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Professionalism and Codes of Ethics

SECTIONS

OBJECTIVES

- Determine whether engineering is a profession.
- Understand what codes of ethics are. Examine some codes of ethics of professional engineering societies.
- The importance of being sensitive to the many ethical issues with which you be will dealing as an engineer.

Late in 1994, reports began to appear in the news media that the latest generation of Pentium microprocessors, the heart and soul of personal computers, was flawed. These reports appeared not only in trade journals and magazines aimed at computer specialists, but also in *The New York Times* and other daily newspapers. The stories reported that computers equipped with these chips were unable to correctly perform some relatively simple multiplication and division operations.

At first, Intel, the manufacturer of the Pentium microprocessor, denied that there was a problem. Later, it argued that although there was a problem, the error would be significant only in sophisticated applications, and most people wouldn't even notice that an error had occurred. It was also reported that Intel had been aware of the problem and already was working to fix it. As a result of this publicity, many people who had purchased Pentium-based computers asked to have the defective chip replaced. Until the public outcry had reached huge proportions, Intel refused to replace the chips. Finally, when it was clear that this situation was a public relations disaster for them, Intel agreed to replace the defective chips when customers requested.

Did Intel do anything unethical? To answer this question, we will need to develop a framework for understanding ethical problems. One part of this framework will be the codes of ethics that have been established by professional engineering organizations. These codes help guide engineers in the course of their professional duties and give them insight into ethical problems such as the one just described. The engineering codes of ethics hold that engineers should not make false claims or represent a product to be something that it is not. In some ways, the Pentium case might seem to simply be a public-relations problem. But, looking at the problem with a *code of ethics* will indicate that there is more to this situation than simple PR, especially since the chip did not operate in the way that Intel claimed it did.

In this chapter, the nature of *professions* will be examined with the goal of determining whether engineering is a profession. Two representative engineering codes of ethics will be looked at in detail. At the end of this chapter, the Pentium case is presented in more detail along with two other cases, and codes of ethics are applied to analyze what the engineers in these cases should have done.

2.1 INTRODUCTION

When confronted by an ethical problem, what resources are available to an engineer to help find a solution? One of the hallmarks of modern *professions* are codes of ethics promulgated by various *professional societies*. These codes serve to guide practitioners of the profession in making decisions about how to conduct themselves and how to resolve ethical issues that might confront them. Are codes of ethics applicable to engineering? To answer this question, we must first consider what *professions* are and how they function and then decide if this definition applies to engineering. Then we will examine codes of ethics in general and look specifically at some of the codes of engineering *professional societies*.

2.2 IS ENGINEERING A PROFESSION?

In order to determine whether engineering is a profession, the nature of *professions* must first be examined. As a starting point, it will be valuable to distinguish the word "profession" from other words that are sometimes used synonymously with "profession": "job" and "occupation." Any work for hire can be considered a job, regardless of the skill level involved and the responsibility granted. Engineering is certainly a job—engineers are paid for their services—but the skills and responsibilities involved in engineering make it more than just a job.

Similarly, the word "occupation" implies employment through which someone makes a living. Engineering, then, is also an occupation. How do the words "job" and "occupation" differ from "profession?"

The words "profession" and "professional" have many uses in modern society that go beyond the definition of a job or occupation. One often hears about "professional athletes" or someone referring to himself as a "professional carpenter," for example. In the first case, the word "professional" is being used to distinguish the practitioner from an unpaid amateur. In the second case, it is used to indicate some degree of skill acquired through many years of experience, with an implication that this practitioner will provide quality services.

Neither of these senses of the word "professional" is applicable to engineers. There are no amateur engineers who perform engineering work without being paid while they train to become professional, paid engineers. Likewise, the length of time one works at an engineering-related job, such as an engineering aide or engineering technician, does not confer professional status no matter how skilled a technician one might become. To see what is meant by the term "professional engineer", we will first examine the nature of *professions*.

2.2.1 What Is a Profession?

What are the attributes of a profession? There have been many studies of this question, and some consensus as to the nature of *professions* has been achieved. Attributes of a profession include:

1. The work requires sophisticated skills, the use of judgment, and the exercise of discretion. Also, the work is not routine and is not capable of being mechanized;
2. Membership in the profession requires extensive formal education, not simply practical training or apprenticeship;
3. The public allows special societies or organizations that are controlled by members of the profession to set standards for admission to the profession, to set standards of conduct for members, and to enforce these standards; and
4. Significant public good results from the practice of the profession [Martin and Schinzinger, 1989].

The terms "judgment" and "discretion" used in the first part of this definition require a little amplification. Many occupations require judgment every day. A secretary must decide what work to tackle first. An auto mechanic must decide if a part is sufficiently worn to require complete replacement, or if rebuilding will do. This is not the type of judgment implied in this definition. In a profession, "judgment" refers to making significant decisions based on formal training and experience. In general, the decisions will have serious impact on people's lives and will often have important implications regarding the spending of large amounts of money.

"Discretion" can have two different meanings. The first definition involves being discrete in the performance of one's duties by keeping information about customers, clients, and patients confidential. This confidentiality is essential for engendering a trusting relationship and is a hallmark of *professions*. While many jobs might involve some discretion, this definition implies a high level of significance to the information that must be kept private by a professional. The other definition of discretion involves the ability to make decisions autonomously. When making a decision, one is often told, "Use your discretion." This definition is similar in many ways to that of the term "judgment" described previously. Many people are allowed to use their discretion in making choices while performing their jobs. However, the significance of the decision marks the difference between a job and a profession.

One thing not mentioned in the definition of a profession is the compensation received by a professional for his services. Although most professionals tend to be relatively well compensated, high pay is not a sufficient condition for professional status. Entertainers and athletes are among the most highly paid members of our society, and yet few would describe them as professionals in the sense described previously. Although professional status often helps one to get better pay and better working conditions, these are more often determined by economic forces.

Earlier, reference was made to "professional" athletes and carpenters. Let's examine these occupations in light of the foregoing definition of *professions* and see if athletics and carpentry qualify as *professions*. An athlete who is paid for her appearances is referred to as a professional athlete. Clearly, being a paid athlete does involve sophisticated skills that most people do not possess, and these skills are not capable of mechanization. However, substantial judgment and discretion are not called for on the part of athletes in their "professional" lives, so athletics fails the first part of the definition of "professional." Interestingly, though, professional athletes are frequently viewed as role models and are often disciplined for a lack of discretion in their personal lives.

Athletics requires extensive training, not of a formal nature, but more of a practical nature acquired through practice and coaching. No special societies (as opposed to unions, which will be discussed in more detail later) are required by athletes, and athletics does not meet an important public need; although entertainment is a public need, it certainly doesn't rank highly compared to the needs met by *professions* such as medicine. So, although they are highly trained and very well compensated, athletes are not professionals.

Similarly, carpenters require special skills to perform their jobs, but many aspects of their work can be mechanized, and little judgment or discretion is required. Training in carpentry is not formal, but rather is practical by way of apprenticeships. No organizations or societies are required. However, carpentry certainly does meet an aspect of the public good—providing shelter is fundamental to society—although perhaps not to the same extent as do *professions* such as medicine. So, carpentry also doesn't meet the basic requirements to be a profession. We can see, then, that many jobs or occupations whose practitioners might be referred to as professionals don't really meet the basic definition of a profession. Although they may be highly paid or important jobs, they are not *professions*.

Before continuing with an examination of whether engineering is a profession, let's look at two occupations that are definitely regarded by society as *professions*: medicine and law. Medicine certainly fits the definition of a profession given previously. It requires very sophisticated skills that can't be mechanized, it requires judgment as to appropriate treatment plans for individual patients, and it requires discretion (physicians have even been granted "physician–patient privilege," the duty not to divulge information given in confidence by the patient to the physician). Although medicine requires extensive practical training learned through an apprenticeship called a residency, it also requires much formal training (four years of undergraduate school, three to four years of medical school, and extensive hands-on practice in patient care). Medicine has a special society, the American Medical Association (AMA), to which a large fraction of practicing physicians belong and that participates in the regulation of medical schools, sets standards for practice of the profession, and enforces codes of ethical behavior for its members. Finally, healing the sick and helping to prevent disease clearly involve the public good. By the definition presented previously, medicine clearly qualifies as a profession.

Similarly, law is a profession. It involves sophisticated skills acquired through extensive formal training; has a professional society, the American Bar Association (ABA); and serves an important aspect of the public good (although this last point is increasingly becoming a point of debate within American society!). The difference between athletics and carpentry on one hand and law and medicine on the other is clear. The first two really cannot be considered *professions*, and the latter two most certainly are.

2.2.2 Engineering as a Profession

Using medicine and law as our examples of *professions*, it is now time to consider whether engineering is a profession. Certainly, engineering requires extensive and sophisticated skills. Otherwise, why spend four years in college just to get a start in engineering? The essence of engineering design is judgment: how to use the available materials, components, devices, etc. to reach a specified objective. Discretion is required in engineering: Engineers are required to keep their employers' or clients' intellectual-property and business information confidential. Also, a primary concern of any engineer is the safety of the public that will use the products and devices he designs. There is always a trade-off between safety and other engineering issues in a design, requiring discretion on the part of the engineer to ensure that the design serves its purpose and fills its market niche safely.

The point about mechanization needs to be addressed a little more carefully with respect to engineering. Certainly, once a design has been performed, it can easily be replicated without the intervention of an engineer. However, each new situation that requires a new design or a modification of an existing design requires an engineer. Industry commonly uses many computer-based tools for generating designs, such as computer-aided design (CAD) software. This shouldn't be mistaken for mechanization of engineering. CAD is simply a tool used by engineers, not a replacement for the skills of an actual engineer. A wrench can't fix an automobile without a mechanic. Likewise, a computer with CAD software can't design an antilock braking system for an automobile without an engineer.

