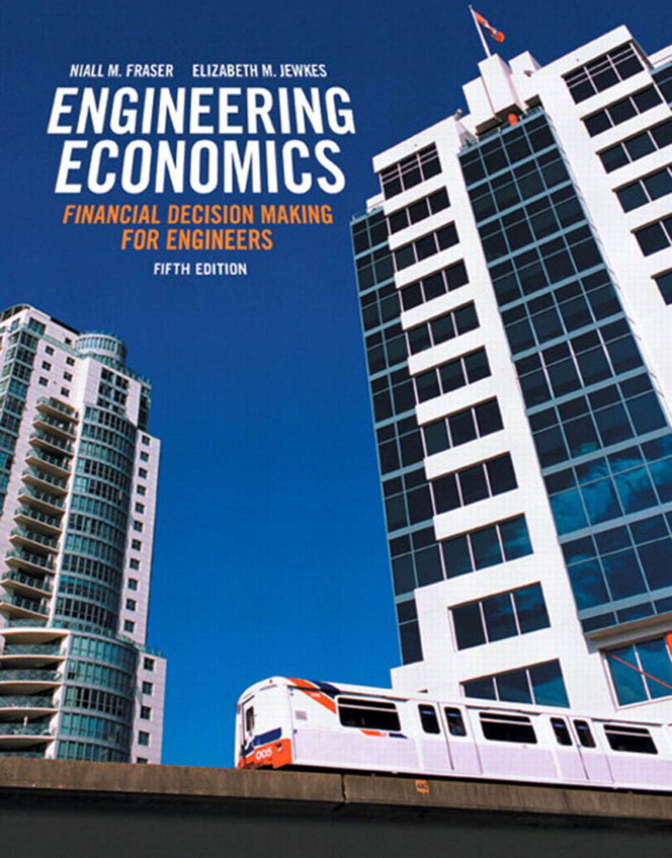
NIALL M. FRASER ELIZABETH M. JEWKES

ENGINEERING ECONOMICS

FINANCIAL DECISION MAKING FOR ENGINEERS

FIFTH EDITION



Preface

Courses on engineering economics are found in engineering curricula in Canada and throughout the world. The courses generally deal with deciding among alternative engineering projects with respect to expected costs and benefits. The topic is so fundamental to engineering knowledge that the Canadian Engineering Accreditation Board requires that all accredited professional engineering programs provide studies in engineering economics. Many engineers have found that a course in engineering economics can be as useful in their practice as any of their more technical courses.

There are several stages to making a good decision. One stage is being able to determine whether a solution to a problem is technically feasible. This is one of the roles of the engineer, who has specialized training to make such technical judgments. Another stage is deciding which of several technically feasible alternatives is best. Deciding among alternatives often does not require the technical competence needed to determine which alternatives are feasible, but it is equally important in making the final choice. Some engineers have found that choosing among alternatives can be more difficult than deciding what alternatives exist.

The role of engineers in Canadian society has changed. In the past, engineers tended to have a fairly narrow focus, concentrating on the technical aspects of a problem and on strictly computational aspects of engineering economics. As a result, many engineering economics texts focused on the mathematics of the subject. Today, engineers are more likely to be involved in many stages of an engineering project, and thus they need to be able to take into account strategic and policy issues.

This book is designed for teaching a course on engineering economics to match engineering practice in Canada today. It recognizes the role of the engineer as a decision maker who has to make and defend sensible decisions. Such decisions must not only take into account a correct assessment of costs and benefits; they must also reflect an understanding of the environment in which the decisions are made.

This book has had four previous editions. The first three editions were focussed on Engineering Economics from a Canadian perspective. Given the increasing globalization of many engineering activities, the title and content were updated in the fourth edition to reflect that engineers increasingly worked in an international setting. Feedback from our users on the fourth edition has brought the fifth edition back to its original Canadian perspective. This book has been the text of choice for many Canadian educators for over 15 years.

Canadian engineers have a unique set of circumstances that warrant a text with a specific Canadian focus. Canadian firms make decisions according to norms and standards that reflect Canadian views on social responsibility, environmental concerns, and cultural diversity. This perspective is reflected in the content and tone of much of the material in this book. Furthermore, Canadian tax regulations are complicated and directly affect engineering economic analysis. These regulations and their effect on decision making are covered in detail in Chapter 8.

