Notes on Engineering Ethics

Outline

These notes are taken from Engineering Ethics (4th Edition) by Charles Fleddermann

Why study engineering ethics?

Engineers research, design and produce products people use. They have duties to the society as well as to their employers and themselves. Careful analysis of product safety and the risk of accidents is one of their responsiblities. News of product failures and associated accidents frequently remind us that these responsibilities have not been exercised:

- Chernobyl nuclear power plant accident
- Challenger space shuttle accident
- Soma mining accident
- Pendik ship-building accidents
- Ankara-İstanbul high speed train accidents
- Weapon designs (atomic bomb, sharapnel, land mine, etc.)
- ...

These cases have led to an awareness of the importance of ethics within the engineering profession as engineers realize how their technical work has far-reaching impacts on society.

The work of engineers can affect public health and safety and can influence business practices and even politics

The goal of Engineering Ethics is to sensitize you to important ethical issues before you have to confront them.
You will study important cases from the past so that you will know what situations other engineers have faced and will know what to do when similar situations arise in your professional career.
Finally, you will learn techniques for analyzing and resolving ethical problems when they arise.

Our ultimate aim is to develop *moral autonomy*, the ability to think critically and independently about moral issues and to apply this moral thinking to situations that arise in the course of professional engineering practice.

Most of the time, the ethical problems encountered in engineering practice are very complex and involve conflicting ethical principles. For example you may have to use cheaper and weaker steels in the design of a car (duty to your employer). But this decision may compromise passenger safety (duty to society)

Engineers need to be to trained to analyze such complex problems and learn to resolve these problems in the most ethical manner

The practice of engineering is governed by many laws on the international, national, and local levels. Many of these laws are based on ethical principles, although many are purely of a practical, rather than a philosophical, nature.

There is a distinction between what is legal and what is ethical. Many things that are legal could be considered unethical. For example, designing a process that releases a known toxic, but unregulated, substance into the environment is probably unethical, although it is legal.

Conversely, just because something is illegal doesn't mean that it is unethical. For example, there might be substances that were once thought to be harmful, but have now been shown to be safe, that you wish to incorporate into a product. If the law has not caught up with the latest scientific findings, it might be illegal to release these substances into the environment, even though there is no ethical problem in doing so.

As an engineer, you are always minimally safe if you follow the requirements of the applicable laws. But in engineering ethics, we seek to go beyond the dictates of the law. Our interest is in areas where ethical principles conflict *and* there is no legal guidance for how to resolve the conflict.

Engineer’s job

Engineers often encounter situations in which they don’t have all of the information that is needed. So they need to manage the unknown.

By its nature, engineering design is about creating new devices and products. When something is new, many questions need to be answered:

- How well does it work?
- How will it affect people?
- What changes will this lead to in society?
- How well will this work under all of the conditions that it will be exposed to?
- Is it safe?
- If there are some safety concerns, how bad are they?
- What are the effects of doing nothing?

The answers to these questions are often only partly known.
As an engineer you can never be absolutely certain that your design will never harm anyone or cause detrimental changes to society. But you must test your design as thoroughly as time and resources permit to ensure that it operates safely and as planned. Also, you must use your creativity to attempt to foresee the possible consequences of your work.

Rights and responsibilities of engineers

There are many rights and responsibilities that engineers must exercise in the course of their professional careers. The codes of ethics of the professional engineering societies determine, sometimes in great detail, the responsibilities entailed in being an engineer. However, the codes don't discuss any of the professional rights that engineers should have. Lets look at the engineer's responsibilities and rights with regard to issues of conscience and conflicts with the rights of employers or clients.

Confidentiality - A hallmark of the professions is the requirement that members of the profession keep certain information of their client secret or confidential. It is mentioned in most engineering codes of ethics. This is a well-established principle in professions such as medicine, where the patient's medical information must be kept confidential, and in law, where attorney–client privilege is a well-established doctrine. This requirement applies equally to engineers, who have an obligation to keep proprietary information of their employer or client confidential.
Most information about how a business is run, its products and its suppliers, directly affects the company's ability to compete in the marketplace. Such information can be used by a competitor to gain advantage or to catch up. Thus, it is in the company's (and the employee's) best interest to keep such information confidential

Some of the types of information that should be kept confidential are obvious:

- test results and data,
- information about upcoming unreleased products,
- designs or formulas for products

Other information that should be kept confidential is not as obvious:

- business information such as the number of employees working on a project,
- the identity of suppliers,
- marketing strategies,
- production costs,
- production yields

Most companies have strict policies regarding the disclosure of business information and require that all employees sign them. Frequently, internal company communications will be labeled as confidential. Engineers working for a client are frequently required to sign a nondisclosure agreement.

It seems straightforward for engineers to keep information confidential but there are gray areas that must be considered, e.g. how long confidentiality extends after an engineer leaves employment with a company

Legally, an engineer is required to keep information confidential even after she has moved to a new employer in the same technical area. In practice, doing so can be difficult. Even if no specific information is transferred to a new employer, an engineer takes with her a great deal of knowledge of what works, what materials to choose, and what components not to choose. This information might be considered confidential by her former employer

The courts have considered this issue and have attempted to strike a balance between the competing needs and rights of the individual and the company. Individuals have the right to seek career advancement wherever they choose, even from a competitor of their current employer. Companies have the right to keep information away from their competitors.

You have the responsibility to ensure that both of these competing interests are recognized and maintained by use of your autonomous morality.

Conflict of interest - A conflict of interest arises when an interest, if pursued, could keep a professional from meeting one of his obligations

For example, a civil engineer working for a state department of highways (KGM) might have a financial interest in a company that has a bid on a construction project. If that engineer has some responsibility for determining which company's bid to accept, then there is a clear conflict of interest. Pursuing his financial interest in the company might lead him not to objectively and faithfully discharge his professional duties to his employer, KGM. The engineering codes are very clear on the need to avoid conflicts of interest like this one.