Engineering requires extensive formal training. Four years of undergraduate training leading to a bachelor's degree in an engineering program is essential, followed by work under the supervision of an experienced engineer. Many engineering jobs even require advanced degrees beyond the bachelor's degree. The work of engineers serves the public good by providing communication systems, transportation, energy resources, and medical diagnostic and treatment equipment, to name only a few.

Before passing final judgment on the professional status of engineering, the nature of engineering societies requires a little consideration. Each discipline within engineering has a professional society, such as the IEEE for electrical engineers and the ASME for mechanical engineers. These societies serve to set professional standards and frequently work with schools of engineering to set standards for admission and curricula. However, these societies differ significantly from the AMA and the ABA. Unlike law and medicine, each specialty of engineering has its own society. There is no overall engineering society that most engineers identify with, although the National Society of Professional Engineers (NSPE) tries to function in this way. In addition, relatively few practicing engineers belong to their *professional societies*. Thus, the engineering societies are weak compared to the AMA and the ABA.

It is clear that engineering meets all of the definitions of a profession. In addition, it is clear that engineering practice has much in common with medicine and law. Interestingly, although they are professionals, engineers do not yet hold the same status within society that physicians and lawyers do.

2.2.3 Differences Between Engineering and Other Professions

Although we have determined that engineering is a profession, it should be noted that there are significant differences between how engineering is practiced and how law and medicine are practiced. Lawyers are typically self employed in private practice, essentially an independent business, or in larger group practices with other lawyers. Relatively few are employed by large organizations such as corporations. Until recently, this was also the case for most physicians, although with the accelerating trend towards managed care and HMOs in the past decade, many more physicians work for large corporations rather than in private practice. However, even physicians who are employed by large HMOs are members of organizations in which they retain much of the decision-making power—often, the head of an HMO is a physician—and are a substantial fraction of the total number of employees.

In contrast, engineers generally practice their profession very differently from physicians and lawyers. Most engineers are not self-employed, but more often are a small part of larger companies involving many different occupations, including accountants, marketing specialists, and extensive numbers of less skilled manufacturing employees. The exception to this rule is civil engineers, who generally practice as independent consultants either on their own or in engineering firms similar in many ways to law firms. When employed by large corporations, engineers are rarely in significant managerial positions, except with regard to managing other engineers. Although engineers are paid well compared to the rest of society, they are generally less well compensated than physicians and lawyers.

Training for engineers is different than for physicians and lawyers. One can be employed as an engineer after four years of undergraduate education, unlike law and medicine, for which training in the profession doesn't begin until after the undergraduate program has been completed. As mentioned previously, the engineering societies are not as powerful as the AMA and the ABA, perhaps because of the number of different professional engineering societies. Also, both law and medicine require licenses granted by the state in order to practice. Many engineers, especially those employed by large industrial companies, do not have engineering licenses. It can be debated whether someone who is unlicensed is truly an engineer or whether he is practicing engineering illegally, but the reality is that many of those who are employed as engineers are not licensed. Finally, engineering doesn't have the social stature that law and medicine have (a fact that is reflected in the lower pay that engineers receive as compared to that of lawyers and doctors). Despite these differences, on balance, engineering is still clearly a profession, albeit one that is not as mature as medicine and law and that should be striving to emulate some of the aspects of these *professions*.

2.2.4 Other Aspects of Professional Societies

We should briefly note that *professional societies* also serve other, perhaps less noble, purposes than those mentioned previously. Sociologists who study the nature of *professional societies* describe two different models of *professions*, sometimes referred to as the social-contract and the business models. The social-contract model views *professional societies* as being set up primarily to further the public good, as described in the definition of a profession given previously. There is an implicit social contract involved with *professions*, according to this model. Society grants the *professions* perks such as high pay, a high status in society, and the ability to self-regulate. In return for these perks, society gets the services provided by the profession.

A perhaps more cynical view of *professions* is provided by the business model. According to this model, *professions* function as a means for furthering the economic advantage of the members. Put another way, professional organizations are labor unions for the elite, strictly limiting the number of practitioners of the profession, controlling the working conditions for professionals, and artificially inflating the salaries of its members. An analysis of both models in terms of law and medicine would show that there are ways in which these *professions* exhibit aspects of both of these models.

Where does engineering fit into this picture? Engineering is certainly a service-oriented profession and thus fits into the social-contract model quite nicely. Although some engineers might wish to see engineering *professional societies* function more according to the business model, they currently don't function that way. The engineering societies have virtually no clout with major engineering employers to set wages and working conditions or to help engineers resolve ethical disputes with their employers. Moreover, there is very little prospect that the engineering societies will function this way in the near future.

2.2.5 If Engineering Were Practiced More Like Medicine

It is perhaps instructive to speculate a little on how engineering might change in the future if our model of the engineering profession were closer to that of law or medicine. One major change would be in the way engineers are educated. Rather than the current system, in which students study engineering as undergraduates and then pursue advanced degrees as appropriate, prospective engineers would probably get a four-year "preengineering" degree in mathematics, physics, chemistry, computer science, or some combination of these fields. After the four-year undergraduate program, students would enter a three- or four-year engineering professional program culminating in a "doctor of engineering" degree (or other appropriately named degree). This program would include extensive study of engineering fundamentals, specialization in a field of study, and perhaps "clinical" training under a practicing engineer.

How would such engineers be employed? The pattern of employment would certainly be different. Engineers in all fields might work for engineering firms similar to the way in which civil engineers work now, consulting on projects for government agencies or large corporations. The corporate employers who now have numerous engineers on their staff would probably have far fewer engineers on the payroll, opting instead for a few professional engineers who would supervise the work of several less highly trained "engineering technicians." Adoption of this model would probably reduce the number of engineers in the work force, leading to higher earnings for those who remain. Those relegated to the ranks of engineering technicians would probably earn less than those currently employed as engineers.

2.3 CODES OF ETHICS

An aspect of *professional societies* that has not been mentioned yet is the codes of ethics that engineering societies have adopted. These codes express the rights, duties, and obligations of the members of the profession.

It should be noted that although most of the discussion thus far has focused on professionalism and *professional societies*, codes of ethics are not limited to professional organizations. They can also be found, for example, in corporations and universities as well. We start with some general ideas about what codes of ethics are and what purpose they serve and then examine two professional engineering codes in more detail.

2.3.1 What Is a Code of Ethics?

Primarily, a *code of ethics* provides a framework for ethical judgment for a professional. The key word here is "framework." No code can be totally comprehensive and cover all possible ethical situations that a professional engineer is likely to encounter. Rather, codes serve as a starting point for ethical decision making. A code can also express the commitment to ethical conduct shared by members of a profession. It is important to note that ethical codes do not establish new ethical principles. They simply reiterate principles and standards that are already accepted as responsible engineering practice. A code expresses these principles in a coherent, comprehensive, and accessible manner. Finally, a code defines the roles and responsibilities of professionals [Harris, Pritchard, and Rabins, 1995].

It is important also to look at what a *code of ethics* is not. It is not a recipe for ethical behavior; as previously stated, it is only a framework for arriving at good ethical choices. A *code of ethics* is never a substitute for sound judgment. A *code of ethics* is not a legal document. One can't be arrested for violating its provisions, although expulsion from the professional society might result from code violations. As mentioned in Section 2.2, with the current state of engineering societies, expulsion from an engineering society generally will not result in an inability to practice engineering, so there are not necessarily any direct consequences of violating engineering ethical codes. Finally, a *code of ethics* doesn't create new moral or ethical principles. As described in Figure 2.1, these principles are well established in society, and foundations of our ethical and moral principles go back many centuries. Rather, a *code of ethics* spells out the ways in which moral and ethical principles apply to professional practice. Put another way, a code helps the engineer to apply moral principles to the unique situations encountered in professional practice.

How does a *code of ethics* achieve these goals? First, a *code of ethics* helps create an environment within a profession where ethical behavior is the norm. It also serves as a guide or reminder of how to act in specific situations. A *code of ethics* can also be used to bolster an individual's position with regard to a certain activity: The code provides a little backup for an individual who is being pressured by a superior to behave unethically. A *code of ethics* can also bolster the individual's position by indicating that there is a collective sense of correct behavior; there is strength in numbers. Finally, a *code of ethics* can indicate to others that the profession is seriously concerned about responsible, professional conduct [Harris, Pritchard, and Rabins, 1995]. A *code of ethics*, however, should not be used as "window dressing," an attempt by an organization to appear to be committed to ethical behavior when it really is not.

2.3.2 Objections to Codes

Although codes of ethics are widely used by many organizations, including engineering societies, there are many objections to codes of ethics, specifically as they apply to engineering practice. First, as mentioned previously, relatively few practicing engineers are members of *professional societies* and so don't necessarily feel compelled to abide by their codes. Many engineers who are members of *professional societies* are not aware of the existence of the society's code, or if they are aware of it, they have never read it. Even among engineers who know about their society's code, consultation of the code is rare. There are also objections that the engineering codes often have internal conflicts, but don't give a method for resolving the conflict. Finally, codes can be coercive: They foster ethical behavior with a stick rather than with a carrot [Harris, Pritchard, and Rabins, 1995]. Despite these objections, codes are in very widespread use today and are generally thought to serve a useful function.

2.3.3 Codes of the Engineering Societies

Professional engineering societies in the United States began to be organized in the late 19th century, with new societies created as new engineering fields have developed in this century. As these societies matured, many of them created codes of ethics to guide practicing engineers.

