicians not shown separately.

Source: *Statistical Abstract of the United States 1994*, 114th ed., U.S. Department of Commerce, Bureau of the Census, Washington, DC, 1994, Table 979, taken from U.S. Bureau of Labor Statistics, *Monthly Labor Review*, November 1993. (Data collected biennially.)

tract basis for organizations in other parts of the economy. Federal, State, and local governments employed another 189,900 (14.0%). Over half of these were in the Federal Government, mainly in the Departments of Defense, Transportation, Agriculture, Interior, and Energy, and in the National Aeronautics and Space Administration (NASA). Most engineers in state and local government agencies worked in highway and public works departments.

Another 75,400 (5.6%) of (especially electrical) engineers worked in communications, public utilities, or transportation. The remaining 144,400 (10.7%) were employed in various commercial occupations, construction, or mining, or were self-employed consultants.

**Engineering jobs in a company.** Manufacturing organizations offer many types of jobs for engineers. Figure 1-1 gives an example.

Many of the engineering positions in this hypothetical manufacturing company would fall under the vice president for research and engineering. Positions in engineering research, engineering design, and related design support activities such as reliability and maintainability engineering are discussed in Chapters 9 and 10. As many or more engineers might report to the vice presidents for manufacturing and (if separate) quality control. These industrial, plant, maintenance, manufacturing, and quality engineering functions 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. A smaller number of engineers will find temporary positions or permanent careers in areas such as purchasing (of technically complex parts and services) and recruiting (of technical personnel). Finally, 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

“Management” 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, garbage collectors are now “waste management experts,” and the glamorous Hollywood actress Jane Fonda even has a “school of figure management.”<sup>13</sup>

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.<sup>14</sup>