Engineering Economic Analysis

FOURTEENTH EDITION

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Brian Newnan, my chemical engineering nephew,
who helped guide this book forward
DN

In memoriam to Richard Corey Eschenbach, for his lifelong example
of engineering leadership and working well with others
TE

To my lovely wife Christine
and sweet daughters Gabrielle, Veronica,
Miriam, Regina, and Magdalen,
who all inspire me daily to be my best!
JL

My wife Joan,
for her continued support
NL

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PREFACE

Our goal has been, and still is, to provide an easy-to-understand and up-to-date presentation of engineering economic analysis for today's students. That means the book's writing style must promote the reader's understanding. We humbly note that our approach has been well received by engineering professors—and more importantly, by engineering students through multiple editions.

Hallmarks of this Book

Since it was first published, this text has become the market-leading book for the engineering economy course. It has always been characterized by

- **A focus on practical applications.** One way to encourage students to read the book, and to remember and apply what they have learned in this course, is to make the book interesting. And there is no better way to do that than to infuse the book with real-world examples, problems, and vignettes.
- **Accessibility.** We meet students where they are. Most don't have any expertise in accounting or finance. We take the time to explain concepts carefully while helping students apply them to engineering situations.
- **Superior instructor and student support packages.** To make this course easier to understand, learn, and teach, Oxford University Press has produced the best support package available. We offer more for students and instructors than any competing text.

New to the 14th Edition

- Since bonus depreciation has been allowed for all but 4 years since 2001, depreciation for corporate tax purposes in the U.S. is best described and taught as bonus plus MACRS—rather than either system alone. Chapter 11 has been heavily revised to reflect this. The chapter also describes why and how straight-line and declining balance methods are used for valuation.
- Chapter 12 on income taxes includes the changes in depreciation and the simplification of corporate tax rates from 8 brackets and a top rate of 39% to a lower and flat 21%. State income taxes at up to 10% are now more important in practice. Pedagogically, progressive state tax rates schedules reinforce student understanding of marginal and average rates.

- Chapter 13 is now "Economic Life and Replacement Analysis."
    - Economic analysis in practice must answer the question, how long will an alternative be used? Examples include overhauls and the costs of unplanned replacements, failures in use, and foregoing the value of newer technology.
    - Students are introduced to spreadsheets designed for choosing the cost minimizing life. Careful function definitions do the financial arithmetic required so that students can focus on learning and reinforce it by doing more problems.
    - Replacement analysis now focuses on an existing, aging asset with increasing costs. This better matches the time constraints and objectives of introductory courses.
- Expansion of online course material to include auto-graded algorithmic variations of new and end-of-chapter problems.
- Other changes include 5 new vignettes. Life-cycle costs have an added figure and discussion in Chapter 2. Chapter 6's coverage of irregular cash flows shows how midlife cash flows for overhauls and expansions are converted to annual equivalents. The chapter clarifies the difference between capital recovery costs and all annual costs. Inflation data has been updated in Chapter 15. After-tax coverage in later chapters is revised.

Strengths of the 14th Edition

- Factor notation and tabulated factors are a clear way to understand and do engineering economic analysis. This is reinforced by spreadsheet annuity functions, which are presented in a visual 5-BUTTON format. The two approaches are mutually reinforcing for faster and deeper student understanding.
- There is an answer icon next to most even-numbered problems with answers in Appendix E.
    - Instructors can easily pick a preferred mix of problems with and without answers.
    - Students can do extra problems and check their own answers.
- Solutions in the *Instructor's Manual* were completed and text corrections were made *before* the book was finalized for printing.
- Each chapter opens with a list of *keywords*, which are **boldfaced** when first explained and indexed for later reference.
- This text has an identified path for learning how to use spreadsheets in economic analysis. This supports student learning and later engineering practice. It supports faculty member choices from no coverage to heavy reliance. Students can choose whether to learn more on their own.
    - Chapter 1 explains data blocks, what-if analysis, and relative/absolute addresses. Appendix A provides more for spreadsheet novices.
    - Spreadsheet annuity functions are introduced beginning with Example 3–5; spreadsheet block functions are covered in Chapter 4 after factor approaches

  for arithmetic and geometric gradients where annuity functions cannot be used.
  - Other spreadsheet functions including XNPV, XIRR, SUMPRODUCT, and GOAL SEEK are presented when they will allow or speed solutions in economic analysis.
  - Problems in Chapters 12, 13, and 14 on taxes, replacement analysis, and inflation tend to involve more calculations than other chapters so spreadsheets are particularly useful.
- Chapter appendices on investing, diversification, and personal finance build on the loans, savings, and other personal finance examples that have long been used to motivate students and engage them with engineering economy concepts. Our first goal is force the realization that engineering economy really does matter. Second, personal financial success contributes to success as a student, as an engineer, and in life.
- Green engineering and ethics are in every chapter. Ethics questions continue to be part of the Questions to Consider in the vignettes. Along with coverage of multiple objectives beginning in Chapter 1, this can extend coverage of economic analysis and engineering decision-making into a broader context.

Teaching and Learning Package

This book is supported by a carefully crafted set of ancillary teaching and learning materials. The supplements package for this text has been updated and expanded again for this edition, making it the most extensive support package available for this course.

Dashboard

New to this edition, Dashboard delivers a wealth of study resources and automatically graded problems in an intuitive, web-based learning environment. A built-in color-coded gradebook allows instructors to track student progress. Instructors can save their students money by ordering Dashboard packaged with the print edition. Students can also purchase stand-alone Dashboard access (which includes the interactive eBook) online directly at www.oup.com/us/dashboard. Dashboard includes:

- Auto-graded, algorithmic problems for online homework assignments.
- Interactive tutorial questions written by Paul Schnitzler of the University of South Florida and William Smyer of Mississippi State University.
- Practice problems in the style of the FE exam authored by Karen Thorsett, University of Phoenix.

Student Resources

- A Study Guide by Ed Wheeler of the University of Tennessee at Martin and the text authors contains more than 500 additional problems with detailed solutions. It is available for print purchase and integrated into the eBook edition and the Dashboard course at no extra charge.
- Additional free student resources are available online at www.oup.com/us/newnan.

- A set of tutorials on engineering economy applications of Excel by Julie L. Fortune of the University of Alabama in Huntsville.
- A set of 54 cases provides realistic, complex problems. These cases, written by William Peterson and Ted Eschenbach and 13 contributors, also include three chapters on case analysis and an example case solution.
- Spreadsheet problem modules, written by Thomas Lacksonen of the University of Wisconsin Stout.

Instructor Resources

Instructors will find an updated and expanded set of resources available at www.oup.com/us/newnan. Please contact your Oxford University Press representative for access.

- An exam file written and edited by Meenakshi Sundaram of Tennessee Technological University.
- PowerPoint lecture notes for all chapters by Neal Lewis of Fairfield University.
- The compound interest tables are available online as PDF files for adopting professors who prefer to give closed-book exams.
- An Instructor's Manual by John M. Usher of Mississippi State University with complete solutions to all end-of-chapter problems.

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This book remains the best text on the market in large part because of feedback from users. We would appreciate hearing comments about the book, including being informed of any errors that have snuck in despite our best attempts to eradicate them. We also look forward to adding problems and vignettes in the next edition that adopters have found effective for their students. Please write us c/o the Engineering Editor at Oxford University Press, 198 Madison Avenue, New York, NY 10016, or email us directly. Thanks for using the Newnan book!

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ENGINEERING ECONOMIC ANALYSIS

CHAPTER 1

MAKING ECONOMIC DECISIONS

Delivered Food and Decision Making

Hungry? Will you order food and get it delivered to your dorm room or home? If you do, will you call the restaurant directly or use an online platform like UberEats, DoorDash, GrubHub (Seamless), Postmates, or Eat24? Today many people want their food delivered to home or office, and restaurants don't want to miss out on possible sales. Restaurants are joining with third-party online platforms and are turning delivery from a small segment of the restaurant industry to a booming new source of sales at establishments well beyond fast food. However, decision making is more complex than it appears on the surface.

Many establishments are part of chains where engineers have designed facilities for a mix of "take-out" and "dine-in." What must change when the mix changes? Does it make sense to separate pickup from drive-through? Turning a profit in the food business is tough. Partnering with delivery platforms squeezes margins even tighter. These platforms usually charge 10%–40% of the order's cost. The online platforms maintain that they bring "incremental" revenue to restaurants—that the restaurants would not otherwise receive. The platforms also emphasize that delivery orders are a form of marketing, exposing potential new customers who might become lucrative in-restaurant patrons.

However, what sounds like a boon for restaurants carries unexpected risks, including shrinking profit margins and shifting customer allegiances. Deliveries can risk cannibalizing more profitable dine-in sales by encouraging customers to stay at home. If an order takes longer than expected or if the food arrives cold, customers may blame the restaurant, not the delivery platform. The customers might not return, and a negative review may discourage other people from trying the restaurant. Customer loyalty may shift from the

restaurant to the third-party delivery service that is now between the restaurant and the customer. Staff compensation at the restaurant may have to change if the driver is tipped, rather than the staff.