Early in the current century, these codes were mostly concerned with issues of how to conduct business. For example, many early codes had clauses forbidding advertising of services or prohibiting competitive bidding by engineers for design projects. Codes also spelled out the duties that engineers had toward their employers. Relatively less emphasis than today was given to issues of service to the public and safety. This imbalance changed greatly in recent decades as public perceptions and concerns about the safety of engineered products and devices have changed. Now, most codes emphasize commitments to safety, public health, and even environmental protection as the most important duties of the engineer.

2.3.4 A Closer Look at Two Codes of Ethics

Having looked at some ideas about what codes of ethics are and how they function, let's look more closely at two of the codes of ethics: the codes of the Institute of Electrical and Electronics Engineers (IEEE) and the National Society of Professional Engineers (NSPE). Although these codes have some common content, the structures of the codes are very different.

The IEEE code is short and deals in generalities, whereas the NSPE code is much longer and more detailed. An explanation of these differences is rooted in the philosophy of the authors of these codes. A short code that is lacking in detail is more likely to be read by members of the society than is a longer code. A short code is also more understandable. It articulates general principles and truly functions as a framework for ethical decision making, as described previously.

A longer code, such as the NSPE code, has the advantage of being more explicit and able to cover more ground. It leaves less to the imagination of the individual and therefore is more useful for application to specific cases. The length of the code, however, makes it less likely to be read and thoroughly understood by most engineers.

There are some specifics of these two codes that are worth noting here. The IEEE code doesn't mention a duty to one's employer. However, the IEEE code does mention a duty to protect the environment, a clause added relatively recently, which is somewhat unique among engineering codes. The NSPE code has a preamble that succinctly presents the duties of the engineer before going on to the more explicit discussions of the rest of the code. Like most codes of ethics, the NSPE code does mention the engineer's duty to her employer in Section I.4, where it states that engineers shall "[a]ct . . . for each employer . . . as faithful agents or trustees."

2.3.5 Resolving Internal Conflicts in Codes

One of the objections to codes of ethics mentioned previously is the internal conflicts that can exist within them, with no instructions on how to resolve these conflicts. An example of this problem would be a situation in which an employer asks or even orders an engineer to implement a design that the engineer feels will be unsafe. It is made clear that the engineer's job is at stake if he doesn't do as instructed. What does the NSPE code tell us about this situation?

In clause I.4, the NSPE code indicates that engineers have a duty to their employers, which implies that the engineer should go ahead with the unsafe design favored by his employer. However, clause I.1 and the preamble make it clear that the safety of the public is also an important concern of an engineer. In fact, it says that the safety of the public is paramount. How can this conflict be resolved?

There is no implication in this or any other code that all clauses are equally important. Rather, there is a hierarchy within the code. Some clauses take precedence over others, although there is generally no explicit indication in the code of what the hierarchy is. The dilemma presented above is easily resolved within the context of this hierarchy. The duty to protect the safety of the public is paramount and takes precedence over the duty to the employer. In this case, the code provides very clear support to the engineer, who must convince his supervisor that he can't design the product as requested. Unfortunately, not all internal conflicts in codes of ethics are so easily resolved.

2.3.6 Can Codes and Professional Societies Protect Employees?

One important area where *professional societies* can and should function is as protectors of the rights of employees who are being pressured by their employer to do something unethical or who are accusing their employers or the government of unethical conduct. The codes of the *professional societies* are of some use in this since they can be used by employees as ammunition against an employer who is sanctioning them for pointing out unethical behavior or who are being asked to engage in unethical acts.

An example of this situation, which we shall discuss in more detail in a later chapter, is the action of the IEEE on behalf of three electrical engineers who were fired from their jobs at the Bay Area Rapid Transit (BART) organization when they pointed out deficiencies in the way the control systems for the BART trains were being designed and tested. After being fired, the engineers sued BART, citing the IEEE *code of ethics* which impelled them to hold as their primary concern the safety of the public who would be using the BART system. The IEEE intervened on their behalf in court, although ultimately the engineers lost the case.

If the codes of ethics of *professional societies* are to have any meaning, this type of intervention is essential when ethical violations are pointed out. However, as mentioned previously, since not all engineers are members of *professional societies* and the engineering societies are relatively weak, the pressure that can be exerted by these organizations is limited.

2.3.7 Other Types of Codes of Ethics

Professional societies aren't the only organizations that have codified their ethical standards. Many other organizations have also developed codes of ethics for various purposes similar to those of the professional engineering organizations. For example, codes for the ethical use of computers have been developed, and student organizations in universities have framed student codes of ethics. In this section, we will examine how codes of ethics function in corporations.

Many of the important ethical questions faced by engineers come up in the context of their work for corporations. Since most practicing engineers are not members of professional organizations, it seems that for many engineers, there is little ethical guidance in the course of their daily work. This problem has led to the adoption of codes of ethics by many corporations.

Even if the professional codes were widely adopted and recognized by practicing engineers, there would still be some value to the corporate codes, since a corporation can tailor its code to the individual circumstances and unique mission of the company. As such, these codes tend to be relatively long and very detailed, incorporating many rules specific to the practices of the company. For example, corporate codes frequently spell out in detail the company policies on business practices, relationships with suppliers, relationships with government agencies, compliance with government regulations, health and safety issues, issues related to environmental protection, equal employment opportunity and affirmative action, sexual harassment, and diversity and racial/ethnic tolerance. Since corporate codes are coercive in nature—your continued employment by the company depends on your compliance with the company code—these codes tend to be longer and more detailed in order to provide very clear and specific guidelines to the employees.

Codes of *professional societies*, by their nature, can't be this explicit, since there is no means for a professional society to reasonably enforce its code.

Some of the heightened awareness of ethics in corporations stems from the increasing public scrutiny that has accompanied well-publicized disasters, such as the cases presented elsewhere in this book, as well as from cases of fraud and cost overruns, particularly in the defense industry, that have been exposed in the media. Many large corporations have developed corporate codes of ethics in response to these problems, to help heighten employee's awareness of ethical issues, and to help establish a strong corporate ethics culture. These codes give employees ready access to guidelines and policies of the corporations. But, as with professional codes, it is important to remember that these codes cannot cover all possible situations that an employee might encounter; there is no substitute for good judgment. A code also doesn't substitute for good lines of communications between employees and upper management and for workable methods for fixing ethical problems when they occur.

APPLICATION: CASES

Codes of ethics can be used as a tool for analyzing cases and for gaining some insight into the proper course of action.Put yourself in the position of an engineer working for these companies—Intel, Paradyne computers, and 3Bs construction—to see what you would have done in each case.

The Intel Pentium Chip

In late 1994, the media began to report that there was a flaw in the new Pentium microprocessor produced by Intel. The microprocessor is the heart of a personal computer and controls all of the operations and calculations that take place. A flaw in the Pentium was especially significant, since it was the microprocessor used in 80% of the personal computers produced in the world at that time.

Apparently, flaws in a complicated integrated circuit such as the Pentium, which at the time contained over one million transistors, are common. However, most of the flaws are undetectable by the user and don't affect the operation of the computer. Many of these flaws are easily compensated for through software. The flaw that came to light in 1994 was different: It was detectable by the user. This particular flaw was in the floating-point unit (FPU) and caused a wrong answer when double-precision arithmetic, a very common operation, was performed.

A standard test was widely published to determine whether a user's microprocessor was flawed. Using spreadsheet software, the user was to take the number 4,195,835, multiply it by 3,145,727, and then divide that result by 3,145,727. As we all know from elementary math, when a number is multiplied and then divided by the same number, the result should be the original number. In this example, the result should be 4,195,835. However, with the flawed FPU, the result of this calculation was 4,195,579. [Infoworld, 1994] Depending on the application, this six-thousandths-of-a-percent error might be very significant.

At first, Intel's response to these reports was to deny that there was any problem with the chip. When it became clear that this assertion was not accurate, Intel switched its policy and stated that although there was indeed a defect in the chip, it was insignificant and the vast majority of users would never even notice it. The chip would be replaced for free only for users who could demonstrate that they needed an unflawed version of the chip. [Infoworld, 1994] There is some logic to this policy from Intel's point of view, since over two million computers had already been sold with the defective chip.

Of course, this approach didn't satisfy most Pentium owners. After all, how can you predict whether you might have a future application where this flaw might be significant? IBM, a major Pentium user, canceled the sales of all IBM computers containing the flawed chip. Finally, after much negative publicity in the popular personal-computer literature and an outcry from Pentium users, Intel agreed to replace the flawed chip with an unflawed version for any customer who asked to have it replaced.

It should be noted that long before news of the flaw surfaced in the popular press, Intel was aware of the problem and had already corrected it on subsequent versions. It did, however, continue to sell the flawed version and, based on its early insistence that the flaw did not present a significant problem to users, seemingly planned to do so until the new version was available and the stocks of the flawed one were exhausted. Eventually, the damage caused by this case was fixed as the media reports of the problem died down and as customers were able to get unflawed chips into their computers.

What did Intel learn from this experience? The early designs for new chips continue to have flaws, and sometimes these flaws are not detected until the product is already in use by consumers. However, Intel's approach to these problems has changed. It now seems to feel that problems need to be fixed immediately. In addition, the decision is now based on the consumer's perception of the significance of the flaw, rather than on Intel's opinion of its significance.

Runway Concrete at the Denver International Airport

In the early 1990s, the city of Denver, Colorado embarked on one of the largest public works projects in history: the construction of a new airport to replace the aging Stapleton International Airport. The new Denver International Airport (DIA) would be the first new airport constructed in the US since the Dallas–Fort Worth Airport was completed in the early 1970s. Of course, the size and complexity of this type of project lends itself to many problems, including cost overruns, worker safety and health issues, and controversies over the need for the project. The construction of DIA was no exception.