There are three types of conflicts of interest that we will consider:

- Actual conflicts of interest, such as the one described in the previous paragraph, which compromise objective engineering judgment
- Potential conflicts of interest which threaten to easily become actual conflicts of interest (e.g. an engineer might find herself becoming friends with a supplier for her company)
- Situations in which there is the appearance of a conflict of interest (e.g. when an engineer is paid based on a percentage of the cost of the design, it may appear that the engineer is making the design more expensive simply to generate a larger fee) The distrust that comes from such situations compromises the engineer's ability to do this work and future work and calls into question the engineer's judgment

A good way to avoid conflicts of interest is to follow the guidance of the company policy.
In the absence of such a policy, asking a coworker or your manager will give you a second opinion and will make it clear that you aren't trying to hide something.
In the absence of either of these options, it is best to examine your motives and use ethical problem-solving techniques.
Finally, you can look to the statements in the professional ethics codes that uniformly forbid conflicts of interest. Some of the codes have very explicit statements that can help determine whether or not your situation is a conflict of interest.

Competitive Bidding – Getting unfair advantage over other engineers in bids for contracts has been histrorically considered unethical because:

- It was considered to be undignified and not at all in keeping with the image that the engineering profession desired to put forth to the public.
- There were concerns that if engineers engaged in competitive bidding, it would lead to price being the most significant (or perhaps only) basis for awarding engineering contracts.
- It could lead to engineers cutting corners on design work and could ultimately undermine engineers' duty to protect the safety and welfare of the public.

From the engineer's perspective, competitive bidding can

- lead to temptations such as submitting an unrealistically low bid in order to secure work and then making up for this through change orders once the work has been secured
- overstating of qualifications to secure work
- making negative comments about potential other bidders
- attempting to subvert the bidding process through back channel contacts

When participating in a competitive bid process, engineers must be fair, honest, and ethical

Professional rights– Not all rights come about due to the professional status of engineering. There are rights that individuals have regardless of the professional status:

- the right to privacy,
- the right to participate in activities of one's own choosing outside of work,
- the right to reasonably object to company policies without fear of retribution

The most fundamental right of an engineer is the right of professional conscience. This involves the right to exercise professional judgment in discharging one's duties and to exercise this judgment in an ethical manner. For example, to refuse to engage in unethical behavior. No employer should ask or pressure an employee into doing something that she considers unethical and unacceptable

Although this issue is very clear in cases for which an engineer is asked to falsify a test result or fudge on the safety of a product, it is less clear in cases for which the engineer refuses an assignment based on an ethical principle that is not shared by everyone. A common case is refusal to work on defense projects or environmentally hazardous work

Whistle-blowing – Both a right and a responsibilty

Engineers have the professional right to disclose wrongdoing within their organizations and expect to see appropriate action taken

Engineers also have a duty to protect the health and safety of the public

In many cases, an engineer is compelled to inform the public or higher management of unethical or illegal behavior by an employer or supervisor

From a company's perspective whistle-blowing is likely to be perceived as disloyalty. It can lead to distrust, disharmony, and an inability of employees to work together. However, keeping it within the company is often seen as less serious than going outside of the company.

Whistle-blowing should only be attempted if the following four conditions are met:

1. There must be a clear and important harm that can be avoided by blowing the whistle.
2. The whistle-blower must be in a very clear position to report and explain on the problem.
3. The whistle-blower must have a reasonable chance of success in stopping the harmful activity.
4. Whistle-blowing should be attempted only if there is no one else more capable or more proximate to blow the whistle and if you feel that all other lines of action within the context of the organization have been explored

Code of ethics

Engineering societies adopt codes of ethics to express the rights, duties and obligations of the members of the profession

Codes of ethics are not limited to professional organizations as they have also been found by universities

A code of ethics provides a **framework** for ethical judgment for a professional

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

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 to code the engineer to apply them to the unique situations encountered in professional practice

Finally, a code defines the roles and responsibilities of professionals

Professional societies should function 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 since they can be used by employees as defense against an employer

If the codes of ethics of professional societies are to have any meaning, their support to the defense of engineers is essential when ethical violations are pointed out. However, 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.

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS* (AICHE)

AIChE Code of Ethics

American Institute of Chemical Engineers

Members of the American Institute of Chemical Engineers shall uphold and advance theintegrity, honor, and dignity of the engineering profession by:

- Being honest and impartial and serving with fidelity their employers, their clients, and the public;
- Striving to increase the competence and prestige of the engineering profession;
- Using their knowledge and skill for the enhancement of human welfare.

To achieve these goals, members shall:

- Hold paramount the safety, health, and welfare of the public and protect the environment in performance of their professional duties.
- Formally advise their employers or clients (and consider further disclosure, if warranted) if they perceive that a consequence of their duties will adversely affect the present or future health or safety of their colleagues or the public.
- Accept responsibility for their actions, seek and heed critical review of their work, and offer objective criticism of the work of others.
- Issue statements or present information only in an objective and truthful manner.
- Act in professional matters for each employer or client as faithful agents or trustees, avoiding conflicts of interest and never breaching confidentiality.
- Treat fairly and respectfully all colleagues and co-workers, recognizing their unique contributions and capabilities.
- Perform professional services only in areas of their competence.
- Build their professional reputations on the merits of their services.
- Continue their professional development throughout their careers and provide opportunities for the professional development of those under their supervision.
- Never tolerate harassment.
- Conduct themselves in a fair, honorable, and respectful manner.

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Ethical theories

Ethical thought has emerged throughout the world at ancient times
e.g. Greek, Hindu, Chinese and İslamic philosophers independently developed ethical principles

Although for many individuals, personal ethics are rooted in religious beliefs, this is not true for everyone. There are many ethical people who are not religious, and there are numerous examples of people who appear to be religious but who are not ethical.