Some restaurants, such as Olive Garden, Texas Roadhouse, and Domino's Pizza, are at least for now avoiding the squeezed margins and other risks of third-party platforms. If you are hungry, it would be much kinder to call the restaurant directly or go to the restaurant's website. There are still delivery charges, but no third-party commission. ■■■

Contributed by Kate D. Abel, Stevens Institute of Technology

QUESTIONS TO CONSIDER

1. What sort of operational issues could be created in the restaurants that choose to use third-party platforms? How could these issues affect the financial viability of joining with the platforms?
2. This vignette was about restaurant delivery. Can you think of another venue where similar delivery services might be desired in the future?
3. Before reading this vignette, did you think that *how* you ordered your food could have an economic impact? Which ordering option do you think you will use moving forward? Why?
4. Develop a list of concerns and questions consumers might have for the restaurants and the third-party platforms. Which are economic and which are noneconomic factors?

After Completing This Chapter...

The student should be able to:

- Distinguish between simple and complex problems.
- Discuss the role and purpose of engineering economic analysis.
- Describe and give examples of the nine steps in the *economic decision-making process*.
- Select appropriate economic criteria for use with different types of problems.
- Describe common ethical issues in engineering economic decision making.
- Solve engineering problems with current costs.
- Solve problems that have multiple objectives.

Key Words

absolute address	fixed input	resolving consequences
benefit	fixed output	shadow price
brainstorming	green engineering	societal costs
cost	maximizing profit	value engineering
criteria	model building	what-if analysis
data block	multiple objectives	
decision making	overhead	

This book is about making decisions. **Decision making** is a broad topic, for it is a major aspect of everyday human existence. This book develops the tools to properly analyze and solve the economic problems that are commonly faced by engineers. Even very complex situations can be broken down into components from which sensible solutions are produced. If one understands the decision-making process and has tools for obtaining realistic comparisons between alternatives, one can expect to make better decisions.

Our focus is on solving problems that confront firms in the marketplace, but many examples are problems faced in daily life. Let us start by looking at some of these problems.

A SEA OF PROBLEMS

A careful look at the world around us clearly demonstrates that we are surrounded by a sea of problems. There does not seem to be any exact way of classifying them, simply because they are so diverse in complexity and "personality." One approach arranges problems by their *difficulty*.

Simple Problems

Many problems are pretty simple, and good solutions do not require much time or effort.

- Should I pay cash or use my credit card?
- Do I buy a semester parking pass or use the parking meters?
- Shall we replace a burned-out motor?
- If we use three crates of an item a week, how many crates should we buy at a time?

Intermediate Problems

At a higher level of complexity we find problems that are primarily economic.

- Shall I buy or lease my next car?
- Which equipment should be selected for a new assembly line?
- Which materials should be used as roofing, siding, and structural support for a new building?
- Shall I buy a 1- or 2-semester parking pass?
- What size of transformer or air conditioner is most economical?

Some numeric examples of operational economics follow the section on ethics later in this chapter.

Complex Problems

Complex problems are a mixture of *economic, political,* and *humanistic* elements.

- Honda Motors in North America illustrates complex problems. In Alliston, Ontario, they employ 4000 workers and manufacture the Acura MDX, ZDX, CSX, and Civic. In Lincoln, Alabama, they employ 4000 workers and manufacture the Odyssey, Pilot, Ridgeline, and Acura MDX. Any decision allocating production must consider, along with economic aspects: reactions of the American, Canadian, Japanese, and Mexican governments; international trade agreements; labor unions in three countries; and the 2014 opening of a second Mexican plant in Celaya.
- The selection of a dating partner (who may later become a permanent partner) is obviously complex. Economic analysis can be of little or no help.
- A firm's annual budget allocates resources and all projects are economically evaluated. The budget process is also heavily influenced by noneconomic forces such as power struggles, geographical balancing, and impact on individuals, programs, and profits. For multinational corporations there are even national interests to be considered.

The chapter's final section presents one approach to more complex problems.

THE ROLE OF ENGINEERING ECONOMIC ANALYSIS

Engineering economic analysis is most suitable for intermediate problems and the economic aspects of complex problems. They have these qualities:

1. The problem is *important enough* to justify our giving it serious thought and effort.
2. The problem can't be worked in one's head—that is, a careful analysis *requires that we organize* the problem and all the various consequences.
3. The problem has *economic aspects* important in reaching a decision.

Engineers determine how money should be spent now to achieve cost savings and to increase revenues and other benefits that span years and often decades. Thus, when engineers face problems meeting the three criteria listed above, engineering economic analysis is required. Engineering in academia focuses on principles and design, but in engineering practice the focus is on money and value—as determined using engineering economy.

Students can apply many engineering economy tools to their personal lives by understanding time value of money, loans, savings, investments, and tax implications. "Trust Me: You'll Use This" (on pp. 76–77), Appendices 9A, 10A, and 12A, are focused on personal finance issues.

Engineering economy is applied professionally in for-profit firms, nonprofit organizations, and government agencies. Many examples and problems focus on for-profit firms. These firms must consider depreciation and taxes, as covered in Chapters 11 and 12. Nonprofit organizations (most private universities and many hospitals) and government agencies (school districts, cities, states, and federal) often have benefits that are hard to value (Chapter 16). Most engineering economy topics apply to a wide variety of people and organizations.

Examples of Engineering Economic Analysis

Engineering economic analysis focuses on costs, revenues, and benefits that occur at different times. For example, when a civil engineer designs a road, a dam, or a building, the construction costs occur in the near future; but the benefits to users begin only when construction is finished and then continue for a long time.

In fact nearly everything that engineers design calls for spending money in the design and building stages, and only after completion do revenues or benefits occur—usually for years. Thus the economic analysis of costs, benefits, and revenues occurring over time is called *engineering* economic analysis.

Engineering economic analysis is used by firms and government agencies to answer many different questions.

- *Which engineering projects are worthwhile?* Has the mining or petroleum engineer shown that the mineral or oil deposit is worth developing?
- *Which engineering projects should have a higher priority?* Has the industrial engineer shown which factory improvement projects should be funded with the available dollars?
- *How should the engineering project be designed?* Has the mechanical or electrical engineer chosen the most economical motor size? Has the civil or mechanical engineer chosen the best thickness for insulation? Has the aeronautical engineer made the best trade-offs between (1) lighter materials that are expensive to buy but cheaper to fly and (2) heavier materials that are cheap to buy and more expensive to fly?

Engineering economic analysis can also be used to answer questions that are personally important.

- *How to achieve long-term financial goals:* How much should you save each month to buy a house, retire, or fund a trip around the world? Is going to graduate school a good investment—will your additional earnings in later years balance the cost of attending and your lost income while in graduate school?
- *How to compare different ways to finance purchases:* Is it better to finance your car purchase by using the dealer's low interest rate loan or by taking an available rebate and borrowing money from your bank or credit union?
- *How to make short- and long-term investment decisions:* Should you buy a 1- or 2-semester parking pass? Is a higher salary better than stock options?

THE DECISION-MAKING PROCESS

Decision making may take place by default; that is, a person may not consciously recognize that an opportunity for decision making exists. This fact leads to our first element in a definition of decision making—there must be at least two alternatives available. If only one course of action is available, there is nothing to decide. The only alternative is to proceed with the single available course of action. (It is rather unusual to find that there are no alternative courses of action. More frequently, alternatives simply are not recognized.)

At this point we might conclude that the decision-making process consists of choosing from among alternative courses of action. But this is an inadequate definition. Consider a bettor at the Kentucky Derby who picks a horse by pointing at the program with closed eyes. Does this racehorse selection represent decision making? Yes (assuming the bettor had already ruled out the "do-nothing" alternative of not betting). But the method of deciding seems inadequate and irrational. We want to deal with rational decision making.

Rational Decision Making

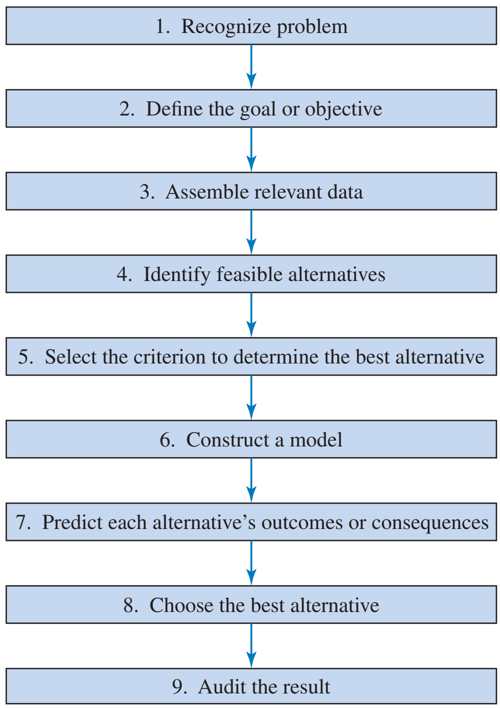
Rational decision making is a complex process that contains nine essential elements, which are shown in Figure 1–1. Although these nine steps are shown sequentially, it is common for a decision maker to repeat steps, take them out of order, and do steps simultaneously. For example, when a new alternative is identified more data will be required. Or when the outcomes are summarized, it may become clear that the problem needs to be redefined or new goals established.