Perhaps the most widely known problem with the airport was the malfunctioning of a new computer-controlled high-tech baggage handling system, which in preliminary tests consistently mangled and misrouted baggage and frequently jammed, leading to the shutdown of the entire system. Problems with the baggage handling system delayed the opening of the airport for over a year and cost the city millions of dollars in expenses for replacement of the system and lost revenues while the airport was unable to open. In addition, the baggage system made the airport the butt of many jokes, especially on late-night television. More interesting from the perspective of engineering ethics are problems during the construction of DIA involving the concrete used for the runways, taxiways, and aprons at the airport.

The story of concrete problems at DIA was first reported by the *Denver Post* in early August of 1993 as the airport neared completion. Two subcontractors filed lawsuits against the runway-paving contractor, California construction company Ball, Ball, & Brosamer (known as 3Bs), claiming that 3Bs owed them money. Parts of these suits were allegations that 3Bs had altered the recipe for the concrete used in the runway and apron construction, deliberately diluting the concrete with more gravel, water, and sand (and thus less cement), thereby weakening it. 3Bs motivation for doing so would be to save money and thus to increase their profits. One of the subcontractors, CSI Trucking, whose job was to haul the sand and gravel used in the concrete, claimed that 3Bs hadn't paid them for materials that had been delivered. They claimed that these materials had been used to dilute the mixture, but hadn't been paid for, since the payment would leave a record of the improper recipe.

At first, Denver officials downplayed the reports of defective concrete, relying on the results of independent tests of the concrete. In addition, the city of Denver ordered core samples to be taken from the runways. Tests on these cores showed that the runway concrete had the correct strength. The subcontractors claimed that the improperly mixed concrete could have the proper test strength, but would lead to a severely shortened runway lifetime. The FBI also became involved in investigating this case, since federal transportation grants were used by Denver to help finance the construction of the runways.

The controversy seemed to settle down for a while, but a year later, in August of 1994, the Denver district attorney's office announced that it was investigating allegations that inspection reports on the runways were falsified during the construction. This announcement was followed on November 13, 1994 by a lengthy story in the *Denver Post* detailing a large number of allegations of illegal activities and unethical practices with regard to the runway construction.

The November 13 story revolved around an admission by a Fort Collins, Colorado company, Empire Laboratories, that test reports on the concrete had been falsified to hide results which showed that some of the concrete did not meet the specifications. Attorneys for Empire said that this falsification had happened five or six times in the course of this work, but four employees of Empire claimed that the altering of test data was standard operating procedure at Empire.

The nature of the test modifications and the rationale behind them illustrate many of the important problems we will discuss in this book, including the need for objectivity and honesty in reporting results of tests and experiments. One Empire employee said that if a test result was inconsistent with other tests, then the results would be changed to mask the difference. This practice was justified by Empire as being "based upon engineering judgment" [*Denver Post*, Nov. 13, 1994]. The concrete was tested by pouring test samples when the actual runways were poured. These samples were subjected to flexural tests, which consist of subjecting the concrete to an increasing force until it fails. The tests were performed at 7 days after pouring and also at 28 days. Many of the test results showed that the concrete was weaker at 28 days than at 7 days. However, the results should have been the opposite, since concrete normally increases in strength as it cures. Empire employees indicated that this apparent anomaly was because many of the 7-day tests had been altered to make the concrete seem stronger than it was.

Other problems with the concrete also surfaced. Some of the concrete used in the runways contained clay balls up to 10 inches in diameter. While not uncommon in concrete batching, the presence of this clay can lead to runways that are significantly weaker than planned.

Questions about the short cement content in 3Bs concrete mixture also resurfaced in the November *Denver Post* article. The main question was: Given that the concrete batching operation was routinely monitored, how did 3Bs get away with shorting the cement content of the concrete? One of the batch plant operators for 3Bs explained that they were tipped off about upcoming inspections. When an inspector was due, they used the correct recipe so that concrete would appear to be correctly formulated. The shorting of the concrete mixture could also be detected by looking at the records of materials delivered to the batch plants. However, DIA administrators found that this documentation was missing, and it was unclear whether it had ever existed.

A batch plant operator also gave a sworn statement that he had been directed to fool the computer that operated the batch plant. The computer was fooled by tampering with the scale used to weigh materials and by inputting false numbers for the moisture content of the sand. In some cases, the water content of the sand that was input into the computer was a negative number! This tampering forced the computer to alter the mixture to use less cement, but the records printed by the computer would show that the mix was properly constituted. In this statement, the batch plant operator also swore that this practice was known to some of the highest officials in 3Bs.

Despite the problems with the batching of the concrete used in the runways, DIA officials insisted that the runways built by 3Bs met the specifications. This assertion was based on the test results, which showed that although some parts of the runway were below standard, all of the runways met FAA specifications. 3Bs was paid for those areas that were below standard at a lower rate than for the stronger parts of the runway. Further investigations about misdeeds in the construction of DIA were performed by several groups, including a Denver grand jury, a federal grand jury, the FBI, and committees of Congress.

On October 19, 1995, the *Denver Post* reported the results of a lawsuit brought by 3Bs against the city of Denver. 3Bs contended that the city still owed them $2.3 million (in addition to the $193 million that 3Bs had already been paid) for the work they did. The city claimed that this money was not owed. The reduction was a penalty due to low test results on some of the concrete. 3Bs claimed that those tests were flawed and that the concrete was fine. A hearing officer sided with the city, deciding that Denver didn't owe 3Bs any more money. 3Bs said that they would take their suit to the next higher level.

As of the summer of 1998, DIA has been in operation for over three years and no problems have surfaced regarding the strength of the runways. Unfortunately, problems with runway durability might not surface until after several more years of use. In the meantime, there is still plenty of litigation and investigation of this and other unethical acts surrounding the construction of this airport.

Competitive Bidding and the Paradyne Case

Although competitive bidding is a very well-established practice in purchasing, it can lead to many ethical problems associated with deception on the part of the vendor or with unfairness on the part of the buyer in choosing a vendor. The idea behind competitive bidding is that the buyer can get a product at the best price by setting up competition between the various suppliers. Especially with large contracts, the temptation to cheat on the bidding is great. Newspapers frequently report stories of deliberate underbidding to win contracts, followed by cost overruns that are unavoidable; theft of information on others' bids in order to be able to underbid them; etc. Problems also exist with buyers who make purchase decisions based on elements other than the advertised bid criteria, who leak information to a preferred bidder, or who give advance notice or detailed knowledge of evaluation procedures to preferred bidders. The Paradyne computer case is useful in illustrating some of the hazards associated with competitive bidding.

The Paradyne case began on June 10, 1980, when the Social Security Administration (SSA) published a request for proposals (RFP) for computer systems to replace the older equipment in its field offices. Its requirement was for computers that provide access to a central database. This database was used by field offices in the processing of benefit claims and in issuing new social security numbers. SSA intended to purchase an off-the-shelf system already in the vendor's product line, rather than a customized system. This requirement was intended to minimize the field testing and bugs associated with customized systems. In March of 1981, SSA let a contract for $115 million for 1,800 computer systems to Paradyne.

Problems occurred immediately upon award of the contract, when the Paradyne computers failed the acceptance testing. The requirements were finally relaxed so that the computers would pass. After delivery, many SSA field offices reported frequent malfunctions, sometimes multiple times per day, requiring manual rebooting of the system. One of the contract requirements was that the computers function 98% of the time. This requirement wasn't met until after 21 months of operation. After nearly two years of headaches and much wasted time and money, the system finally worked as planned. [Davis, 1988]

Subsequent investigation by SSA indicated that the product supplied by Paradyne was not an off-the-shelf system, but rather was a system that incorporated new technology that had yet to be built and was still under development. Paradyne had proposed selling SSA their P8400 model with the PIOS operating system. The bid was written as if this system currently existed. However, at the time that the bid was prepared, the 8400 system did not exist and had not been developed, prototyped, or manufactured. [Head, 1986]

There were other problems associated with Paradyne's performance during the bidding. The RFP stated that there was to be a preaward demonstration of the product, not a demonstration of a prototype. Paradyne demonstrated to SSA a different computer, a modified PDP 11/23 computer manufactured by Digital Equipment Corporation (DEC) placed in a cabinet that was labeled P8400. Apparently, many of the DEC labels on the equipment that was demonstrated to SSA had Paradyne labels pasted over them. Paradyne disingenuously claimed that since the DEC equipment was based on a 16-bit processor, as was the P8400 they proposed, it was irrelevant if the machine demonstrated were the DEC or the actual P8400. Of course, computer users recognize that this statement is nonsense. Even modern "PC-compatible" computers with the same microprocessor chip and operating system can have widely different operating characteristics in terms of speed, software that can be run, etc.

There were also questions about the operating system. Apparently, at the time of Paradyne's bid, the PIOS system was under development as well and hadn't been tested on a prototype of the proposed system. Even a functioning hardware system will not operate correctly without the correct operating system. No software has ever worked correctly the first time, but rather requires extensive "debugging" to make it operate properly with a new system. Significantly, the DEC system with the P8400 label that was actually tested by SSA was not running with the proposed PIOS system.

Some of the blame for this fiasco can also be laid at the feet of the SSA. There were six bidders for this contract. Each of the bidders was to have an on-site visit from SSA inspectors to determine whether it was capable of doing the work that it included in its bid. Paradyne's capabilities were not assessed using an on-site visit. Moreover, Paradyne was judged based on its ability to manufacture modems, which was then its main business. Apparently, its ability to produce complete computer systems wasn't assessed. As part of its attempt to gain this contract, Paradyne hired a former SSA official who, while still working for SSA, had participated in preparing the RFP and had helped with setting up the team that would evaluate the bids. Paradyne had notified SSA of the hiring of this person, and SSA decided that there were no ethical problems with this. However, when the Paradyne machine failed the initial acceptance test, this Paradyne official was directly involved in negotiating the relaxed standards with his former boss at SSA.