This book also relates to students' everyday lives. In addition to examples and problems with an engineering focus, there are a number that involve decisions that many students might face, such as renting an apartment, getting a job, or buying a car. Other examples in the text are adapted from familiar sources such as Canadian newspapers and well-known Canadian companies.

Content and Organization

Because the mathematics of finance has not changed dramatically over the past number of years, there is a natural order to the course material. Nevertheless, a modern view of the role of the engineer flavours this entire book and provides a balanced exposure to the subject.

Chapter 1 frames the problem of engineering decision making as one involving many issues. Manipulating the cash flows associated with an engineering project is an important process for which useful mathematical tools exist. These tools form the bulk of the remaining chapters. However, throughout the text, students are kept aware of the fact that the eventual decision depends not only on the cash flows, but also on less easily quantifiable considerations of business policy, social responsibility, and ethics.

Chapters 2 and 3 present tools for manipulating monetary values over time. Chapters 4 and 5 show how students can use their knowledge of manipulating cash flows to make comparisons among alternative engineering projects. Chapter 6 provides an understanding of the environment in which the decisions are made by examining depreciation and the role it plays in the financial functioning of a company and in financial accounting. Because students frequently ask "where do the numbers come from?" we have added in this new edition a brief overview of cost estimating as an appendix to Chapter 6.

Chapter 7 deals with the analysis of replacement decisions. Chapters 8 and 9 are concerned with taxes and inflation, which affect decisions based on cash flows. Chapter 10 provides an introduction to public sector decision making.

Chapter 11, new to this edition, provides an introduction to project management. Engineers should have an appreciation of the phases that all engineering projects pass through, as well as the role engineering economics plays in evaluating the economic feasibility of a project.

Most engineering projects involve estimating future cash flows as well as other project characteristics. Since estimates can be made in error and the future is unknown, it is important for engineers to take uncertainty and risk into account as completely as possible. Chapter 12 addresses several approaches for dealing with uncertainty and risk in economic evaluations.

New to This Edition

In addition to updating material and correcting errors, we have made the following important changes in the fifth edition:

- We have introduced a **Spreadsheet Savvy** feature to each chapter. As a running theme, each feature highlights how spreadsheets and, in particular, Excel functionality, can be used to support the student as he or she learns the basic concepts covered in the chapter. The textbook does not provide a tutorial on the general use of spreadsheets; this task is left to others. However, it does highlight spreadsheet features that are relevant to the engineering economic topics contained in each chapter and instructs students on their use.

While many instructors will want to ensure that students are able to conduct the economic analysis from first principles, in practice, students should also know how to make best use of the tools commonly available in the workplace. In addition to the Spreadsheet Savvy features, for selected examples in each chapter, we have noted where Excel spreadsheets can be used to compute the answer to a problem.

- Chapter 6 now features an appendix on cost estimation. This appendix provides an overview of how cash flows are estimated and how the level of detail contained in the estimation depends on the purpose of the estimation, whether it is for early-stage project assessment or later detailed estimates for use in project monitoring and control.
- Chapter 8 on taxation has undergone a major revision in order to focus on the Canadian tax system. The current chapter benefits from the fourth edition material in that the information was reorganized around generic themes in taxation. The current chapter includes these generic themes, but now also contains an emphasis on Canadian tax rules.
- Chapters 11, 12, and 13 from the fourth edition have been combined and shortened into a new Chapter 12 entitled "Dealing with Uncertainty and Risk." We removed more advanced topics that will likely be covered in other courses and focused on key decision-making topics that will be useful for any instructor who wants to include an introduction to uncertainty and risk in decision making.
- The text has a completely new Chapter 11 on project management. This chapter responds well to the new Canadian Engineering Accreditation Board (CEAB) accreditation criteria for engineering schools to teach both economics and project management in their curricula. Chapter 11 provides introductory coverage of project management and can be used as the basis for reinforcement and mastery through subsequent course projects, team competitions, and other program components.
- We reorganized and renumbered the problem sets throughout the text. Each chapter-end problem set is divided into three categories: Key Concepts, Applications, and More Challenging Problems. These correspond well with the new CEAB requirement for learning outcome levels of "introduction," "reinforcement," and "mastery."
- Minor changes to all other chapters have been made to update and improve the overall flow and presentation of the material.