The value of this sequential diagram is to show all the steps that are usually required, and to show them in a logical order. Occasionally we will skip a step entirely. For example, a new alternative may be so clearly superior that it is immediately adopted at Step 4 without further analysis. The following sections describe the elements listed in Figure 1–1.

1. Recognize the Problem

The starting point in rational decision making is recognizing that a problem exists.

FIGURE 1–1 One possible flowchart of the decision process.



Some years ago, for example, it was discovered that several species of ocean fish contained substantial concentrations of mercury. The decision-making process began with this recognition of a problem, and the rush was on to determine what should be done. Research revealed that fish taken from the ocean decades before and preserved in laboratories also contained similar concentrations of mercury. Thus, the problem had existed for a long time but had not been recognized.

In typical situations, recognition is obvious and immediate. An auto accident, an overdrawn check, a burned-out motor, an exhausted supply of parts all produce the recognition of a problem. Once we are aware of the problem, we can solve it as best we can. Many firms establish programs for total quality management (TQM) or continuous process improvement (CPI) that are designed to identify problems so that they can be solved.

2. Define the Goal or Objective

The goal or objective can be an overall goal of a person or a firm. For example, a personal goal could be to lead a pleasant and meaningful life, and a firm's goal is usually to operate profitably. The presence of multiple, conflicting goals is often the foundation of complex problems.

But an objective need not be an overall goal of a business or an individual. It may be quite narrow and specific: "I want to pay off the loan on my car by May," or "The plant must produce 300 golf carts in the next 2 weeks," are more limited objectives. Thus, defining the objective is the act of exactly describing the task or goal.

3. Assemble Relevant Data

To make a good decision, one must first assemble good information. In addition to all the published information, there is a vast quantity of information that is not written down anywhere but is stored as individuals' knowledge and experience. There is also information that remains ungathered. A question like "How many people in your town would be interested in buying a pair of left-handed scissors?" cannot be answered by examining published data or by asking any one person. Market research or other data gathering would be required to obtain the desired information.

From all this information, what is relevant in a specific decision-making process? Deciding which data are important and which are not may be a complex task. The availability of data further complicates this task. Published data are available immediately at little or no cost; other data are available from specific knowledgeable people; still other data require surveys or research to assemble the information. Some data will be of high quality—that is, precise and accurate, while other data may rely on individual judgment for an estimate.

If there is a published price or a contract, the data may be known exactly. In most cases, the data is uncertain. What will it cost to build the dam? How many vehicles will use the bridge next year and twenty years from now? How fast will a competing firm introduce a competing product? How will demand depend on growth in the economy? Future costs and revenues are uncertain, and the range of likely values should be part of assembling relevant data.

The problem's time horizon is part of the data that must be assembled. How long will the building or equipment last? How long will it be needed? Will it be scrapped, sold, or shifted to another use? In some cases, such as for a road or a tunnel, the life may be centuries with regular maintenance and occasional rebuilding. A shorter time period, such as 50 years, may be chosen as the problem's time horizon, so that decisions can be based on more reliable data.

In engineering decision making, an important source of data is a firm's own accounting system. These data must be examined quite carefully. Accounting data focuses on past information, and engineering judgment must often be applied to estimate current and future values. For example, accounting records can show the past cost of buying computers, but engineering judgment is required to estimate the future cost of buying computers.

Financial and cost accounting are designed to show accounting values and the flow of money—specifically **costs** and **benefits**—in a company's operations. When costs are directly related to specific operations, there is no difficulty; but there are other costs that are not related to specific operations. These indirect costs, or **overhead,** are usually allocated to a company's operations and products by some arbitrary method. The results are generally satisfactory for cost-accounting purposes but may be unreliable for use in economic analysis.

To create a meaningful economic analysis, we must determine the *true* differences between alternatives, which might require some adjustment of cost-accounting data. The following example illustrates this situation.

EXAMPLE 1–1

A firm's printing department charges the other departments for its services to recover its monthly costs. For example, the charge to run 30,000 copies for the shipping department is:

Direct labor	$228
Materials and supplies	294
Overhead costs	271
Cost to shipping department	$793

The shipping department checks with a commercial printer, which would print the same 30,000 copies for $688. The shipping department foreman wants to have the work done externally. The in-house printing department objects to this. The general manager has asked you to recommend what should be done.

SOLUTION

Some of the printing department's output reveals the firm's costs, prices, and other financial information. Thus, the printing department is necessary to prevent disclosing such information to people outside the firm. The firm cannot switch to an outside printer for all needs.

A review of the cost-accounting charges reveals nothing unusual. The charges made by the printing department cover direct labor, materials and supplies, and overhead. The allocation of indirect costs is a customary procedure in cost-accounting systems (see Chapter 17 for more). It can be misleading for decision making, as the following discussion indicates.

The shipping department would reduce its cost by \$105 (= \$793 – \$688) by using the outside printer. In that case, how much would the printing department's costs decline, and which solution is better for the firm?

1. *Direct Labor.* If the printing department had been working overtime, then the overtime could be reduced or eliminated. But, assuming no overtime, how much would the saving be? It seems unlikely that an employee could be fired or even put on less than a 40-hour work week. Thus, although there might be a \$228 saving, it is much more likely that there will be no reduction in direct labor.
2. *Materials and Supplies.* There would be a \$294 saving in materials and supplies.
3. *Allocated Overhead Costs.* There will be no reduction in the printing department's monthly overhead, and in fact the firm will incur \$50 of additional expenses in purchasing and accounting for processing the purchase order, invoice, and payment.

The firm will save \$294 in materials and supplies, will spend \$50 in purchasing and accounting, and may or may not save \$228 in direct labor if the printing department no longer does the shipping department work. The maximum saving would be $\$294 + 228 - 50 = \$472$. Either value of \$294 or \$472 is less than the \$688 the firm would pay the outside printer. The shipping department should not be allowed to send its printing to the outside printer.

Gathering cost data presents other difficulties. One way to look at the financial consequences—costs and benefits—of various alternatives is as follows.

- *Market Consequences.* These consequences have an established price in the marketplace. We can quickly determine raw material prices, machinery costs, labor costs, and so forth.
- *Extra-Market Consequences.* There are other items that are not directly priced in the marketplace. But by indirect means, a price may be assigned to these items. (Economists call these prices **shadow prices.**) Examples might be the cost of an employee injury or the value to employees of going from a 5-day to a 4-day, 40-hour week.
- *Intangible Consequences.* Numerical economic analysis probably never fully describes the real differences between alternatives. The tendency to leave out consequences that do not have a significant impact on the analysis itself, or on the conversion of the final decision into actual money, is difficult to resolve or eliminate. How does one evaluate the potential loss of workers' jobs due to automation? What is the value of landscaping around a factory? These and a variety of other consequences may be left out of the numerical calculations, but they must be considered in reaching a decision.

4. Identify Feasible Alternatives

One must keep in mind that unless the best alternative is considered, the result will always be suboptimal.[1] Two types of alternatives are sometimes ignored. First, in many situations

[1] A group of techniques called value analysis or **value engineering** is used to examine past decisions and current trade-offs in designing alternatives.

a do-nothing alternative is feasible. This may be the "Let's keep doing what we are now doing," or the "Let's not spend any money on that problem" alternative. Second, there are often feasible (but unglamorous) alternatives, such as "Patch it up and keep it running for another year before replacing it."

There is no way to ensure that the best alternative is among the alternatives being considered. One should try to be certain that all conventional alternatives have been listed and then make a serious effort to suggest innovative solutions. Sometimes a group of people considering alternatives in an innovative atmosphere—**brainstorming**—can be helpful. Even impractical alternatives may lead to a better possibility. The payoff from a new, innovative alternative can far exceed the value of carefully selecting between the existing alternatives.

Any good listing of alternatives will produce both practical and impractical alternatives. It would be of little use, however, to seriously consider an alternative that cannot be adopted. An alternative may be infeasible for a variety of reasons. For example, it might violate fundamental laws of science, require resources or materials that cannot be obtained, violate ethics standards, or conflict with the firm's strategy. Only the feasible alternatives are retained for further analysis.

5. Select the Criterion to Determine the Best Alternative

The central task of decision making is choosing from among alternatives. How is the choice made? Logically, to choose the best alternative, we must define what we mean by *best*. There must be a **criterion,** or set of **criteria,** to judge which alternative is best. Now, we recognize that *best* is on one end of the following relative subjective judgment:

Worst	Bad	Fair	Good	Better	Best

relative subjective judgment spectrum

Since we are dealing in *relative terms,* rather than *absolute values,* the choice will be the alternative that is relatively the most desirable. Consider a driver found guilty of speeding and given the alternatives of a $475 fine or 3 days in jail. In absolute terms, neither alternative is good. But on a relative basis, one simply makes the best of a bad situation.

There may be an unlimited number of ways that one might judge the various alternatives. Several possible criteria are:

- Create the least disturbance to the environment.
- Improve the distribution of wealth among people.
- Minimize the expenditure of money.
- Ensure that the benefits to those who gain from the decision are greater than the losses of those who are harmed by the decision.[2]

[2]This is the Kaldor criterion.