While the ethical principles that we will discuss come to us filtered through a religious tradition, these principles are now cultural norms in the modern world and they are widely accepted regardless of their origin

Ethical theories are applied to the ethical problems confronted by engineers for analysis and reaching solutions in ethical problems

In order to develop workable ethical problem-solving techniques, we must first look at several theories of ethics in order to have a framework for decision making

In most engineering classes, there is generally just one theory to consider when tackling a problem. In studying engineering ethics, there are several theories that will be considered. The relatively large number of theories doesn’t indicate a weakness in theoretical understanding of ethics
Rather, it reflects the complexity of ethical problems and the diversity of approaches to ethical problem solving that have been developed over the centuries

Having multiple theories to apply actually enriches the problem-solving process, allowing problems to be looked at from different angles, since each theory stresses different aspects of a problem

The basic ethical problem-solving technique utilizes different theories and approaches to analyze the problem and then tries to determine the best solution

An ethical theory defines terms in uniform ways and links ideas and problems together in consistent ways

There are four ethical theories that will be considered here, each differing according to what is held to be the most important moral concept:

1. Utilitarianism seeks to produce the most utility, defined as a balance between good and bad consequences of an action, taking into account the consequences for everyone affected
2. Duty ethics argues that there are duties that should be performed regardless of whether these acts lead to the most good
3. Rights ethics emphasizes that we all have moral rights, and any action that violates these rights is ethically unacceptable
4. Virtue ethics regards actions as right, that manifest good character traits (virtues) and regards actions as bad, that display bad character traits (vices)

Any complete analysis of an ethical problem must incorporate multiple theories if valid conclusions are to be drawn

Utilitarianism upholds those actions that serve to maximize human well-being
The emphasis in utilitarianism is not on maximizing the well-being of the individual, but rather on maximizing the well-being of society as a whole, and as such it is somewhat of a collectivist approach

Utilitarianism is fundamental to many types of engineering analysis, including risk–benefit analysis and cost–benefit analysis. However, as good as the utilitarian principle sounds, there are some problems with it:

- what is best for everyone may be bad for a particular individual or a group of individuals
- its implementation depends greatly on knowing what will lead to the most good. Frequently, it is impossible to know exactly what the consequences of an action are
- maximizing the benefit to society involves guesswork and the risk that the best guess might be wrong

2 basic types of utilitarianism:
Act utilitarianism focuses on individual actions rather than on rules and argues that individual actions should be judged based on whether the most good was produced in a given situation, and rules should be broken if doing so will lead to the most good
Rule utilitarianism holds that moral rules are most important and although adhering to these rules might not always maximize good in a particular situation, overall, adhering to moral rules will ultimately lead to the most good

An application of this theory that has been commonly seen in the last centuty is the building of dams:
Dams often lead to great benefit to society by providing stable supplies of drinking water, flood control, and recreational opportunities. However, these benefits often come at the expense of people who live in areas that will be flooded by the dam and are required to find new homes, or lose the use of their land. Utilitarianism tries to balance the needs of society with the needs of the individual, with an emphasis on what will provide the most benefit to the most people.

Cost-benefit analysis is a tool often used in engineering analysis, especially when trying to determine whether a project makes sense. Only those projects with the highest ratio of benefits to costs will be implemented. This principle is the same asthe utilitarian goal of maximizing the overall good.
While it is often easy to predict the costs for most projects, the benefits that are derived from them are often harder to predict and to assign a value to

From a pure cost–benefit discussion, it might seem that the building of a dam is an excellent idea. But this analysis won’t include other issues such as whether the benefits outweigh the loss of a living area or the loss of an endangered species with no current economic value. Finally, it is also important to make sure that those who benefit are also those who will pay the costs

Duty ethics and Rights ethics are similar to each other. These theories argue that those actions are good that respect the rights of the individual. Here, good consequences for society as a whole are not the only moral consideration.

Moral actions are those actions that could be written down on a list of duties:

- be honest,
- don’t cause suffering to other people,
- be fair to others, etc.

These actions are our duties because they express respect for people, express a regard for autonomous morality , and are universal principles

Once one’s duties are recognized, the ethically correct moral actions are obvious.

In this formulation, ethical acts are a result of proper performance of one’s duties.

Rights ethics upholds the fundamental rights of people such as the rights to life, liberty and property, that other people have a duty to respect.

Both duty ethics and rights ethics achieve the same end: Individual persons must be respected, and actions are ethical that maintain this respect for the individual.

In duty ethics, people have duties, an important one of which is to protect the rights of others. And in rights ethics, people have fundamental rights that others have duties to protect.

As with utilitarianism, there are problems with these theories:

- The basic rights of one person or a group may conflict with the basic rights of another
- They don’t always account for the overall good of society very well

For example, in the case of building of a dam, people have the right to use their property. If their land happens to be in the way of a proposed dam, then rights ethics would hold that this property right is paramount and is sufficient to stop the dam project. A single property holder’s objection would require that the project be terminated. However, there is a need for others living in nearby communities to have a reliable water supply and to be safe from continual flooding.

Whose rights are paramount here? Rights and duty ethics don’t resolve this conflict very well; hence, the utilitarian approach of trying to determine the most good is more useful in this case.

Virtue ethics is interested in determining what kind of people we should be
Virtue is often defined as moral distinction and goodness. A virtuous person exhibits good and beneficial qualities. Here, actions are considered right if they support good character traits (virtues like responsibility, honesty, competence, loyalty, citizenship, trustworthiness, fairness, caring, and respect) and wrong if they support bad character traits (vices like dishonesty, disloyalty, irresponsibility, or incompetence).
It is closely tied to personal character with the perspective of 'we do good things because we are virtuous people and seek to enhance these character traits in ourselves and in others'

This theory may seem to be mostly personal ethics and not particularly applicable to engineering or professional ethics. But If a behavior is virtuous in the individual's personal life, the behavior is virtuous in his or her professional life as well.