This situation was resolved when the Paradyne computers were finally brought to the point of functioning as required. However, as a result of these problems, there were many investigations by government agencies, including the Securities and Exchange Commission, the General Accounting Office, the House of Representative's Government Operations Committee, the Health and Human Services Department (of which SSA is part), and the Justice Department.

2.4 DEALING WITH ETHICAL ISSUES

Engineers frequently have to make tough ethical decisions that involve a wide range of issues, from balancing cost and safety to addressing the environmental impact of their designs. In certain cases, poor engineering decisions can lead to loss of life. Examples include the Challenger explosion, the Chernobyl nuclear accident, the Union Carbide plant gas leak in Bhopal, India, and the Ford Pintos that exploded upon rear impact. Clearly, *ethics* are central to the engineering design process. For this reason, most engineering groups have developed a *code of ethics* to guide their members.

PROFESSIONAL SUCCESS: ETHICS

Two successful engineers share their insights in dealing with *ethical issues*:

"I think that society has a view of technology that is erroneous. I think engineers owe it to society to tell it over and over again that technology will not solve all of its problems. Technology is a tool. But societies are built of something more than technology.

"Technology is a two-edged sword. For example, it is technology that has made us efficient at waging war. Even the technology that allows us to construct a building is a two-edged sword. That technology can be used to store munitions as easily as food.

"The point is that we must be careful how we use our technology. When you give someone a power saw, you hand it to the person and you say, 'You're going to build your house with this power saw. But if you're not careful, you're going to cut off your fingers.' "

Joe Engel
Structural Engineer
Engel & Company Engineers

"In general, for a small consulting firm, the biggest ethical dilemma is cost versus performance. We make money by making proposals and getting those bids accepted. More and more today, It's price that counts more than experience or professionalism. You're constantly put in situations where clients expect good, professional work, but want it for virtually no cost. And that, to me, is the biggest ethical issue.

"You just have to be very honest with your clients. In my work it is particularly difficult. In R&D you don't know how long it is going to take you to find an answer, if there is one. There's an awful lot of guesswork, but experience goes into trying to find an appropriate price at the beginning of the job that will get you to the end successfully."

Ian Buist
Vice President
S. L. Ross Environmental Research Ltd.

2.4.1 Ethical Issues

One of the most common ethical issues an engineer faces is that of providing a quality product at reasonable cost. Sometimes clients want more than they are willing to pay for. The engineer must decide whether to cut corners in a design to save money or time, or simply to refuse to do the job. On the opposite side of the coin is the issue of wasting the client's money by overspecifying a design to ensure it meets certain specifications. Spend too little to satisfy the customer, and strength or safety may be compromised.

Spend too much, wasting the customer's money, and you may not get any more jobs as other firms outbid you on future work.

The ethical engineer designs not only for safety and low production cost, but also for lower future costs. For example, some of the costs of a machine design not seen up front include the machine's life expectancy, speed of operation, power efficiency, and required number of operators. These are costs that a client may not completely consider. The ethical engineer is qualified to find the correct balance of present and future costs and is self-confident enough to know that the resulting product will be safe. Good communication skills come into play as you convince clients or management that they can trust your expertise. However, at some time in your career, you may experience a situation in which a client or manager cannot be convinced. To maintain an ethical posture in such a case, you may have to refuse to bid on a project or refuse to approve a design.

Other ethical issues are those of confidentiality and conflict of interest. As an engineer you may be privy to your employer's trade secrets, patent applications, and copyrights. This information may be on a computer system that allows you to make copies easily. Such information obviously should stay within company walls. If you leave a company, you should return or erase all data, whether in hard copy or on computer disks. Engineers who change employers must also ensure that their knowledge creates no conflicts of interest. For example, they should not work on a product that will compete with a former employer's product if they have signed an agreement that specifies that they not do so for a certain period of time.

Whistle-blowing is a controversial issue that is sometimes faced by engineers, especially when contrasted with their obligation to maintain the confidentiality of colleagues and employers. If you become aware of criminal activity, such as industrial espionage or bribery, you have an obligation to report it. If faced with a situation in which you believe your organization or someone within it is creating a design that might jeopardize public safety, you will have to decide whether or not to act. Of course, you should first attempt to resolve any problem within the organization. If that attempt is unsuccessful, whistle-blowing may be your only alternative. However whistle-blowing does have consequences, ranging from the loss of your colleagues' respect or friendship to the loss of your job.

A basic issue in ethics is simply telling the truth. When you give an oral presentation or write a report, be sure that what you say is the complete truth. Omit no relevant information. Be aware that your managers will always want to hear only good news, but that you cannot always give them good news. A good case study of political pressure affecting engineering performance is the Challenger disaster. The rocket engine manufacturer, Morton Thiokol International, was in the process of contract negotiations with NASA. The Shuttle project was behind schedule, and congressional support was waning. The result was a situation in which the engineers were feeling peer and management pressure to "get the product to market" while overlooking obvious safety issues.

If you become a manager, you will be responsible for not only your own performance, but also the performance of others. Encourage those working for you to be honest in their reporting. When things go wrong, it is not acceptable to lay the blame on a junior engineer. It will be your job to see that things are done correctly. Read your engineers' reports critically, and be ready to ask questions.

Ultimately, the ethical decisions you will make as an engineer will depend on the situations in which you find yourself. Many engineering schools are now including discussions of ethical responsibility in their curricula. These discussions typically are included both in freshman introductory engineering courses and in senior project courses. If they are not, you should do your own research on the subject. A good approach is to read case studies and decide what you would do if you were involved in the cases studied.

PROFESSIONAL SUCCESS: ETHICS

Two successful engineers share their insights regarding ethics and safety:

"We are working on a project with a company called Medtronics that builds pacemakers. These are software intensive systems. So as a software engineer on these projects, not only do you want to build good software, but you also have to realize that your failure might cause someone's death. Because the world is becoming so software intensive, ethics is more in the forefront."

Grady Brooch
Chief Scientist
Rational Software Corporation

"Achieving a balance between safety and cost is one of the most difficult and interesting ethical issues a civil engineer must deal with day in and day out. It is hard to explain to the public that there is no such thing as a perfect engineering design. Even the best engineering work involves the possibility of failure. I think the biggest obligation of civil engineers is to provide engineering designs of the greatest safety at a reasonable cost."

Guoming Lin
Geotechnical Engineer
S&ME, Inc.

2.4.2 The "Green" Engineer

The industrial revolution of the 19th century marked the beginning of today's environmental *pollution* problems. Over the past 100 years, industry and the internal combustion engine have generated uncountable millions of tons of pollutants. Until recently the philosophy in dealing with the problem could be stated as, "The solution to pollution is dilution." The ill effects of contaminating products were minimized by merely mixing the products with air, water, or land. Smoke stacks were made taller to emit exhausts into faster moving air. Chemicals were dumped into the oceans because it was thought that their capacity to absorb waste was limitless. Landfills were made increasingly large as users ignored the fact that much of what was placed in the landfills was not biodegradable.

It has now become clear that the earth's resources are not limitless and that the environment cannot forever sustain high levels of pollution and other forms of degradation. Today engineers must factor environmental costs into the equation when designing new products and technologies.

In the past, pollution control was considered after the fact, at the end of a process. Companies added scrubbers to smokestacks or catalytic converters to cars. Today, however, environmental considerations must be factored into the entire design process. Those concerned realize that pollution control must begin at the beginning. Design engineers must design products that can be manufactured cleanly, maintained easily, and ultimately recycled or salvaged. Materials engineers must design materials that do not include, or do not require in their production, chemicals that harm the environment. Production engineers must design processes to use more environmentally friendly chemicals. Sales engineers must convince clients that they will benefit from purchasing environmentally sound products.

Progress is being made. Many organizations are rethinking their engineering and production processes. For example, many newspapers have substituted soy-based ink for oil-based ink in color printing. Some industries have substituted water-based cleaning agents for chlorinated solvents. The Air Force now removes old paint from airplane fuselages using a spray of plastic pellets rather than chemical solvents. Many organizations have adopted improved chemical storage, handling, and recycling practices.

While there are many government regulations and organizational guidelines that force engineers to deal with ecological issues, engineers should be leaders, not followers, in this crucial area. The engineering profession still has a good public image. To maintain that image and remain self-regulating, engineering professionals must uphold high ethical standards, hold public safety as the highest priority, and have respect for the environment and the conservation of its resources.

PROFESSIONAL SUCCESS: THE GREEN ENGINEER

Engineers have an obligation to protect both the public and the environment. Two successful engineers share their insights into the impacts of engineering projects on our environment:

"All engineers have a tremendous obligation to protect the public. As professionals, the public depends on us to make the right decisions and also to protect the environment. If we can do things in an environmentally sensible way, I think That's important. And we should not waste resources."

Ian Buist
Vice President
S. L. Ross Environmental Research Ltd.

"As engineers involved in designing, developing, and manufacturing products, we should be very concerned with the consequences and impacts such products will have on our environment. There is only one earth with a finite amount of resources, many of them critical to human existence. We all need to take responsibility to ensure that in the long run we are making this world a better place in which to live."

Jose E. Hernandez
Electrical Engineer
Lawrence Livermore National Laboratory

2.4.3 Code of Ethics of Engineers

The Accreditation Board for Engineering and Technology (ABET), the accrediting body for engineering schools in the United States, developed the code of ethics for engineers, as seen in Figure 2.1.