- Minimize the time to accomplish the goal or objective.
- Minimize unemployment.
- Maximize profit.

Selecting the criterion for choosing the best alternative will not be easy if different groups support different criteria and desire different alternatives. The criteria may conflict. For example, minimizing unemployment may require increasing the expenditure of money. Or minimizing environmental disturbance may conflict with minimizing time to complete the project. The disagreement between management and labor in collective bargaining (concerning wages and conditions of employment) reflects a disagreement over the objective and the criterion for selecting the best alternative.

The last criterion—maximize profit—is the one normally selected in engineering decision making. When this criterion is used, all problems fall into one of three categories: neither input nor output fixed, fixed input, or fixed output.

Neither input nor output fixed. The first category is the general and most common situation, in which the amount of money or other inputs is not fixed, nor is the amount of benefits or other outputs. For example:

- A consulting engineering firm has more work available than it can handle. It is considering paying the staff for working evenings to increase the amount of design work it can perform.
- One might wish to invest in the stock market, but the total cost of the investment is not fixed, and neither are the benefits.
- A car battery is needed. Batteries are available at different prices, and although each will provide the energy to start the vehicle, the useful lives of the various products are different.

What should be the criterion in this category? Obviously, to be as economically efficient as possible, we must maximize the difference between the return from the investment (benefits) and the cost of the investment. Since the difference between the benefits and the costs is simply profit, a businessperson would define this criterion as **maximizing profit.**

Fixed input. The amount of money or other input resources (like labor, materials, or equipment) is fixed. The objective is to effectively utilize them. For economic efficiency, the appropriate criterion is to maximize the benefits or other outputs. For example:

- A project engineer has a budget of $350,000 to overhaul a portion of a petroleum refinery.
- You have $300 to buy clothes for the start of school.

Fixed output. There is a fixed task (or other output objectives or results) to be accomplished. The economically efficient criterion for a situation of fixed output is to minimize the costs or other inputs. For example:

- A civil engineering firm has been given the job of surveying a tract of land and preparing a “record of survey” map.

- You must choose the most cost-effective design for a roof, an engine, a circuit, or other component.

For the three categories, the proper economic criteria are:

Category	Economic Criterion
Neither input nor output fixed	Maximize profit = value of outputs − cost of inputs.
Fixed input	Maximize the benefits or other outputs.
Fixed output	Minimize the costs or other inputs.

6. Constructing the Model

At some point in the decision-making process, the various elements must be brought together. The *objective, relevant data, feasible alternatives,* and *selection criterion* must be merged. For example, if one were considering borrowing money to pay for a car, there is a mathematical relationship between the loan's variables: amount, interest rate, duration, and monthly payment.

Constructing the interrelationships between the decision-making elements is frequently called **model building** or **constructing the model.** To an engineer, modeling may be a scaled *physical representation* of the real thing or system or a *mathematical equation,* or set of equations, describing the desired interrelationships. In economic decision making, the model is usually mathematical.

In modeling, it is helpful to represent only that part of the real system that is important to the problem at hand. Thus, the mathematical model of the student capacity of a classroom might be

$$\text{Capacity} = \frac{lw}{k}$$

where l = length of classroom, in meters
w = width of classroom, in meters
k = classroom arrangement factor

The equation for student capacity of a classroom is a very simple model; yet it may be adequate for the problem being solved.

7. Predicting the Outcomes for Each Alternative

A model and the data are used to predict the outcomes for each feasible alternative. As was suggested earlier, each alternative might produce a variety of outcomes. Selecting a motorcycle, rather than a bicycle, for example, may make the fuel supplier happy, the neighbors unhappy, the environment more polluted, and one's savings account smaller. But, to avoid unnecessary complications, we assume that decision making is based on a single criterion for measuring the relative attractiveness of the various alternatives. As will be shown in Example 1–5, one can devise a single composite criterion that is the weighted average of several different choice criteria.

To choose the best alternative, the outcomes for each alternative must be stated in a *comparable* way. Usually the consequences of each alternative are stated in terms of money, that is, in the form of costs and benefits. **Resolving the consequences** is done with all monetary and nonmonetary consequences. The consequences can also be categorized as follows:

Market consequences—where there are established market prices available

Extra-market consequences—no direct market prices, so priced indirectly

Intangible consequences—valued by judgment, not monetary prices.

In the initial problems we will examine, the costs and benefits occur over a short time period and can be considered as occurring at the same time. In other situations the various costs and benefits take place in a longer time period. The result may be costs at one point in time followed by periodic benefits. We will resolve these in the next chapter into a *cash flow diagram* to show the timing of the various costs and benefits.

For these longer-term problems, the most common error is to assume that the current situation will be unchanged for the do-nothing alternative. In reality if a firm does nothing new then current profits will shrink or vanish as a result of the actions of competitors and the expectations of customers. As another example, traffic congestion normally increases over the years as the number of vehicles increases—doing nothing does not imply that the situation will not change.

8. Choosing the Best Alternative

Earlier we said that choosing the best alternative may be simply a matter of determining which alternative best meets the selection criterion. But the solutions to most problems in economics have market consequences, extra-market consequences, and intangible consequences. Since the intangible consequences of possible alternatives are left out of the numerical calculations, they should be introduced into the decision-making process at this point. The alternative to be chosen is the one that best meets the choice criterion after considering both the numerical consequences and the consequences not included in the monetary analysis.

During the decision-making process certain feasible alternatives are eliminated because they are dominated by other, better alternatives. For example, shopping for a computer on-line may allow you to buy a custom-configured computer for less money than a stock computer in a local store. Buying at the local store is feasible, but dominated. While eliminating dominated alternatives makes the decision-making process more efficient, there are dangers.

Having examined the structure of the decision-making process, we can ask, When is a decision made, and who makes it? If one person performs *all* the steps in decision making, then she is the decision maker. *When* she makes the decision is less clear. The selection of the feasible alternatives may be the key item, with the rest of the analysis a methodical process leading to the inevitable decision. We can see that the decision may be drastically affected, or even predetermined, by the way in which the decision-making process is carried out. This is illustrated by the following example.

> Liz, a young engineer, was assigned to develop an analysis of additional equipment needed for the machine shop. The single criterion for selection was that the equipment should be the most economical, considering both initial costs and future operating costs. A little investigation by Liz revealed three practical alternatives:
>
> 1. A new specialized lathe
> 2. A new general-purpose lathe
> 3. A rebuilt lathe available from a used-equipment dealer

> A preliminary analysis indicated that the rebuilt lathe would be the most economical. Liz did not like the idea of buying a rebuilt lathe, so she decided to discard that alternative. She prepared a two-alternative analysis that showed that the general-purpose lathe was more economical than the specialized lathe. She presented this completed analysis to her manager. The manager assumed that the two alternatives presented were the best of all feasible alternatives, and he approved Liz's recommendation.

At this point we should ask: Who was the decision maker, Liz or her manager? Although the manager signed his name at the bottom of the economic analysis worksheets to authorize purchasing the general-purpose lathe, he was merely authorizing what already had been made inevitable, and thus he was not the decision maker. Rather Liz had made the key decision when she decided to discard the most economical alternative from further consideration. The result was a decision to buy the better of the two *less economically desirable* alternatives.

9. Audit the Results

An audit of the results is a comparison of what happened against the predictions. Do the results of a decision analysis reasonably agree with its projections? If a new machine tool was purchased to save labor and improve quality, did it? If so, the economic analysis seems to be accurate. If the savings are not being obtained, what was overlooked? The audit may help ensure that projected operating advantages are ultimately obtained. On the other hand, the economic analysis projections may have been unduly optimistic. We want to know this, too, so that the mistakes that led to the inaccurate projection are not repeated. Finally, an effective way to promote *realistic* economic analysis calculations is for all people involved to know that there *will* be an audit of the results!

ETHICS

You must be mindful of the ethical dimensions of engineering economic analysis and of your engineering and personal decisions. This text can only introduce the topic, and we hope that you will explore this subject in greater depth.

Ethics can be described variously; however, a common thread is the concept of distinguishing between right and wrong in decision making. Ethics includes establishing systems of beliefs and moral obligations, defining values and fairness, and determining duty and guidelines for conduct. Ethics and ethical behavior are important because when people behave in ethical ways, individuals and society benefit. Usually the ethical choice is reasonably clear, but there are ethical dilemmas with conflicting moral imperatives. Consider an overloaded and sinking lifeboat. If one or more passengers are thrown into the shark-infested waters, the entire lifeboat can be saved. How is the decision made, how is it implemented, and who if anyone goes into the water? Ethical dilemmas also exist in engineering and business contexts. Ethical decision making requires the understanding of problem context, choices, and associated outcomes.

Ethical Dimensions in Engineering Decision Making

Ethical issues can arise at every stage of the integrated process for engineering decision making described in Figure 1–1. Ethics is such an important part of professional and business decision making that ethical codes or standards of conduct exist for professional engineering societies, small and large organizations, and every individual. Written professional codes are common in the engineering profession, serving as a reference basis for new engineers and a basis for legal action against engineers who violate the code.