- Virtue ethics is less concrete and less susceptible to detailed analysis
- It is harder to describe nonhuman entities such as a corporation or government in terms of virtue
- Problems can arise with words that on the face seem to be virtues, but can actually lead to vices (like honor)

We can use virtue ethics in our engineering career by answering questions such as:

- Is this action honest?
- Will this action demonstrate loyalty to my community and/or my employer?
- Have I acted in a responsible fashion?

Often, the answer to these questions makes the proper course of action obvious

To use virtue ethics in an analysis of an ethical problem, we should first identify the virtues or vices that are applicable to the situation. Then, determine what course of action each of these suggests.

For the case of companies, they should be held accountable for ethics in the same way that individuals are, even if the ability to do this within the legal system is limited.
In other words, with regard to an ethical problem, responsibility for corporate wrongdoing shouldn't be hidden behind a corporate mask.

Just because it isn't really a moral agent like a person doesn't mean that a corporation can do whatever it pleases. Instead, in its interactions with individuals or communities, a corporation must respect the rights of individuals and should exhibit the same virtues that we expect of individuals.

Analysis of ethical problems

Analysis and problem-solving tools are presented below for an engineer who needs to decide which path is the ethically correct path to take

In solving engineering problems, it is always useful to look for an appropriate formula, plug in the numbers, and calculate an answer. This type of problem-solving approach, is less useful for ethical problem solving.

There are theories that help us to frame our understanding of the problem, but there are no formulas

The main step in solving any ethical problem is to completely understand all of the issues involved which may be categorized into factual, conceptual, and moral issues

<u>Factual issues</u> involve what is actually known about a case - i.e., what the facts are

The facts of a particular case are not always clear and may be controversial

For example – global warming debate is based on incomplete understanding of nature

Factual issues can often be resolved through research to establish the truth

Conceptual issues include the meaning or applicability of an idea
For example – Definition of a bribe in contrast to an acceptable gift or definition of confidential business information
Conceptually it must be determined whether accepting a gift will lead to unfair influence on a business decision
Like factual issues, conceptual issues are not always clear-cut and will often result in controversy as well
Conceptual issues are resolved by agreeing on the meaning and applicability of terms and concepts

Moral issues are the ethical principles that are applicable to the situation
Resolution of moral issues is often more obvious. Once the problem is defined, it is usually clear which moral concept applies, and the correct decision becomes obvious.

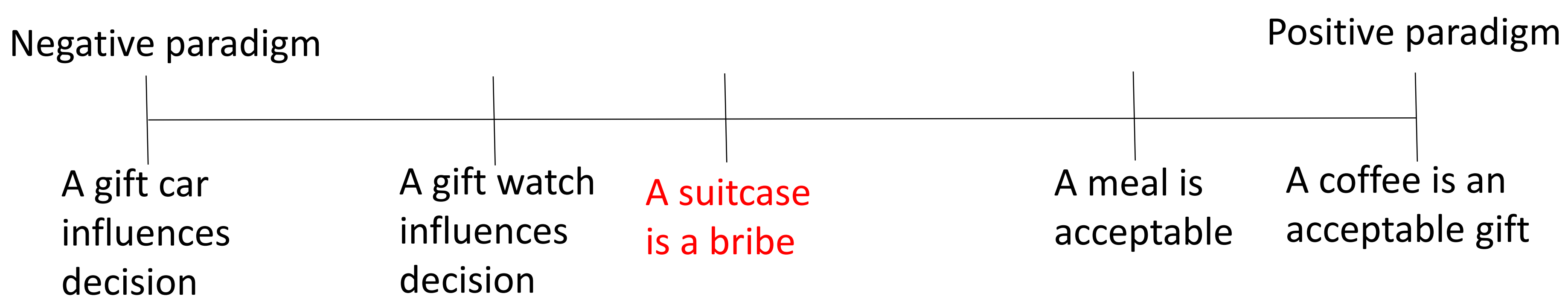
In the example of a "gift" offered by a sales representative, once it is determined whether it is simply a gift or is really a bribe, then the appropriate action is obvious.
If we determine that it is indeed a bribe, all four ethical points of view consider it unethical
Moral issues are resolved by agreement as to which moral principles are valid and how they should be applied

Ethical problem solving techniques

- Line drawing

Useful for situations in which the applicable moral principles are clear, but it is not clear which ethical principle applies

Line drawing is performed by drawing a line along which various examples and hypothetical situations are placed
At one end is placed the “positive paradigm,” an example of something that is totally morally acceptable
At the other end, the “negative paradigm,” an example of something that is clearly not morally acceptable
In between is placed the problem under consideration, along with other similar examples, the problem being the last