The ABET code of ethics is just one example; every major engineering discipline has developed its own unique code. You should obtain a copy of your discipline's code of ethics from the student chapter or national office of your engineering society. You might find it interesting to compare this code of ethics with ABET's or those of other disciplines.

The Fundamental Principles

Engineers uphold and advance the integrity, honor, and dignity of the engineering profession by:

1. using their knowledge and skill for the enhancement of human welfare;
2. being honest and impartial, and serving with fidelity the public, their employers, and clients;
3. striving to increase the competence and prestige of the engineering profession; and
4. supporting the professional and technical societies of their disciplines.

The Fundamental Canons

1. Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties.
2. Engineers shall perform services only in areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
6. Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the profession.
7. Engineers shall continue their professional development throughout their careers and shall provide opportunities for the professional development of those engineers under their supervision.

Figure 2.1 Code of ethics of engineers.

2.5 CASE STUDIES

Before starting to learn the theoretical ideas regarding engineering ethics and before looking at some interesting real-life cases that will illustrate these ideas, let's begin by looking at a very well-known engineering ethics case: the space shuttle *Challenger* accident. This case is presented in depth following this chapter, but at this point we will look at a brief synopsis of the case to further illustrate the types of ethical issues and questions that arise in the course of engineering practice.

Many readers are already familiar with some aspects of this case. The space shuttle *Challenger* was launched in extremely cold weather. During the launch, an O-ring on one of the solid-propellant boosters, made more brittle by the cold, failed. This failure led to the explosion during liftoff. Engineers who had designed this booster had concerns about launching under these cold conditions and recommended that the launch be delayed, but they were overruled by their management (some of whom were trained as engineers), who didn't feel that there was enough data to support a delay in the launch. The shuttle was launched, resulting in the well-documented accident.

On the surface, there appear to be no engineering ethical issues here to discuss. Rather, it seems to simply be an accident. The engineers properly recommended that there be no launch, but they were overruled by management. In the strictest sense this can be considered an accident—no one wanted the *Challenger* to explode—but there are still many interesting questions that should be asked. When there are safety concerns, what is the engineer's responsibility before the launch decision is made? After the launch decision is made, but before the actual launch, what duty does the engineer have? If the decision doesn't go the engineer's way, should she complain to upper management? Or should she bring the problem to the attention of the press? After the accident has occurred, what are the duties and responsibilities of the engineers? If the launch were successful, but the *post mortem* showed that the O-ring had failed and an accident had very nearly occurred, what would be the engineer's responsibility? Even if an engineer moves into management, should he separate engineering from management decisions?

These types of questions will be the subject of this book. In subsequent chapters, ideas about the nature of the engineering profession, ethical theories, and the application of these theories to situations that are likely to occur in professional practice will be presented. Many other real-life cases taken from newspaper accounts and books will be discussed to examine what engineers should do when confronted with ethically troubling situations. Most of these cases will be *post mortem* examinations of disasters, but two will involve analysis of situations in which disaster was averted when many of the individuals involved made ethically sound choices and cooperated to solve a problem.

A word of warning is necessary before these cases are studied. The cliché "Hindsight is 20/20" will seem very true as we examine many of these cases. When studying a case several years after the fact and knowing the ultimate outcome, it is easy to see what the right decision should have been. Obviously, had NASA owned a crystal ball and been able to predict the future, the *Challenger* would never have been launched. Had Ford known the number of people who would be killed as a result of gas-tank failures in the Pinto and the subsequent financial losses in lawsuits and criminal cases, it would have found a better solution to the problem of gas-tank placement. However, we rarely have such clear predictive abilities and must base decisions on our best guess of what the outcome will be. It will be important in studying the cases presented here to try to look at them from the point of view of the individuals who were involved at the time, using their best judgment about how to proceed, and not to judge the cases solely based on the outcome.

APPLICATION: THE SPACE SHUTTLE CHALLENGER ACCIDENT

The explosion of the space shuttle *Challenger* is perhaps the most widely-written about case in engineering ethics because of the extensive media coverage at the time of the accident and also because of the many available government reports and transcripts of congressional hearings regarding the explosion. The case illustrates many important ethical issues that engineers face: What is the proper role of the engineer when safety issues are a concern? Who should have the ultimate decision-making authority to order a launch? Should the ordering of a launch be an engineering or a managerial decision? This case has already been presented briefly, and we will now take a more in-depth look.

Background

The space shuttle was designed to be a reusable launch vehicle. The vehicle consists of an orbiter, which looks much like a medium-sized airliner (minus the engines!), two solid-propellant boosters, and a single liquid-propellant booster. At takeoff, all of the boosters are ignited and lift the orbiter out

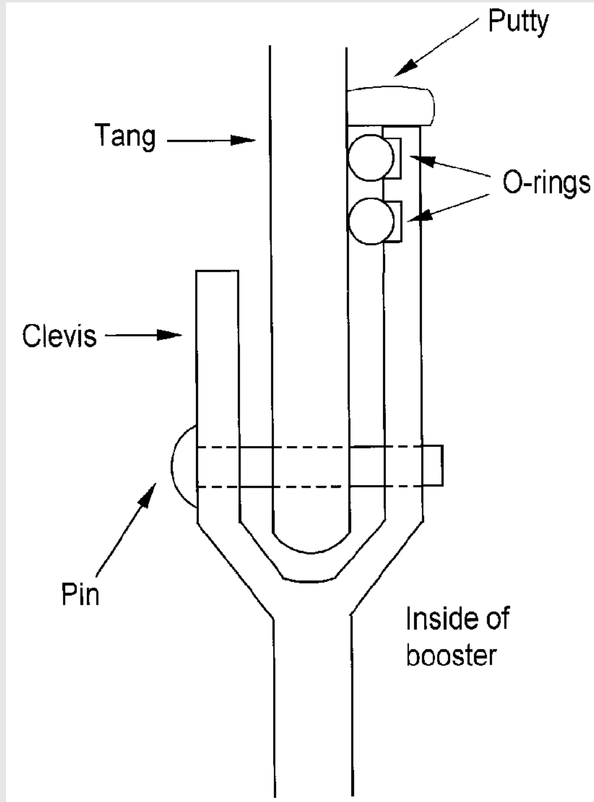

Figure 2.2 A schematic drawing of a tang and clevis joint like the one on the *Challenger* solid rocket boosters..

of the earth's atmosphere. The solid rocket boosters are only used early in the flight and are jettisoned soon after takeoff, parachute back to earth, and are recovered from the ocean. They are subsequently repacked with fuel and are reused. The liquid-propellant booster is used to finish lifting the shuttle into orbit, at which point the booster is jettisoned and burns up during reentry. The liquid booster is the only part of the shuttle vehicle that is not reusable. After completion of the mission, the orbiter uses its limited thrust capabilities to reenter the atmosphere and glides to a landing.

The accident on 28, 1986 was blamed on a failure of one of the solid rocket boosters. Solid rocket boosters have the advantage that they deliver far more thrust per pound of fuel than do their liquid-fueled counterparts, but have the disadvantage that once the fuel is lit, there is no way to turn the booster off or even to control the amount of thrust produced. In contrast, a liquid-fuel rocket can be controlled by throttling the supply of fuel to the combustion chamber or can be shut off by stopping the flow of fuel entirely.

In 1974, the National Aeronautics and Space Administration (NASA) awarded the contract to design and build the solid rocket boosters for the shuttle to Morton Thiokol. The design that was submitted by Thiokol was a scaled-up version of the Titan missile, which had been used successfully for many years to launch satellites. This design was accepted by NASA in 1976. The solid rocket consists of several cylindrical pieces that are filled with solid propellant and stacked one on top of the other to form the completed booster. The assembly of the propellant-filled cylinders was performed at Thiokol's plant in Utah. The cylinders were then shipped to the Kennedy Space Center in Florida for assembly into a completed booster.

A key aspect of the booster design are the joints where the individual cylinders come together, known as the field joints, illustrated schematically in Figure 2.2. These are tang and clevis joints, fastened with 177 clevis pins. The joints are sealed by two O-rings, a primary and a secondary. The O-rings are designed to prevent hot gases from the combustion of the solid propellant from escaping. The O-rings are made from a type of synthetic rubber and so are not particularly heat resistant. To prevent the hot gases from damaging the O-rings, a heat-resistant putty is placed in the joint. The Titan booster had only one O-ring in the field joint. The second O-ring was added to the booster for the shuttle to provide an extra margin of safety since, unlike the Titan, this booster would be used for a manned space craft.

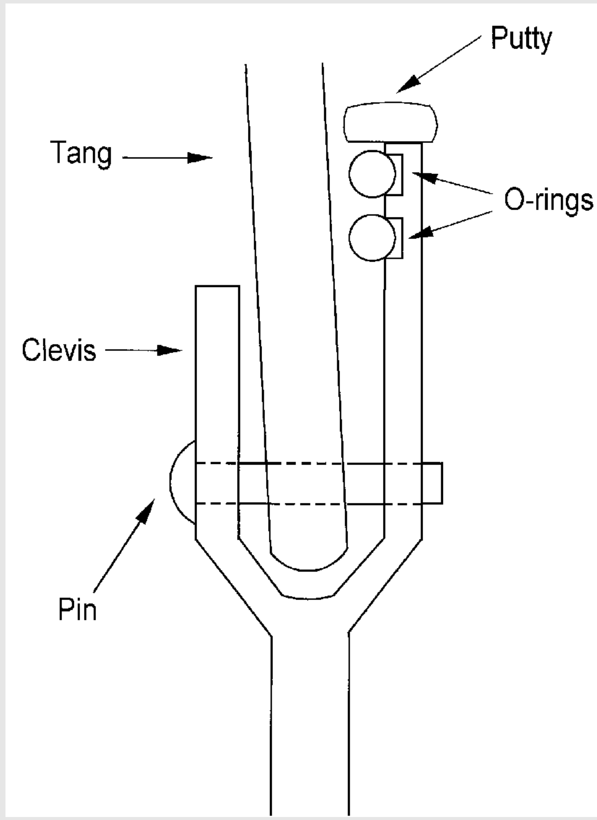

Figure 2.3 The same joint as in Figure 2.2, but with the effects of joint rotation exaggerated. Note that the O–rings no longer seal the joint..