One such example is the Code of Ethics of the National Society of Professional Engineers (NSPE). Here is NSPE's fundamental canon of ethical behavior for engineering:

Engineers, in the fulfillment of their professional duties, shall:

- Hold paramount the safety, health and welfare of the public.
- Perform services only in areas of their competence.
- Issue public statements only in an objective and truthful manner.
- Act for each employer or client as faithful agents or trustees.
- Avoid deceptive acts.
- Conduct themselves honorably, responsibly, ethically and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

In addition, NSPE has Rules of Practice and Professional Obligations for its members. Most engineering organizations have similar written standards. For all engineers difficulties arise when they act contrary to these written or internal codes, and opportunities for ethical dilemmas are found throughout the engineering decision-making process. Table 1–1 provides examples of ethical lapses that can occur at each step of the decision-making process.

TABLE 1–1 Example Ethical Lapses by Decision Process Step

Decision Process Step	Example Ethical Lapses
1. Recognize the problem	• "Looking the other way," that is, not to recognize the problem—due to bribes or perhaps fear of retribution for being a "whistle-blower"
2. Define the goal or objective	• Favoring one group of stakeholders by focusing on their objective for a project
3. Assemble relevant data	• Using faulty or inaccurate data
4. Identify feasible alternatives	• Leaving legitimate alternatives out of consideration
5. Select the criterion to determine the best alternative	• Considering only monetary consequences when there are other significant consequences
6. Construct a model	• Using a short horizon that favors one alternative over another
7. Predict each alternative's outcomes or consequences	• Using optimistic estimates for one alternative and pessimistic ones for the other alternatives
8. Choose the best alternative	• Choosing an inferior alternative, one that is unsafe, adds unnecessary cost for the end user, harms the environment, etc.
9. Audit the result	• Hiding past mistakes

Ethical dilemmas for engineers may arise in connection with engineering economic analysis in many situations. Following are examples of a few of these.

Gaining Knowledge and Building Trust Versus Favors for Influence

Consider these three situations:

- The salesman for a supplier of HVAC (heating, ventilating, and air conditioning) equipment invites a mechanical engineer and spouse to come along on the company jet for a users' conference at a vacation resort.
- Same salesman and same engineer, but the invitation is for a day of golfing at an exclusive club.
- Same salesman invites the same engineer to lunch.

In each case the salesman is trying to "get the order," and there is likely to be some mix of business—discussing specifications—and pleasure. The first case, which brings up the largest ethical questions, also has the largest business justification. This is the opportunity to meet other users of the products and see displays of the product line. Often, firms and government agencies have strict guidelines that dictate behavior in these situations.

Cost, Quality, and Functionality

One of the most common conflicts in the conceptual and design phase involves the trade-offs between cost, quality, and required functionality. Most modern products entail many thousands of decisions by designers that ultimately affect the cost and quality for the end user.

- A designer in an engineering consulting firm knows that a "gold-plated" solution would be very profitable for his firm (and for his bonus). This solution may also provide excellent reliability and require little maintenance cost.
- Engineers in the consumer durables division of a multinational company know that by using lower-quality connectors, fasteners, and subcomponents they can lower costs and improve the firm's market position. In addition, they know that these design elements have only a limited usable life, and the firm's most profitable business is repairs and extended warranties.

The Environment We Live In

Projects for transportation and power generation typically must consider environmental impacts in their design and in deciding whether the project should be done in any form. Who incurs the costs for the project, and who receives the benefits? Many other engineering products are designed to promote recycling, reduce energy usage, and reduce pollution. Ethical issues can be particularly difficult because there are often stakeholders with opposing viewpoints, and some of the data may be uncertain and hard to quantify.

Green engineering design includes the effects of environmental impacts and gives consideration to life-cycle sustainability issues. In this context, **societal costs** are the negative impacts of a project or product. Reducing these societal costs is the goal of environmental fees and regulation. For the opening vignette on electric vehicles, examples of the social costs of combustion-engine automobiles include tailpipe emissions and the negative environmental impact of mining, refining, and distributing gasoline/diesel fuels. Other examples of difficult choices include:

- Protecting the habitat of an endangered species versus flood control projects that protect people, animals, and structures.
- Meeting the needs for electrical power when all choices have some negative environmental impacts:
    - Hydroelectric—reservoir covers land and habitat
    - Coal—underground mining can be dangerous, open-pit mining damages habitat, and burning the coal can cause air pollution
    - Nuclear—disposal of radioactive waste
    - Fuel oil—air pollution and economic dependence
    - Wind—visual pollution of wind farms; birds killed by whirling blades
- Determining standards for pollutants: Is 1 part per million OK, or is 1 part per billion needed?

Safety and Cost

Some of the most common and most difficult ethical dilemmas involve trade-offs between safety and cost. If a product is "too safe," then it will be too expensive, and it will not be used. Also sometimes the cost is incurred by one party and the risk by another.

- Should the oil platform be designed for the 100-year, 500-year, or 1000-year hurricane?
- Should the auto manufacturer add run-flat tires, stability control, side-cushion airbags, and rear-seat airbags to every car?
- Should a given product design go through another month of testing?
- Are stainless steel valves required, or is it economically better to use less corrosion-resistant valves and replace them more frequently?

Emerging Issues and "Solutions"

Breaches of the law by corporate leaders of Enron, Tyco, and other firms have led to attempts to prevent, limit, and expose financial wrongdoing within corporations. One part of the solution has been the Sarbanes–Oxley Act of 2002, which imposed requirements on firm executives and auditing accounting firms, as well as penalties for violations.

Globalization is another area of increasing importance for ethical considerations. One reason is that different ethical expectations prevail in the world's various countries and regions. A second reason is that jobs may be moved to another country based on differences in cost, productivity, environmental standards, and so on. What may be viewed as a sweatshop from a U.S. perspective may be viewed as a wonderful opportunity to support many families from the perspective of a less developed nation.

Importance of Ethics in Engineering and Engineering Economy

Many times engineers and firms try to act ethically, but mistakes are made—the data were wrong, the design was changed, or the operating environment was different than expected. In other cases, a choice was made between expediency (profit) and ethics. For example, some engineers and managers within VW chose to manipulate diesel vehicle performance during emission testing. Estimates of international costs to VW exceeded $38B. The firm and management are driven by the need to make a profit, and they expect the engineer to identify when safety will be compromised.

Ethics in engineering economic analysis focuses on how well and how honestly the decision-making process is conducted—the data, method of analysis, recommendations, and follow-up. The first step in avoiding problems is to recognize that ethical issues exist and to make them an explicit part of your decision-making process.

As a student, you've no doubt heard discussions about cheating on exams, plagiarism on written reports, violating university drinking and drug use policies, accepting one job while continuing to interview for others, and selling student sports tickets to nonstudents. You've made your own decisions about your behavior, and you've established patterns of behavior.

You should know that your professors care deeply about the ethical decisions you make at school. Your ethical habits there form a foundation for the character of your work and personal behavior after graduation.

Often recent engineering graduates are asked, "What is the most important thing you want from your supervisor?" The most common response is mentoring and opportunities to learn and progress. When employees with 5, 15, 25, or more years of experience are asked the same question, the most common response at all experience levels is *integrity*. This is what your subordinates, peers, and superiors will expect and value the most from you. Integrity is the foundation for long-term career success.

ENGINEERING DECISION MAKING FOR CURRENT COSTS

Some of the easiest forms of engineering decision making deal with problems of alternative *designs, methods,* or *materials.* If results of the decision occur in a very short period of time, one can quickly add up the costs and benefits for each alternative. Then, using the suitable economic criterion, the best alternative can be identified. Three example problems illustrate these situations.

EXAMPLE 1–2

A concrete aggregate mix must contain at least 31% sand by volume for proper batching. One source of material, which has 25% sand and 75% coarse aggregate, sells for $3 per cubic meter ($m^3$). Another source, which has 40% sand and 60% coarse aggregate, sells for $4.40/$m^3$. Determine the least cost per cubic meter of blended aggregates.

SOLUTION

The least cost of blended aggregates results from using just enough higher-cost material to meet the minimum 31% proportion of sand.

$$\text{Let } x = \text{Portion of blended aggregates from \$3.00/m}^3 \text{ source}$$
$$1 - x = \text{Portion of blended aggregates from \$4.40/m}^3 \text{ source}$$

Sand Balance

$$x(0.25) + (1 - x)(0.40) = 0.31$$
$$-.15x = -.09 \Rightarrow x = 0.60$$

The 60%/40% blended aggregate will cost

$$0.60(\$3.00) + 0.40(\$4.40) = 1.80 + 1.76 = \$3.56/\text{m}^3$$

EXAMPLE 1–3

A machine part is manufactured at a unit cost of 40¢ for material and 15¢ for direct labor. An investment of $500,000 in tooling is required. The order calls for 3 million pieces. Halfway through the order, managers learn that a new method of manufacture can be put into effect that will reduce the unit costs to 34¢ for material and 10¢ for direct labor—but it will require $100,000 for additional tooling. This tooling will not be useful for future orders. Other costs are allocated at 2.5 times the direct labor cost. What, if anything, should be done?