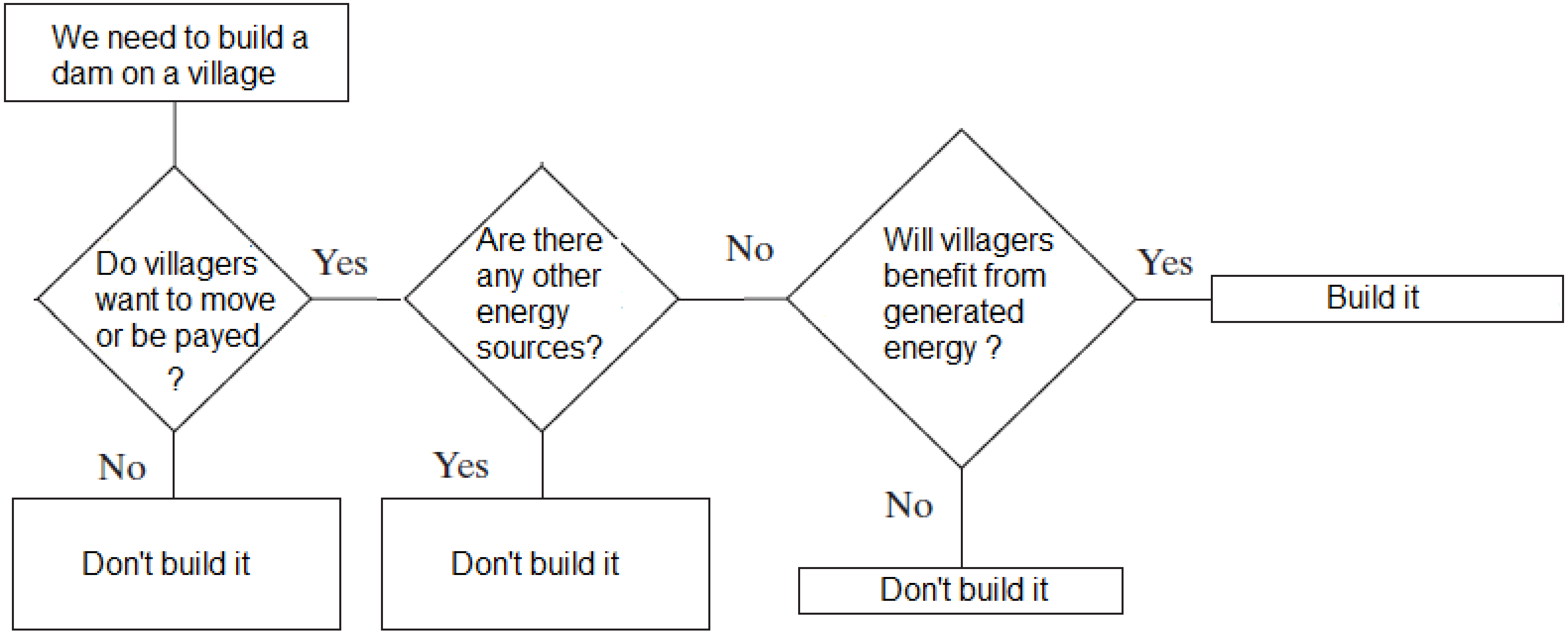


Ethical problem solving techniques

- Flow charting

Helpful for analyzing a variety of cases, especially those in which there is a sequence of events to be considered or a series of consequences that flows from each decision

The key to effective use of flow charts for solving ethical problems is to be creative in determining possible outcomes and scenarios and also to not be shy about getting a negative answer and deciding to stop the project



Conflict problem solving techniques

- Commonsense

Often, there are conflicting moral choices, but one is obviously more significant than the other

For example, protecting the health and safety of the public is more important than your duty to your employer

- Creative middle way

This solution is an attempt at some kind of a compromise that will work for everyone. The emphasis here should be on the word "creative," because it takes a lot of creativity to find a middle ground that is acceptable to everyone and a lot of diplomacy to sell it to everyone

For example, rather than moving the villagers away from the dam, an apartment complex can be built next to the dam

No one will be completely satisfied with this alternative, since it will take more time and money. Some people will not want to leave their homes

- Hard choice

When there is no easy choice and attempts to find a middle way are not succesful, you need to trust your feelings and autonomous morality

Safety and Risk

Nearly everything an engineer designs has some health or safety risk associated with it

The most important duty of an engineer is to ensure the safety of the people who will be affected by the products that he designs

All of the codes of ethics of the professional engineering societies stress the importance of protecting the health and safety of the public in the engineer's duties

All products have a warranty that they will perform as advertised
Similarly, there is an implied warranty that products are safe to use. Nothing can be 100% safe, but engineers are required to make their designs as safe as reasonably possible.

Thus, safety should be an integral part of any engineering design
It is impossible to discuss safety without also including a discussion of risk
It is impossible to design anything to be completely risk free.
Risk is the possibility of suffering harm or loss. It is sometimes used synonymously with danger
Safety is defined as freedom from damage, injury, or risk.

There are four criteria that must be met to help ensure a safe engineering design:

1. A design must comply with the applicable laws. This requirement is easy to meet, since legal standards for product safety are generally well known, are published, and are easily accessible
2. A design must meet the standard of "accepted engineering practice." You can't create a design that is less safe than what everyone else in the profession understands to be acceptable. To achieve this an engineer must continually upgrade her skills by attending conferences and short courses, discussing issues with other engineers, and constantly surveying the literature and trade magazines for information on the current state of the art in the field
3. Alternative designs that are potentially safer must be explored. This requirement is also difficult to meet, since it requires a fair amount of creativity in seeking alternative solutions. This creativity can involve discussing design strategies with others in your field and brainstorming new alternatives with them. The best way to know if your design is the safest available is to compare it to other potential designs
4. You must attempt to foresee potential misuses of the product by the consumer and must design to avoid these problems. an engineer should execute designs in such a way as to protect even someone who misuses the product. Placing a warning label on a product is not sufficient and is not a substitute for doing the extra engineering work required to produce a safe design

Risk and safety case: Nanotechnology in medicine

The potential for nanotechnology to bring benefits to humankind is huge. However, to harvest these benefits, we will need to pay attention to the many potential pitfalls of this technology. Nanotechnology is defined by size. A nanometer is a billionth of a meter and the nanoscale ranges from 1 to 100 nm. Nanotechnology is the design and production of materials, devices, and systems that exploit the phenomena of the nanoscale. The challenge of the nanoscale lies not just in miniaturization, but in the fact that materials behave differently as their dimensions shrink. For example, when a structure consists of only a few atoms or molecules, its behavior is governed by quantum mechanics or surface-volume ratios rather than by bulk properties.