Early Problems with the Solid Rocket Boosters

Problems with the field-joint design had been recognized long before the launch of the *Challenger*. When the rocket is ignited, the internal pressure causes the booster wall to expand outward, putting pressure on the field joint. This pressure causes the joint to open slightly, a process called "joint rotation," illustrated in Figure 2.3.

The joint was designed so that the internal pressure pushes on the putty, displacing the primary O-ring into this gap, helping to seal it. During testing of the boosters in 1977, Thiokol became aware that this joint-rotation problem was more severe than on the Titan and discussed it with NASA. Design changes were made, including an increase in the thickness of the O-ring, to try to control this problem.

Further testing revealed problems with the secondary seal, and more changes were initiated to correct that problem. In November of 1981, after the second shuttle flight, a postlaunch examination of the booster field joints indicated that the O-rings were being eroded by hot gases during the launch. Although there was no failure of the joint, there was some concern about this situation, and Thiokol looked into the use of different types of putty and alternative methods for applying it to solve the problem. Despite these efforts, approximately half of the shuttle flights before the *Challenger* accident had experienced some degree of O-ring erosion. Of course, this type of testing and redesign is not unusual in engineering. Seldom do things work correctly the first time, and modifications to the original design are often required.

It should be pointed out that erosion of the O-rings is not necessarily a bad thing. Since the solid rocket boosters are only used for the first few minutes of the flight, it might be perfectly acceptable to design a joint in which O-rings erode in a controlled manner. As long as the O-rings don't completely burn through before the solid boosters run out of fuel and are jettisoned, this design should be fine. However, this was not the way the space shuttle was designed, and O-ring erosion was one of the problems that the Thiokol engineers were addressing.

The first documented joint failure came after the launch on January 24, 1985, which occurred during very cold weather. The postflight examination of the boosters revealed black soot and grease on the outside of the booster, which indicated that hot gases from the booster had blown by the O-ring seals. This observation gave rise to concern about the resiliency of the O-ring materials at reduced temperatures. Thiokol performed tests of the ability of the O-rings to compress to fill the joints and found that they were inadequate. In July of 1985, Thiokol engineers redesigned the field joints without O-rings. Instead, they used steel billets, which should have been better able to withstand the hot gases. Unfortunately, the new design was not ready in time for the *Challenger* flight in early 1986. [Elliot, 1991]

The Political Climate

To fully understand and analyze the decision making that took place leading to the fatal launch, it is important also to discuss the political environment under which NASA was operating at the time. NASA's budget was determined by Congress, which was becoming increasingly unhappy with delays in the shuttle project and shuttle performance, which wasn't meeting initial promises. NASA had billed the shuttle as a reliable, inexpensive launch vehicle for a variety of scientific and commercial purposes, including the launching of commercial and military satellites. It had been promised that the shuttle would be capable of frequent flights (several per year) and quick turnarounds and would be competitively priced with more traditional nonreusable launch vehicles. NASA was feeling some urgency in the program because the European Space Agency was developing what seemed to be a cheaper alternative to the shuttle, which could potentially put the shuttle out of business.

These pressures led NASA to schedule a record number of missions for 1986 to prove to Congress that the program was on track. Launching a mission was especially important in January 1986, since the previous mission had been delayed numerous times by both weather and mechanical failures. NASA also felt pressure to get the *Challenger* launched on time so that the next shuttle launch, which was to carry a probe to examine Halley's comet, would be launched before a Russian probe designed to do the same thing. There was additional political pressure to launch the *Challenger* before the upcoming state-of-the-union address, in which President Reagan hoped to mention the shuttle and a special astronaut—the first teacher in space, Christa McAuliffe—in the context of his comments on education.

The Days Before the Launch

Even before the accident, the *Challenger* launch didn't go off without a hitch, as NASA had hoped. The first launch date had to be abandoned due to a cold front expected to move through the area. The front stalled, and the launch could have taken place on schedule. But the launch had already been postponed in deference to Vice President George Bush, who was to attend. NASA didn't want to antagonize Bush, a strong NASA supporter, by postponing the launch due to inclement weather after he had arrived. Launch of the shuttle was further delayed by a defective microswitch in the hatch-locking mechanism. When this problem was resolved, the front had changed course and was now moving through the area. The front was expected to bring extremely cold weather to the launch site, with temperatures predicted to be in the low 20's (°F) by the new launch time.

TABLE 2-1 Space Shuttle *Challenger* Accident: Who's Who

ORGANIZATIONS	
NASA	The National Aeronautics and Space Administration, responsible for space exploration. The space shuttle is one of NASA's programs.
Marshall Space Flight Center	A NASA facility that was in charge of the solid rocket booster development for the shuttle.
Morton Thiokol	A private company that won the contract from NASA for building the solid rocket boosters for the shuttle.
People	
NASA	
Larry Mulloy	Solid Rocket Booster Project manager at Marshall
Morton Thiokol	
Roger Boisjoly	Engineers who worked on the Solid Rocket Booster Development Program.
Arnie Johnson	
Joe Kilminster	Engineering manager on the Solid Rocket Booster Development Program.
Alan McDonald	Director of the Solid Rocket Booster Project.
Bob Lund	Vice president for engineering.
Jerald Mason	General manager.

Given the expected cold temperatures, NASA checked with all of the shuttle contractors to determine if they foresaw any problems with launching the shuttle in cold temperatures. Alan McDonald, the director of Thiokol's Solid Rocket Motor Project, was concerned about the cold weather problems that had been experienced with the solid rocket boosters. The evening before the rescheduled launch, a teleconference was arranged between engineers and management from the Kennedy Space Center, NASA's Marshall Space Flight Center in Huntsville, Alabama, and Thiokol in Utah to discuss the possible effects of cold temperatures on the performance of the solid rocket boosters. During this teleconference, Roger Boisjoly and Arnie Thompson, two Thiokol engineers who had worked on the solid-propellant booster design, gave an hour-long presentation on how the cold weather would increase the problems of joint rotation and sealing of the joint by the O-rings.

Their point was that the lowest temperature at which the shuttle had previously been launched was 53°F, on January 24, 1985, when there was blow-by of the O-rings. The O-ring temperature at *Challenger*'s expected launch time the following morning was predicted to be 29°F, far below the temperature at which NASA had previous experience. After the engineer's presentation, Bob Lund, the vice president for engineering at Morton Thiokol, presented his recommendations. He reasoned that since there had previously been severe O-ring erosion at 53°F and the launch would take place at significantly below this temperature where no data and no experience were available, NASA should delay the launch until the O-ring temperature could be at least 53°F. Interestingly, in the original design, it was specified that the booster should operate properly down to an outside temperature of 31°F.

Larry Mulloy, the Solid Rocket Booster Project manager at Marshall and a NASA employee, correctly pointed out that the data were inconclusive and disagreed with the Thiokol engineers. After some discussion, Mulloy asked Joe Kilminster, an engineering manager working on the project, for his opinion. Kilminster backed up the recommendation of his fellow engineers. Others from Marshall expressed their disagreement with the Thiokol engineer's recommendation, which prompted Kilminster to ask to take the discussion off line for a few minutes. Boisjoly and other engineers reiterated to their management that the original decision not to launch was the correct one.

A key fact that ultimately swayed the decision was that in the available data, there seemed to be no correlation between temperature and the degree to which blow-by gasses had eroded the O-rings in previous launches. Thus, it could be concluded that there was really no trend in the data indicating that launch at the expected temperature would necessarily be unsafe. After much discussion, Jerald Mason, a senior manager with Thiokol, turned to Lund and said, "Take off your engineering hat and put on your management hat," a phrase that has become famous in engineering ethics discussions. Lund reversed his previous decision and recommended that the launch proceed. The new recommendation included an indication that there was a safety concern due to the cold weather, but that the data was inconclusive and the launch was recommended. McDonald, who was in Florida, was surprised by this recommendation and attempted to convince NASA to delay the launch, but to no avail.

The Launch

Contrary to the weather predictions, the overnight temperature was 8°F, colder than the shuttle had ever experienced before. In fact, there was a significant accumulation of ice on the launchpad from safety showers and fire hoses that had been left on to prevent the pipes from freezing. It has been estimated that the aft field joint of the right-hand booster was at 28°F.

NASA routinely documents as many aspects of launches as possible. One part of this monitoring is the extensive use of cameras focused on critical areas of the launch vehicle. One of these cameras, looking at the right booster, recorded puffs of smoke coming from the aft field joint immediately after the boosters were ignited. This smoke is thought to have been caused by the steel cylinder of this segment of the booster expanding outward and causing the field joint to rotate. But, due to the extremely cold temperature, the O-ring didn't seat properly. The heat-resistant putty was also so cold that it didn't protect the O-rings, and hot gases burned past both O-rings. It was later determined that this blow-by occurred over 70° of arc around the O-rings.