SOLUTION

Since there is only one way to handle the first 1.5 million pieces, our problem concerns only the second half of the order. While the arithmetic can easily be done on a calculator, in the real world problems like these are usually done using a spreadsheet. This allows easy substitution of "better" numbers for the initial estimates and supports **what-if analysis**. The first spreadsheet shows the data entry stage of the problem. These values form the problem's **data block** (see

	A	B	C	D	E
1	1,500,000	Number of pieces			
2	2.5	Other cost $/direct labor $			
3		A: Present Method		B: New method	
4	Costs	unit	total	unit	total
5	Material	0.4		0.34	
6	Direct labor	0.15		0.1	
7	Other				
8	Added tooling			$100,000	

Appendix A). Note that we want a clear, compact table, so columns of these values are alternated with calculation columns for our two alternatives.

The second spreadsheet includes column F to show the formulas for the cells in column E. Note that the formulas in cells E5, E6, and C6 are all copied from cell C5. Because the C5 formula was originally written as =B5*$A$1, the **absolute address** of $A$1 does not change when copied. Note: Appendix A discusses how to efficiently do this and other examples of addressing alternatives that maximize the flexibility of copying formulas.

The most efficient way to create the formulas is to:

- Write the formula for C5 as = "click on B5" ∗ "click on A1" "F4 or Apple T to toggle to $A$1"
- Copy it to C6
- Write the formula for C7 (including an absolute address)
- Copy C5:C7 to E5:E7

Select E5:E9 and click on the "sum" formula button. This can be copied to C9.

	A	B	C	D	E	F
1	1,500,000	Number of pieces				
2	2.5	Other cost $/direct labor $				
3		A: Present Method		B: New method		
4	Costs	unit	total	unit	total	
5	Material	0.4	$600,000	0.34	$510,000	=D5*$A$1
6	Direct labor	0.15	$225,000	0.1	$150,000	=D6*$A$1
7	Other		$562,500		$375,000	=E6*$A$2
8	Added tooling			$100,000	$100,000	
9	Total		$1,387,500		$1,135,000	
10			Possible savings		$252,500	

Looking at the results, we can see that much of the total $252,500 in savings comes from the reduced value of other costs. Thus, before making a final decision, one should closely examine the *other costs* to see whether they do, in fact, vary as the *direct labor cost* varies. Assuming they do, the decision would be to change the manufacturing method.

EXAMPLE 1–4

Two different liquid filter systems are being studied to clarify a liquid stream. A traditional filter will operate for one 8-hour shift before being replaced. A special pleated design can last one full week, operating 24 hours a day (3 shifts), 5 days per week. Labor cost to change a filter is estimated to be worth $10.00 for each filter change because a mechanic would work overtime to change the filter. The traditional filters cost $3.50; the special pleated filters cost $90.00. Which filter should be chosen?

SOLUTION

Material costs

Traditional: $\frac{\$3.50}{\text{filter change}} \times \frac{\text{3 filter changes}}{\text{day}} \times \frac{\text{5 days}}{\text{week}} = \$52.50/\text{week}$

Special: $\frac{\$90.00}{\text{filter change}} \times \frac{\text{1 filter change}}{\text{week}} = \$90.00/\text{week}$

Labor costs

Traditional: $\frac{\$10.00}{\text{filter change}} \times \frac{\text{3 filter changes}}{\text{day}} \times \frac{\text{5 days}}{\text{week}} = \$150.00/\text{week}$

Special: $\frac{\$10.00}{\text{filter change}} \times \frac{\text{1 filter change}}{\text{week}} = \$10.00/\text{week}$

Total costs

Traditional: $\$52.50 + \$150.00 = \$202.50/\text{week}$

Special: $\$90.00 + \$10.00 = \$100.00/\text{week}$

The special pleated filter offers a lower total cost alternative. Even though material costs are higher, these are offset by lower labor costs. When comparing alternatives, it is important to include all relevant costs.

WHEN MORE THAN ECONOMICS IS INVOLVED

Consider the moderately complex problem of which job offer to accept. Example 1–5 shows a simple way to address this **multiple-objective** problem. These models should:

- Include all important objectives.
- Weight the relative importance of the objectives.
- Select an objective and rate all alternatives. Then repeat for all objectives.
- Disqualify alternatives that do not meet the minimum performance requirements of one or more objectives.

This example uses simple 0 to 10 rating scales. Since the weights are stated as percentages (or their decimal equivalents), the totals show how close to a perfect 10 each alternative is.

Multi-objective models do much more than calculate a measure of each alternative's attractiveness. Constructing the model enforces a level of clarity about the importance of each objective and how each alternative performs. The model also communicates those assumptions and estimates to others, who may suggest changes. Since there may be multiple iterations in arriving at the final model, spreadsheets are particularly effective here.

Examples in later chapters will show how to convert numeric values to a 0 to 10 point scale. For those who want to search the web for additional examples, this is an *additive* model, because the scores are added together. This is also a *compensatory* model, because strength on one objective can compensate for a weakness on another objective.

Example 1–5 is linked to an individual's financial and life decision making. But this situation can also be viewed from the firm's or government agency's perspective. Which applicant(s) should receive offer(s) of employment? In that case, evaluations from multiple individuals might be combined for the overall total.

EXAMPLE 1–5

A senior undergraduate has received four job offers, but the salary on one is unacceptably low. The other three offers have been rated on three criteria or objectives, with a scale of 0 = barely acceptable and 10 = outstanding! *Job* considers the salary relative to the local cost of housing and the job itself. The latter was hard to estimate because it considered the initial job, growth prospects, the firm, and the industry. *Family* is important to this senior, but the senior wanted to live the right distance away—neither too close nor too far. *Livability* covers the senior's desires on community size, climate, commuting time, and overall political balance. The senior weighted the importance of the three criteria at 50%, 30%, and 20% respectively. Given the following table of ratings, which job offer should the senior accept?

Offer	Job	Family	Livability
A	4	9	5
B	8	5	4
C	6	3	8

SOLUTION

None of the job offers is ideal in any respect, and each has some aspect that is less attractive than the other offers. Comparing the total values, offer B is the most attractive. This table is the result of many hours of thinking, and more model iterations would not be useful. Thus offer B should be accepted.

There are many ways to write the formula, but the easiest uses the function SUMPRODUCT. As shown, the function uses a fixed address for the weights, so the formula for offer A can be copied for the other offers.

	A	B	C	D	E
1		Job	Family	Livability	
2	Weight	50%	30%	20%	
3	Offer				Total
4	A	4	9	5	5.7
5	B	8	5	4	6.3
6	C	6	3	8	5.5
7					
8		=SUMPRODUCT($B$2:$D$2,B4:D4)			

SUMMARY

Classifying Problems

Many problems are simple and thus easy to solve. Others are of intermediate difficulty and need considerable thought and/or calculation to properly evaluate. These intermediate problems tend to have a substantial economic component and to require economic analysis. Complex problems, on the other hand, often contain people elements, along with political and economic components. Economic analysis is still very important, but the best alternative must be selected by considering all criteria—not just economics.

The Decision-Making Process

Rational decision making uses a logical method of analysis to select the best alternative from among the feasible alternatives. The following nine steps can be followed sequentially, but decision makers often repeat some steps, undertake some simultaneously, and skip others altogether.

1. Recognize the problem.
2. Define the goal or objective: What is the task?
3. Assemble relevant data: What are the facts? Is more data needed, and is it worth more than the cost to obtain it?
4. Identify feasible alternatives.
5. Select the criterion for choosing the best alternative: possible criteria include political, economic, environmental, and social. The single criterion may be a composite of several different criteria.
6. *Mathematically model* the various interrelationships.
7. Predict the outcomes for each alternative.
8. Choose the best alternative.
9. Audit the results.

Engineering decision making refers to solving substantial engineering problems in which economic aspects dominate and economic efficiency is the criterion for choosing from among possible alternatives. It is a particular case of the general decision-making process. Some of the unusual aspects of engineering decision making are as follows:

1. Cost-accounting systems, while an important source of cost data, contain allocations of indirect costs that may be inappropriate for use in economic analysis.
2. The various consequences—costs and benefits—of an alternative may be of three types:
   (a) Market consequences—there are established market prices.
   (b) Extra-market consequences—there are no direct market prices, but prices can be assigned by indirect means.
   (c) Intangible consequences—valued by judgment, not by monetary prices.
3. The economic criteria for judging alternatives can be reduced to three cases:
   (a) When neither input nor output is fixed: maximize profit, which equals the difference between benefits and costs.

(b) For fixed input: maximize benefits or other outputs.

(c) For fixed output: minimize costs or other inputs.

The first case states the general rule from which both the second and third cases may be derived.

4. To choose among the alternatives, the market consequences and extra-market consequences are organized into a cash flow diagram. We will see in Chapter 3 that engineering economic calculations can be used to compare differing cash flows. These outcomes are compared against the selection criterion. From this comparison *plus* the consequences not included in the monetary analysis, the best alternative is selected.
5. An essential part of engineering decision making is the postaudit of results. This step helps to ensure that projected benefits are obtained and to encourage realistic estimates in analyses.

Importance of Ethics in Engineering and Engineering Economy

One of the gravest responsibilities of an engineer is protecting the safety of the public, clients, and/or employees. In addition, the engineer can be responsible for the economic performance of projects and products on which bonuses and jobs depend. Not surprisingly, in this environment one of the most valued personal characteristics is integrity.