Many people predict that nanotechnology will lead to dramatic advances in health care, including drug delivery systems, bone repair, diagnostic tools, and therapies for cancer, diabetes, and other chronic diseases. However, nanoparticles also pose a health and safety challenge. This concern lies in the fact that surfaces of many materials can be highly reactive, while the bulk of the material is fairly inert. In the large-scale bulk materials that we are used to dealing with, surface atoms are only a tiny fraction of the total number of atoms in the material. So even if the surface is highly reactive, a large piece of the material is not particularly reactive. This is no longer true when small nanosized particles are fabricated. A 30-nm particle has 5% of its atoms on the surface, while a 3-nm particle has 50% of its atoms on the surface. Thus, a vial of nanopowder made of a material with a reactive surface can be far more reactive than the same weight of a solid piece of this material. A material can be perfectly safe in bulk, but toxic in its nanoform because the surface properties can dominate in small particles. For example, some studies suggest that carbon nanotubes, structurally similar to asbestos fi bers, may be carcinogenic, while carbon in its bulk diamond or graphite forms is inert.

Research has shown that some nanoparticles are able to penetrate living cells. Medical researchers are attempting to exploit this property to create new ways to diagnose and cure disease. However, nanoparticles in the environment may pose a health hazard. A nanoparticle transported through the bloodstream to cells within the body might directly attack the cell, leading to new diseases. Or, a nanoparticle made from a material with a reactive surface might adsorb pollutants or other contaminants directly into cells within a human body. Currently there are relatively few companies in the world manufacturing carbon nanotubes. However, this number is surely bound to increase rapidly in the future.

There are products on the market today that utilize nanoparticles, most notably cosmetics and sunscreens. While products using nanoparticles have already been introduced, studies regarding the safety of these particles are being undertaken at several universities and other research laboratories, though today these studies are in their infancy. Regulatory agencies have only begun to think about how to regulate these new materials.

We have the same obligation to act responsibly and professionally with nanotechnology as we do with conventional technologies; many of the issues associated with nanotechnology need to be addressed for any technology. In the past, new technologies and materials have generally been introduced without regard to their ethical and societal implications. For example, X-rays were initially used for entertainment purposes since people were ignorant of its ionizing effects. However, this is changing, as can be seen by the fact that government agencies funding research in nanotechnology now require that some of the money for these projects be used for projects designed to assess potential ethical and societal impacts of nanotechnology.

Problems

- What new ethical issues do you think nanotechnology brings about?
- What are the dangers of introducing a new technology without thorough testing of its safety?
- Is it possible to thoroughly test the safety of new technology before it is introduced?

Ethical problems in engineering

There are many unique ethical issues that arise in engineering practice that may not be encountered in other professions

The most common three areas where engineers may encounter ethical concerns are environment, computers and research

1. Environmental ethics

Environmental conscienceness in the modern world helps to control the introduction of toxic and unnatural substances into the environment, to protect the integrity of the biosphere, and to ensure a healthy environment for humans.

Engineers are responsible in part for the creation of the technology that has led to damage of the environment and are also working to find solutions to the problems caused by modern technology

The environmental movement has led to an increased awareness among engineers that they have a responsibility to use their knowledge and skills to help protect the environment. This duty is even found in many of the engineering codes of ethics.

Engineers have a responsibility to ensure that their work is conducted in the most environmentally safe manner possible

There are multiple approaches that can be taken to resolving environmental problems. Interestingly, these approaches mirror the general ethical theories

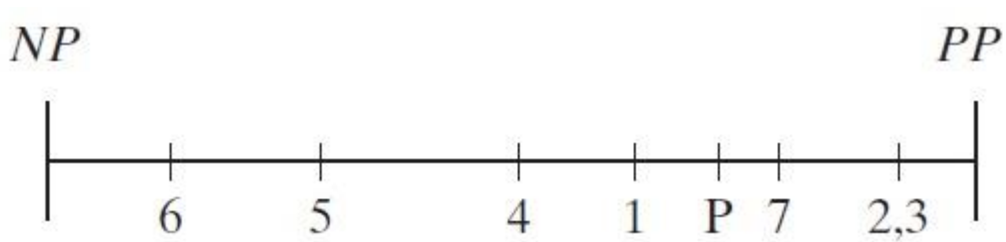
- In the first approach cost is not taken into account, but rather the environment is made as clean as possible. No level of environmental degradation is seen as acceptable. This approach is similar to rights and duty ethics.
  - It is difficult to uphold, in a modern industrial society
  - It is very difficult to enforce, since the definition of "as clean as possible" is hard to agree on
  - Not taking into account the cost isn't practical in any realistic situation in which there are not infinite resources to apply to a problem.
- A second approach is based on cost–benefit analysis, which is derived from utilitarianism. Here, the problem is analyzed in terms of the benefits derived by reducing the pollution (e.g. improvements in human health) and the costs required to solve the problem. In this approach, the goal is not to achieve a completely clean environment, but rather to achieve an economically beneficial balance of pollution with health or environmental considerations
  - The true cost of a human life or the loss of a species are difficult to determine
  - It is difficult to accurately assess costs and benefits, and guesswork is done
  - It doesn't take into account who pays the costs and who gets the benefits
  - The only considerations are costs and benefits, with no room for a discussion of whether what is being done is right or not.

Environmental case study

It is proposed that our company dispose of a slightly hazardous waste by dumping it into a lake. A nearby town takes its drinking water supply from this lake. Our research shows that with the amount of waste we plan to put into the lake, the average concentration of the waste in the lake will be 5 parts per million (ppm). The EPA limit for this material has been set at 10 ppm. At the 5-ppm level, we expect no health problems, and consumers would not be able to detect the compound in their drinking water.