Very quickly, the field joint was sealed again by byproducts of the solid rocket-propellant combustion, which formed a glassy oxide on the joint. This oxide formation might have averted the disaster had it not been for a very strong wind shear that the shuttle encountered almost one minute into the flight. The oxides that were temporarily sealing the field joint were shattered by the stresses caused by the wind shear. The joint was now opened again, and hot gases escaped from the solid booster. Since the booster was attached to the large liquid-fuel booster, the flames from the solid-fuel booster blow-by quickly burned through the external tank. The liquid propellant was ignited and the shuttle exploded.

The Aftermath

As a result of the explosion, the shuttle program was grounded as a thorough review of shuttle safety was conducted. Thiokol formed a failure-investigation team on January 31, 1986 which included Roger Boisjoly. There were also many investigations into the cause of the accident, both by the contractors involved (including Thiokol) and by various government bodies. As part of the governmental investigation, President Reagan appointed a "blue-ribbon" commission, known as the Rogers commission, after its chair. The commission consisted of distinguished scientists and engineers who were asked to look into the cause of the accident and to recommend changes in the shuttle program.

One of the commission members was Richard Feynman, a Nobel prize winner in physics, who ably demonstrated to the country what had gone wrong. In a demonstration that was repeatedly shown on national news programs, he demonstrated the problem with the O-rings by taking a sample of the O-ring material and bending it. The flexibility of the material at room temperature was evident. He then immersed it in ice water. When Feynman again bent the O-ring, it was very clear that the resiliency of the material was severely reduced, a very clear demonstration of what happened to the O-rings on the cold launch date in Florida.

As part of the commission hearings, Boisjoly and other Thiokol engineers were asked to testify. Boisjoly handed over to the commission copies of internal Thiokol memos and reports detailing the design process and the problems that had already been encountered. Naturally, Thiokol was trying to put the best possible spin on the situation, and Boisjoly's actions hurt this effort. According to Boisjoly, after this action he was isolated within the company, his responsibilities for the redesign of the joint were taken away, and he was subtly harassed by Thiokol management [Boisjoly, 1991, and Boisjoly, Curtis, and Mellicam, 1989].

Eventually, the atmosphere became intolerable for Boisjoly, and he took extended sick leave from his position at Thiokol. The joint was redesigned, and the shuttle has since flown numerous successful missions. However, the ambitious launch schedule originally intended by NASA has never been met.

Figure 2.4 Explosion of the space shuttle *Challenger* soon after lift-off in January 1986..

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KEY TERMS

code of ethics	Green Engineer	professions
ethical issues	pollution	Whistle-blowing
ethics	professional societies	

Problems

1. What do you think is the most serious ethical issue facing your engineering school? What are your reasons for choosing this issue?
2. If you knew a group of your fellow students had devised and were going to implement a way to cheat on an upcoming exam, would you report the students to the professor? Why or why not? Would it make a difference if the professor graded on a curve, so that the cheating would lower your grade?

Space Shuttle Challenger

3. The astronauts on the *Challenger* mission were aware of the dangerous nature of riding a complex machine such as the space shuttle, so they can be thought of as having given

informed consent to participating in a dangerous enterprise. What role did informed consent play in this case? Do you think that the astronauts had enough information to give informed consent to launch the shuttle that day?

4. Can an engineer who has become a manager truly ever take off her engineer's hat? Should she?
5. Some say that the shuttle was really designed by Congress rather than NASA. What does this statement mean? What are the ramifications if this is true?
6. Aboard the shuttle for this flight was the first teacher in space. Should civilians be allowed on what is basically an experimental launch vehicle? At the time, many felt that the placement of a teacher on the shuttle was for purely political purposes. President Reagan was widely seen as doing nothing while the American educational system decayed. Cynics felt that the teacher-in-space idea was cooked up as a method of diverting attention from this problem and was to be seen as Reagan's doing something for education while he really wasn't doing anything. What are the ethical implications if this scenario is true?
7. Should a launch have been allowed when there was no test data for the expected conditions? Keep in mind that it is probably impossible to test for all possible operating conditions. More generally, should a product be released for use even when it hasn't been tested over all expected operational conditions? When the data is inconclusive, which way should the decision go?
8. During the aftermath of the accident, Thiokol and NASA investigated possible causes of the explosion. Boisjoly accused Thiokol and NASA of intentionally downplaying the problems with the O-rings while looking for other causes of the accident. If true, what are the ethical implications of this type of investigation?
9. It might be assumed that the management decision to launch was prompted in part by concerns for the health of the company and the space program as a whole. Given the political climate at the time of the launch, if problems and delays continued, ultimately Thiokol might have lost NASA contracts, or NASA budgets might have been severely reduced. Clearly, this scenario could have lead to the loss of many jobs at Thiokol and NASA. How might these considerations ethically be factored into the decision?
10. Engineering codes of ethics require engineers to protect the safety and health of the public in the course of their duties. Do the astronauts count as "public" in this context?
11. What should NASA management have done differently? What should Thiokol management have done differently?
12. What else could Boisjoly and the other engineers at Thiokol have done to prevent the launch from occurring?
13. What changes would have to be made for engineering to be a profession more like medicine or law?
14. In which ways do law, medicine, and engineering fit the social-contract and the business models of a profession?
15. The first part of the definition of a profession presented previously said that *professions* involve the use of sophisticated skills. Do you think that these skills are primarily physical or intellectual skills? Give examples from professions such as law, medicine, and engineering, as well as from nonprofessions.
16. Apply one of the codes of ethics to the space shuttle *Challenger* case described at the end of Section 2.5. What guidance might one of the engineering society codes of ethics have given the Thiokol engineers when faced with a decision to launch? Which specific parts of the code are applicable to this situation? Does a manager who is trained as an engineer still have to adhere to an engineering *code of ethics*?

17. Write a code of ethics for students in your college or department. Start by deciding what type of code you want: short, long, detailed, etc. Then, list the important ethical issues you think students face. Finally, organize these ideas into a coherent structure.
18. Imagine that you are the president of a small high-technology firm. Your company has grown over the last few years to the point where you feel that it is important that your employees have some guidelines regarding ethics. Define the type of company you are running; then develop an appropriate code of ethics. As in Question 2, start by deciding what type of code is appropriate for your company. Then, list specific points that are important—for example, relationships with vendors, treatment of fellow employees, etc. Finally, write a code that incorporates these features.

Intel Pentium Chip

19. Was this case simply a customer-relations and PR problem, or are there ethical issues to be considered as well?
20. Use one of the codes of ethics to analyze this case. Especially, pay attention to issues of accurate representation of engineered products and to safety issues.
21. When a product is sold, is there an implication that it will work as advertised?
22. Should you reveal defects in a product to a consumer? Is the answer to this question different if the defect is a safety issue rather than simply a flaw? (It might be useful to note in this discussion that although there is no apparent safety concern for someone using a computer with this flaw, PCs are often used to control a variety of instruments, such as medical equipment. For such equipment, a flaw might have a very real safety implication.) Is the answer to this question different if the customer is a bank that uses the computer to calculate interest paid, loan payments, etc. for customers?
23. Should you replace defective products even if customers won't recognize the defect?
24. How thorough should testing be? Is it ever possible to say that no defect exists in a product or structure?
25. Do flaws that Intel found previously in the 386 and 486 chips have any bearing on these questions? In other words, if Intel got away with selling flawed chips before without informing consumers, does that fact have any bearing on this case?
26. G. Richard Thoman, an IBM senior vice president was quoted as saying, "Nobody should have to worry about the integrity of data calculated on an IBM machine." How does this statement by a major Intel customer change the answers to the previous questions?
27. Just prior to when this problem surfaced, Intel had begun a major advertising campaign to make Intel a household name. They had gotten computer manufacturers to place "Intel Inside" labels on their computers and had spent money on television advertising seeking to increase the public demand for computers with Intel processors, with the unstated message that Intel chips were of significantly higher quality than other manufacturers' chips. How might this campaign have affected what happened in this case?
28. What responsibilities did the engineers who were aware of the flaw have before the chip was sold? After the chips began to be sold? After the flaw became apparent?

DIA Runway Concrete

29. Using one of the codes of ethics, analyze the actions of the batch plant operators and Empire Laboratories.
30. Is altering data a proper use of "engineering judgment"? What alternative might have existed to altering the test data on the concrete?
31. Who is responsible for ensuring that the materials used in a project meet the specifications, the supplier or the purchaser?

Paradyne Computers

32. Choose one of the codes of ethics and use it to analyze this case. Were the engineers and managers of Paradyne operating ethically?

33. In preparing their bid, Paradyne wrote in the present tense, as if the computer they proposed currently existed, rather than in the future tense, which would have indicated that the product was still under development. Paradyne claimed that the use of the present tense in its bid (which led SSA to believe that the P8400 actually existed) was acceptable, since it is common business practice to advertise products under development this way. Was this a new product announcement with a specified availability date? Is there a distinction between a response to a bid and company advertising? Is it acceptable to respond to a bid with a planned system if there is no indication when that system is expected to be available?

34. Paradyne also claimed that it was acting as a system integrator (which was allowed by the RFP), using components from other manufacturers to form the Paradyne system. These other components were mostly off-the-shelf, but they had never been integrated grated into a system before. Does this meet the SSA requirement for an existing system?

35. Once the Paradyne machine failed the initial test, should the requirements have been relaxed to help the machine qualify? If the requirements were going to be modified, should the bidding process have been reopened to the other bidders and others who might now be able to bid? Should bidding be reopened even if it causes a delay in delivery, increased work for the SSA, etc.?

36. Was it acceptable for Paradyne to submit another manufacturer's system for testing with a Paradyne label on it?

37. Was it acceptable to represent a proposed system as existing, if indeed that is what Paradyne did?

38. Is it ethical for a former SSA employee to take a job negotiating contracts with the SSA for a private company? Did this relationship give Paradyne an unfair advantage over its competition?