Decision Making with Current Costs

When all costs and benefits occur within a brief period of time, the time value of money is not a consideration. We still must use the criteria of maximizing profit, minimizing cost, or maximizing benefits.

PROBLEMS

Key to icons: A = Answer in Appendix E; G = Green, which may include environmental ethics; E = Ethics other than green; = autograded problems that are available online in Dashboard.

Many end-of-chapter problems are primarily numerical, but others require more discussion—especially the case studies and questions linked to ethics. Section C in Chapter 2 of *Cases in Engineering Economy* 2nd on the student website may be helpful for the more discussion-oriented questions.

Decision Making

1-1 Think back over your past academic year and decisions that you made. List a few decisions that you would classify as simple, intermediate, and complex. What did you learn about your decision making by the way you approached these decisions?

1-2 A G Some of the following problems would be suitable for solution by engineering economic analysis. Which ones are they?

(*a*) Would it be better to buy a hybrid car?

(*b*) Should an automatic machine be purchased to replace three workers now doing a task by hand?

(*c*) Would it be wise to enroll for an early morning class to avoid traveling during the morning traffic rush hours and thus improve fuel efficiency?

(*d*) Would you be better off if you changed your major?

(*e*) Should you work more and borrow less even if it delays your graduation?

(*f*) Should a corporate farm build waste mitigation ponds or continue using a contracted service?

1-3 Which one of the following problems is *most* suitable for analysis by engineering economic analysis?

(*a*) One of your two favorite sandwich shops offers a 10-punch loyalty card and the other does not. Where should you stop today?

(*b*) A woman has $150,000 in a bank checking account that pays no interest. She can either invest it immediately at a desirable interest rate or wait a week and know that she will be able to obtain an interest rate that is 0.15% higher.

(*c*) Joe backed his car into a tree, damaging the fender. He has car insurance that will pay for the fender repair. But if he files a claim for payment, they may charge him more for car insurance in the future.

1-4 If you have $1000 and could make the right decisions, how long would it take you to become a millionaire? Explain briefly what you would do.

1-5 E One can find books on "How I Made My Millions" in any bookstore. In some cases the authors seem to plan to make millions by selling that book. Do you think this is ethical? How would you lay out the factors to analyze this question?

1-6 E The owner of a small machine shop has just lost one of his larger customers. The solution to his problem, he says, is to fire three machinists to balance his workforce with his current level of business. The owner says it is a simple problem with a simple solution.

(*a*) The three machinists disagree. Why?
(*b*) What are the ethical factors from the perspective of the owner and the workers?

1-7 G Designing a chair for use in a classroom seems like a simple task. Make an argument for how this can be considered a complex decision and include environmental and ethical factors in your argument.

1-8 Toward the end of the twentieth century, the U.S. government wanted to save money by closing a small portion of its domestic military installations. While many people agreed that saving money was a desirable goal, people in areas potentially affected by a closing soon reacted negatively. Congress finally selected a panel whose task was to develop a list of installations to close, with the legislation specifying that Congress could not alter the list. Since the goal was to save money, why was this problem so hard to solve?

1-9 The college bookstore has put pads of engineering computation paper on sale at half price. What is the minimum and maximum number of pads you might buy during the sale? Explain.

1-10 Consider the five situations described. Which one situation seems most suitable for solution by economic analysis?

(*a*) John has met two college students that interest him. Beth is a music major who is lots of fun to be with. Alice is a fellow engineering student, but she does not like to party. John wonders what to do.
(*b*) You drive periodically to the post office to send or pick up packages. The parking meters cost $1 for 15 minutes—about the time required for medium length lines. If parking fines cost $20, do you put money in the meter or not?
(*c*) The cost of car insurance varies widely from company to company. Should you check with several insurance companies when your policy comes up for renewal?
(*d*) There is a special local sales tax ("sin tax") on a variety of things that the town council would like to remove from local distribution. As a result, a store has opened up just outside the town and offers an abundance of these specific items at prices about 30% less than is charged in town. Should you shop there?
(*e*) One of your professors mentioned that you have a poor attendance record in her class. You wonder whether to drop the course now or wait to see how you do on the first midterm exam. Unfortunately, the course is required for graduation.

1-11 G A car manufacturer is considering locating an assembly plant in your region.

(*a*) List two simple, two intermediate, and two complex problems associated with this proposal.
(*b*) What is NIMBY? Does this come into play for this complex decision?

1-12 Consider the following situations. Which ones appear to represent rational decision making? Explain.

(*a*) Joe's best friend has decided to become a civil engineer, so Joe has decided that he will also become a civil engineer.
(*b*) Jill needs to get to the university from her home. She bought a car and now drives to the university each day. When Jim asks her why she didn't buy a bicycle instead, she replies, "Gee, I never thought of that."
(*c*) Don needed a wrench to replace the spark plugs in his car. He went to the local automobile supply store and bought the cheapest one they had. It broke before he had finished replacing all the spark plugs in his car.

1-13 Identify possible objectives for NASA. For your favorite of these, how should alternative plans to achieve the objective be evaluated?

1-14 E Suppose you have just 2 hours to determine how many students would be interested in a highway trash pickup event. Give a step-by-step outline of how you would proceed.

1-15 A college student determines he will have only half of the cost for university housing available for the coming year. List five feasible alternatives.

1-16 E Think about the issue of implementing renewable energies in the U.S. Research/find an instance where a decision was made to implement without adequately looking at other potential alternative solutions.

1-17 If there are only two alternatives available and both are unpleasant and undesirable, what should you do?

1-18 A The three economic criteria for choosing the best alternative are maximize the difference between output and input, minimize input, and maximize output. For each of the following situations, what is the correct economic criterion?

(*a*) A manufacturer can sell up to two full shifts of production at a fixed price. As production is increased, unit costs increase as a result of overtime pay and so forth. The manufacturer's criterion should be ______.

(*b*) An architectural and engineering firm has been awarded the contract to design a wharf with fixed performance specifications for a petroleum company. The engineering firm's criterion for its client should be ______.

(*c*) An off-campus bookstore is choosing its target used/new split for next year. Its criterion should be ______

(*d*) At an auction of antiques, a bidder for a particular porcelain statue would be trying to ______.

1-19 As in Problem 1-18, state the correct economic criterion for each of the following situations.

(*a*) The engineering student club raffled off a donated car; tickets sold for \$5 each or three for \$10. When the students were selling tickets, they noted that many people had trouble deciding whether to buy one or three tickets. This indicates the buyers' criterion was ______.

(*b*) A student organization bought a soft-drink machine and then had to decide whether to charge 75¢, \$1, or \$1.25 per drink. The organization recognized that the number of soft drinks sold would depend on the price charged. Eventually the decision was made to charge \$1. The criterion was ______.

(*c*) In many cities, grocery stores find that their sales are much greater on days when they advertise special bargains. However, the advertised special prices do not appear to increase the total physical volume of groceries sold by a store. This leads us to conclude that many shoppers' criterion is ______.

(*d*) A recently graduated engineer has decided to return to school in the evenings to obtain a master's degree. He feels it should be accomplished in a manner that will allow him the maximum amount of time for his regular day job plus time for recreation. In working for the degree, he will ______.

1-20 Seven criteria are given in the chapter for judging which is the best alternative. After reviewing the list, devise three additional criteria that might be used.

1-21 Suppose you are assigned the task of determining the route of a new highway through an older section of town. The highway will require that many older homes be either relocated or torn down. Two possible criteria that might be used in deciding exactly where to locate the highway are:

(*a*) Ensure that there are benefits to those who gain from the decision and that no one is harmed by the decision.

(*b*) Ensure that the benefits to those who gain from the decision are greater than the losses of those who are harmed by the decision.

Which criterion will you select to use in determining the route of the highway? Explain.

1-22 For the project in Problem 1-21, identify the major costs and benefits. Which are market consequences, which are extra-market consequences, and which are intangible consequences?

1-23 You must fly to another city for a Friday meeting. If you stay until Sunday morning your ticket will be \$250, rather than \$800. Hotel costs are \$200 per night. Compare the economics with reasonable assumptions for meal expenses. What intangible consequences may dominate the decision?

1-24 In the fall, Jay Thompson decided to live in a university dormitory. He signed a dorm contract under which he was obligated to pay the room rent for the full college year. One clause stated that if he moved out during the year, he could sell his dorm contract to another student who would move into the dormitory as his replacement. The dorm cost was \$6300 for the two semesters, which Jay had already paid.

A month after he moved into the dorm, he decided he would prefer to live in an apartment. That week, after some searching for a replacement to fulfill his dorm contract, Jay had two offers. One student offered to move in immediately and to pay Jay \$500 per month for the seven remaining months of the school year. A second student offered to move in the second semester and pay \$2800 to Jay.

Jay estimates his food cost per month is \$350 if he lives in the dorm and \$300 if he lives in an apartment with three other students. His share of the apartment rent and utilities will be \$450 per month. Assume each semester is $4^1/_2$ months long. Disregard the small differences in the timing of the disbursements or receipts.

(*a*) What are the three alternatives available to Jay?
(*b*) Evaluate the cost for each of the alternatives.
(*c*) What do you recommend that Jay do?