A third approach to solve this environmental conflict of interest problem is available

Positive paradigm: The water supply for the town should be clean and safe.
Negative paradigm: Toxic levels of waste are put into the lake.
The company dumps the chemical into the lake. At 5 ppm, the chemical will be harmless, but the town's water will have an unusual taste.
The chemical can be effectively removed by the town's existing water-treatment system.
The chemical can be removed by the town with new equipment that will be purchased by the company.
The chemical can be removed by the town with new equipment for which the taxpayer will pay.
Occasionally, exposure to the chemical can make people feel ill, but this only lasts for an hour and is rare.
At 5 ppm, some people can get fairly sick, but the sickness only lasts a week, and there is no long-term harm.
Equipment can be installed at the plant to further reduce the waste level to 1 ppm.



2. Computer ethics

There are ways in which computers have brought benefits to society. Unfortunately, there are also numerous ways in which computers have been misused, leading to serious ethical issues. Many ethical problems associated with computer use relate to unauthorized use of information stored on computer databases and are thus related to the issues of confidentiality

The engineer's roles as designer, manager, and user of computers bring with them a responsibility to help foster the ethical use of computers.

Unique to engineering are two uses of computers: as design tools and as components integrated into engineered systems

Numerous software packages are available for the design of engineered devices and structures. They include CAD/CAM, circuit analysis, finite element analysis, structural analysis, and other modeling and analysis programs. Software also exists that is designed to aid in the process of testing engineered devices by performing tests, recording data, and presenting data for analysis. These all serve to allow an engineer to work more efficiently and to help take away some of the hard aspects of an engineer's work.

Software can never be a substitute for good engineering judgment.
The engineer who uses software in the design process is still responsible for the designs that were generated and the testing that was done using a computer.
Engineers must be careful to make sure that the software is appropriate to the problem being worked on, and should be knowledgeable about the limitations and applicability of a software package.

Computer software can also give an engineer the illusion that she is qualified to do a design in fields beyond her expertise. Software can be so easy to use that you might imagine that by using it, you are competent in the area that it is designed for.
It is a common obligation in codes of ethics that engineers should not make desicions in fields they are not competent.

Computers have also become a component of many engineered systems. However, the ability to control aspects of system performance using software removes humans from the control loop. There are numerous examples of situations in which computerized systems malfunctioned without giving the operator any indication that a problem existed. In some cases, the operator was unable to intervene to solve a problem because the software design wouldn’t allow it. It is essential when designing systems with embedded computers and software that engineers ensure that software is adequately tested, that humans can intervene when necessary

Computer case study

Between June of 1985 and January of 1987, at least six patients receiving treatment using the Therac-25 were exposed to high doses of radiation, leading to serious injury or death. The Therac-25 was a radiation therapy machine capable of irradiating tumors with either electrons or X-rays. Based on earlier versions of the machine, the Therac-25 was the first to incorporate significant computer controls.

The use of radiation for treating cancer is a well-established medical tool. Machines have been developed that deliver precisely controlled doses to tumors and the surrounding tissue without causing harm to healthy tissue in the patient. The Therac-25 was one of these machines and was based on earlier models produced by the same company. These machines had successfully treated thousands of patients. The problem with the Therac-25 was that the computer software used to control the machine and monitor the dose delivered to the patient was inadequate. Under certain circumstances, the software allowed the machine to be energized when it wasn't in the correct configuration. When this happened, patients could receive doses orders of magnitude larger than planned. Investigations in these cases determined that accepted standards for writing, testing, and documenting the software that controlled the Therac-25 had not been followed, directly leading to the accidents.

The proximate cause of these accidents was a "bug" in the software. As the operators became comfortable with the software, they became quite proficient and fast at entering the data that set the type of treatment, dose, and energy. However, the hardware of the system required several seconds to reset when a command was changed on the computer keyboard. If the operator input the wrong information initially, quickly changed the settings to the correct ones, and hit the key that turned the beam on, the machine would go ahead and energize the beam, resulting in an incorrect dose being delivered. Basically, the software didn't wait for the hardware to reset before turning the beam on. Compounding the problem, there were no hardware interlocks available to shut the beam off when excessive doses were detected. The earlier versions of the Therac machines had this type of hardware safety system, but the Therac-25 relied on software to provide this protection

3. Research ethics

There are two major ethical issues related to research:

<u>Honesty in approaching the research problem</u>

It relates to a state of mind essential to objectively performing research. This includes being open to changing the hypothesis when the evidence points that way

<u>Honesty in reporting the results</u>

Results must be accurately reported. Once an experiment or test has been performed, the results of the experiment must not be overstated, but rather an accurate assessment and interpretation of the data must be given.

The environment that most researchers work in fosters temptations and rewards for overstating research results. Academic researchers must publish significant research results in order to get tenure at their universities. If an experiment isn't working out, it is tempting to alter the results to achieve the desired outcome

It is also important to ensure that proper credit is given to everyone who participated in a research project. Generally, there is participation by other people who should be acknowledged for their contributions such as discussions or guidance, construction of experimental apparatus, or substantial help with performing experiments or interpreting data.

Several ethical theories can be used to analyze issues involving research.

Utilitarianism or rights and duty ethics can be applied to research, but it is easiest to examine research issues using virtue ethics.

One of the virtues is honesty. Honesty facilitates trust and good relations between individuals, whereas dishonesty leads to doubts and misgivings about others. Making false claims about the results of experiments is certainly a form of dishonesty. Likewise, not giving credit to everyone who has participated in a project is dishonest, and virtue ethics indicates that this practice is unacceptable.

Research case study

After the discovery of X-rays in the late 19th century, there was a great deal of interest among scientists in finding other similar types of rays. Many scientists joined this search in the hopes of achieving the fame that such a discovery would bring. The search to find new rays was joined by a well-known French physicist, René Blondlot, at the University of Nancy.

In 1903, Professor Blondlot was working with gas discharges that produced the newly discovered X-rays. His previous experience was in the study of electromagnetic phenomena, and he was hoping to discover if X-rays were a wave or particle by determining if the X-rays could be polarized as visible light can be. Using a spark gap and an apparatus similar to the one that Roentgen had used to discover X-rays, Blondlot attempted to determine the polarization of X-rays by rotating the spark gap in the X-ray fi eld. In his initial study, Blondlot discovered that, indeed, the spark gap became brighter when rotated to a certain angle with respect to the discharge tube. This was an important discovery.

Subsequent experiments indicated that the radiation impinging on the spark gap could be bent by a quartz prism. This feature was a major problem, since X-rays had already been shown by many scientists to be unaffected by lenses and prisms. The fact that the radiation he was measuring appeared to be bent by the prism convinced Blondlot that he had discovered a new form of radiation that he called N-rays (for the University of Nancy).

The reports of the discovery of a new type of ray set off a fl urry of activity in other laboratories around the world, and Blondlot himself continued to study the phenomenon. Despite the explosion of research on N-rays, there were also some doubts about Blondlot's findings. Many researchers outside France, including Lord Kelvin in England, had been unable to reproduce the results reported by Blondlot. Prof. J. W. Wood of Johns Hopkins University was also unable to reproduce the results and traveled to Nancy to observe the experiments fi rsthand. In a paper published in *Nature* , he described the experiments that he had witnessed. Wood reported that when he observed the spark gap and someone placed a hand in the path of the N-rays, Wood didn't see the expected changes in intensity. Publication of Wood's findings ended research into N-rays everywhere except in France. Blondlot responded to the criticisms and continued to present results of new, more controlled experiments. He even published a set of instructions for properly observing the phenomenon. For example, the instructions stated that the observer had to avoid gazing directly at the spark gap and instead had to look at it obliquely. The observer had to remain silent, avoid smoke, and had to look at the detector in the "way an impressionist painter would view a landscape". Acquisition of this ability required a great deal of practice and might be impossible for some people. In other words, the key to the measurement was the sensitivity of the observer, rather than the validity of the phenomena. As more research was performed, it became clear even to the French that there were no N-rays.

General case study

The space shuttle *Challenger* was launched in the winter of 1986 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 an explosion soon after lift-off. 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 were 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 because 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 *postmortem* 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?

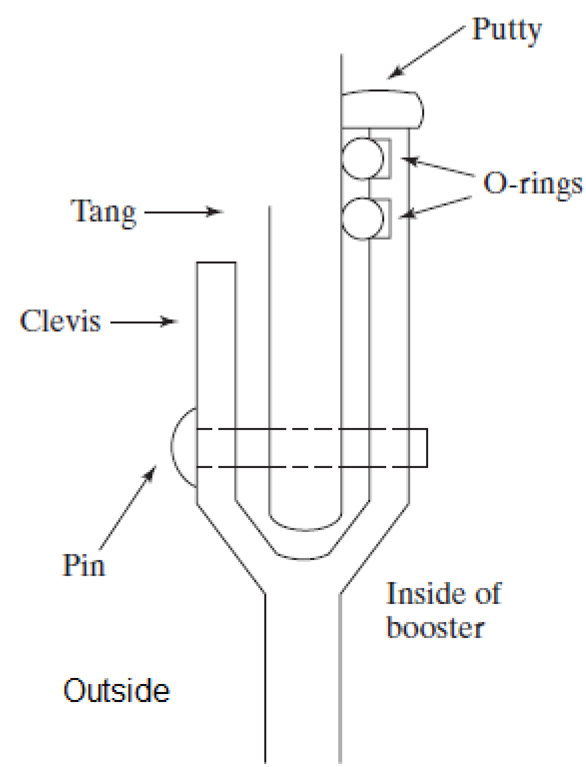
Warning: When studying a case several years after the fact and knowing the ultimate outcome, it is easy to see what the right decision should have been. Obviously, had NASA owned a crystal ball and been able to predict the future, the *Challenger* would never have been launched. However, we rarely have 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.

Analysis

The space shuttle was designed to be a reusable launch vehicle. The vehicle consists of an orbiter, which looks much like a medium-sized plane, two solid-propellant boosters, and a single liquid-propellant booster. At take-off, all of the boosters are ignited and lift the orbiter out of the earth's atmosphere. The solid rocket boosters are only used early in the flight and are dumped soon after take-off, 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 dumped 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 January 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.

A key aspect of the booster design are the joints where the individual cylinders come together. 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 second O-ring was added to the booster for the shuttle to provide an extra margin of safety. 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.



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 that time. NASA's budget was determined by Congress, which was becoming increasingly unhappy with delays in the shuttle project and shuttle performance. 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 non-reusable 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 election talks, in which President Reagan hoped to mention the shuttle as his success.

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. The director of the 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 a large group of engineers and managers of the project 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 engineers of the project company 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. The engineers' point was that the lowest temperature at which the shuttle had previously been launched was 53°F, on January 24, 1985, when there was deformation 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 engineers' presentation, the vice president for engineering for the company 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

The Solid Rocket Booster Project manager correctly pointed out that the data were inconclusive and disagreed with the engineers. A number of other managers also expressed their disagreement with the engineers' recommendations. A key fact that ultimately affected the decision was that in the available data, there seemed to be no correlation between temperature and the degree to which combustion 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 a launch at the expected temperature would necessarily be unsafe. After much discussion, a senior manager told the vice president of engineering the famous phrase "Take off your engineering hat and put on your management hat"

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Just before the launch, one of NASA’s safety cameras, looking at the solid booster, recorded puffs of smoke coming from the 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. Very quickly, the 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 prevented 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 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 quickly burned through the external tank. The liquid propellant was ignited and the shuttle exploded.