1-25 An electric motor on a conveyor burned out. The foreman told the plant manager that the motor had to be replaced. The foreman said that there were no alternatives and asked for authorization to order the replacement. In this situation, is any decision making taking place? If so, who is making the decision(s)?

1-26 G A farmer must decide what combination of seed, water, fertilizer, and pest control will be most profitable and environmentally conscious for the coming year. The local agricultural college did a study of this farmer's situation and prepared the following table.

Plan	Direct Cost/Acre	Extra-market Cost/Acre	Income/Acre
A	\$750	\$150	\$1200
B	800	450	1400
C	1000	250	1500
D	1300	200	1650

The last page of the college's study was torn off, and hence the farmer is not sure which plan the agricultural college recommends. Which plan should the farmer adopt considering:

(*a*) only the direct costs,
(*b*) both the direct and extra-market costs?

1-27 Identify the alternatives, outcomes, criteria, and process for the selection of your college major. Did you make the best choice for you?

1-28 Describe a major problem you must address in the next two years. Use the techniques of this chapter to structure the problem and recommend a decision.

1-29 Apply the steps of the decision-making process from this chapter and develop plans to achieve one each of your 5-year, 10-year, and 25-year goals.

1-30 One strategy for solving a complex problem is to break it into a group of less complex problems and then find solutions to the smaller problems. The result is the solution of the complex problem. Give an example in which this strategy will work. Then give another example in which this strategy will not work.

Ethics

1-31 E When you make professional decisions involving investments in engineering projects, what criteria will you use?
Contributed by D. P. Loucks, Cornell University

1-32 E What are ethics?
Contributed by D. P. Loucks, Cornell University

1-33 E A student accepts a full-time job in November, but a better job comes before graduation in May. What are the ethical dimensions of the student's decision? Would you take the better job? Why or why not?

1-34 E Suppose you are an engineer working in a private engineering firm and you are asked to sign documents verifying information that you believe is not true. You like your work and your colleagues in the firm, and your family depends on your income. What criteria can you use to guide your decision regarding this issue?
Contributed by D. P. Loucks, Cornell University

1-35 E Find the ethics code for the professional society of your major.

(*a*) Summarize its key points.
(*b*) What are its similarities and differences in comparison to NSPE's ethics code?

1-36 E Use a personal example or a published source to analyze what went wrong or right with respect to ethics at the assigned stage(s) of the decision-making process.

(*a*) Recognize problem.
(*b*) Define the goal or objective.
(*c*) Assemble relevant data.
(*d*) Identify feasible alternatives.
(*e*) Select the criterion for determining the best alternative.
(*f*) Construct a model.
(*g*) Predict each alternative's outcomes or consequences.
(*h*) Choose the best alternative.
(*i*) Audit the result.

For problems 1–37 to 1–49:

(*a*) What ethical issues can arise—personal, business, and/or environmental?
(*b*) Use local, state, national, or international news sources to identify an example situation.
(*c*) Summarize and analyze the ethical issues, including relevant laws, regulations, codes, and processes.

1-37 G Municipal assemblies, school boards, transit boards, and municipal utility boards are responsible for public infrastructure, such as roads and schools. Especially for this responsibility, engineers bring skills, knowledge, and perspectives that can improve public decision making. Often the public role is a part-time one; engineers that fulfill it will also have full-time jobs as employees or owners of engineering firms.

1-38 G Increasing population and congestion often are addressed through road improvement projects. These may pit the interests of homeowners and business owners in the project area against the interests of people traveling through the improvement project and environmental activists.

1-39 E Stadiums for professional sports teams often involve some level of municipal support. Some businesses and home owners benefit, while others do not; some pay more in taxes, while others pay less.

1-40 E Economic development and redevelopment often require significant acreage that is assembled by acquiring smaller parcels. Sometimes this is done through simple purchase, but the property of an "unwilling seller" can be acquired through the process of eminent domain.

1-41 E State governments use a variety of advisory and regulatory bodies. Example responsibilities include oversight of professional engineering licensing and the pricing and operation of regulated utilities. Often the public role is a part-time one, and engineers that fulfill it will also have full-time jobs as employees or owners of engineering firms.

1-42 E Many engineers work in state governments, and some are in high-profile roles as legislators, department commissioners, and so on. Many of these individuals move between working in the private and public sectors.

1-43 E In the U.S., regulation of payment for overtime hours is done at the state and federal levels. Because most engineering work is accomplished through projects, it is common for engineers to be asked or required to work overtime as projects near deadlines. Sometimes the overtime is paid at time and a half, sometimes as straight time, and sometimes the engineer's salary is treated as a constant even when overtime occurs. In a particular firm, engineering interns, engineers, and partners may be treated the same or differently.

1-44 E At the federal government level, the economic consequences of decisions can be very large. Firms hire lobbyists, legislators may focus on their constituents, and advocacy organizations promote their own agendas. In addition, sometimes some of the players are willing to be unethical.

1-45 E At both state and federal levels, legislators can be involved in "pork barrel" funding of capital projects. These projects may even bypass the economic evaluation using engineering economy that normal projects are subject to.

1-46 G At the international level, a common ethics issue important to engineering and project justification is that of environmental regulation. Often different nations have different environmental standards, and a project or product might be built in either location.

1-47 E At the international level, a common ethics issue important to engineering and project justification is that of worker health and safety. Often different nations have different standards, and a project or product could be built in either location.

1-48 G At the international level, engineering decisions are critical in matters of "sustainable development," a common ethics issue.

1-49 E At the international level, questions arise about whether the U.S. ban on bribery is practical or appropriate. In some countries government workers are very poorly paid, and they can support their families only by accepting money to "grease" a process.

1-50 In the 1970s the Ford Motor Company sold its subcompact Pinto model with known design defects. In particular, the gas tank's design and location led to rupture, leaks, and explosion in low-speed, rear-impact collisions. Fifty-nine people burned to death in Pinto accidents. In a cost–benefit analysis weighing the cost of fixing the defects ($11 per vehicle) versus the firm's potential liability for lawsuits on behalf of accident victims, Ford had placed the value of a human life at $200,000. Ford eventually recalled 1.4 million Pintos to fix the gas tank problem for a cost of $30 million to $40 million. In addition the automaker ultimately paid out millions more in liability settlements and incurred substantial damage to its reputation.

(*a*) Critique Ford's actions from the perspective of the NSPE Code of Ethics.

(*b*) One well-known ethical theory, utilitarianism, suggests that an act is ethically justified if it results in the "greatest good for the greatest number" when all relevant stakeholders are considered. Did Ford's cost–benefit analysis validly apply this theory?

(*c*) What should engineers do when the product they are designing has a known safety defect with an inexpensive remedy?

Contributed by Joseph R. Herkert, North Carolina State University

1-51 The decision-making process used to launch the Challenger shuttle has been extensively analyzed. Briefly summarize the key institutional groups, how the decision was made, and the ethical principles that may have been compromised.

1-52 One of the elements in the flooding of New Orleans during Hurricane Katrina was the failure of some of the levees that protected the city. Outline the role that ethical failures by engineers may have played in this situation. How could society structure decision making to minimize such failures?

1-53 G Hurricane Sandy's flooding of New York City highlighted the vulnerability of coastal cities to extreme weather events, which are becoming more common. Strengthening and protecting infrastructure and the environment before the fact can be very expensive—and perhaps never needed. The possible availability of after-the-fact disaster aid can distort economic perspectives. Why is minimizing economic, environmental, and human costs related to extreme weather such a difficult problem for public infrastructure?

Current Costs

1-54 A A manufacturing firm has received a contract to assemble 1000 units of test equipment in the next year. The firm must decide how to organize its assembly operation. Skilled workers, at $32 per hour each, can individually assemble the test equipment in 2.7 hours per unit. Alternatively, teams of five less-skilled workers (at $22 per hour each) can assemble a unit in 0.8 hours. Which approach is more economical?

1-55 G Two manufacturing firms, located in cities 90 miles apart, both send their trucks four times a week to the other city full of cargo and return empty. Each driver costs $275 per day with benefits (the round trip takes all day) and each firm has truck operating costs of $1.20 a mile.

(*a*) How much could each firm save weekly if each sent its truck twice a week and hauled the other firm's cargo on the return trip?

(*b*) What would the savings be if there was a $0.20 per mile emissions tax on all business truck travel?

1-56 A G An oil company is considering adding a more environmentally friendly grade of fuel at its service stations. To do this, an additional 3600-gallon tank must be buried at each station. Discussions with tank fabricators indicate that the least expensive tank would be cylindrical with minimum surface area. What size tank should be ordered?

1-57 Cathy Gwynn for a class project is analyzing a "Quick Shop" grocery store. The store emphasizes quick service, a limited assortment of grocery items, and higher prices. Cathy wants to see if the store hours (currently 0600 to 0100) can be changed to make the store more profitable.

Time Period	Daily Sales in the Time Period
0600–0700	$ 40
0700–0800	70
0800–0900	120
0900–1200	400
1200–1500	450
1500–1800	500
1800–2000	600
2000–2200	200
2200–2300	50
2300–2400	85
2400–0100	40