Special Features

We have created special features for this book in order to facilitate the learning of the material and an understanding of its applications:

- **Engineering Economics in Action** boxes near the beginning and end of each chapter recount the fictional experiences of a young engineer at a Canadian company. These vignettes reflect and support the chapter material. The first box in each chapter usually portrays one of the characters trying to deal with a practical problem. The second box demonstrates how the character has solved the problem by applying material discussed in the chapter above. All these vignettes are linked to form a narrative that runs throughout the book. The main character is Naomi, a recent engineering graduate. In the first chapter, she starts her job in the engineering department at Canadian Widgets and is given a decision problem by her supervisor. Over the course of the book, Naomi learns about engineering economics on the job. There are several characters, who relate to one another in various ways, exposing students to practical, ethical, and social issues as well as mathematical problems.

ENGINEERING ECONOMICS IN ACTION, PART 1A

Naomi Arrives

Naomi's first day on the job wasn't really her first day on the job. Ever since she had received the acceptance letter three weeks earlier, she had been reading and rereading all her notes about the company. Somehow she had arranged to walk past the plant entrance going on errands that never would have taken her that route in the past. So today wasn't the first time she had walked through that tidy brick entrance to the main offices of Canadian Widgets—she had done it the same way in her imagination a hundred times before.

Clement Sheng, the engineering manager who had interviewed Naomi for the job, was waiting for her at the reception desk. His warm smile and easy manner did a lot to break the ice. He suggested that they could go through the plant on the way to her desk. She agreed enthusiastically. "I hope you remember the engineering economics you learned in school," he said.

Naomi did, but rather than sound like a know-it-all, she replied, "I think so, and I still have my old textbook. I suppose you're telling me I'm going to use it."

"Yes. That's where we'll start you out, anyhow. It's a good way for you to learn how things work around here. We've got some projects lined up for you already, and they involve some pretty big decisions for Canadian Widgets. We'll keep you busy."

- **Spreadsheet Savvy** boxes in the chapters point out elements of Excel that relate to the chapter material and how Excel can be used to support the computations necessary to implement the concepts covered. From the basics of computing interest rates or the present worth of a series of cash flows to a full-blown analysis of major projects, spreadsheets help engineers compute results, evaluate alternatives, document outcomes, and make recommendations to colleagues and other stake holders.

SPREADSHEET SAVVY

A spreadsheet program is a useful way of performing calculations that are more complex than can be easily handled using a calculator. In particular, a spreadsheet program allows you to organize data into a grid and perform simultaneous calculations on rows, columns, or other subsets of the data. Spreadsheet programs are used extensively by engineers and are particularly helpful for engineering economics calculations. In this book, we will focus on the popular Microsoft Excel, but other spreadsheet programs have similar functionality.

A sample Excel spreadsheet is shown below. Each cell in the spreadsheet contains either a value (such as a number or text) or a formula. Text was entered into cells A1 and A2 to label rows 1 and 2. Then the integers 1 through 5 were entered into cells B2 through F2. Row 2 computes the cumulative sum of the values in row 1. The summation starts by entering "=B1" in cell B2. Proceeding to the right, cell C2 is the sum of B2 and C1, cell D2 is the sum of C2 and D1, and so forth.

	A	B	C	D	E	F
1	Numbers	1	2	3	4	5
2	Cumulative Sum	1	3	6	10	15

In normal use of a spreadsheet, the calculation result (as shown in row 2) appears by default. If you wish to display the formulas in a spreadsheet, click on the Formulas tab and select Show Formulas. The forumlas for the above spreadsheet are as follows:

	A	B	C	D	E	F
1	Numbers	1	2	3	4	5
2	Cumulative Sum	=B1	=B2+C1	=C2+D1	=D2+E1	=E2+F1

To return to the default display, go back to the Formulas tab and click on Show Formulas again.

- **Close-Up** boxes in the chapters present additional material about concepts that are important but not essential to the chapter.

CLOSE-UP 2.1 Interest Periods

The most commonly used interest period is one year. If we say, for example, "6 percent interest" without specifying an interest period, the assumption is that 6 percent interest is paid for a one-year period. However, interest periods can be of any duration. Here are some other common interest periods:

Interest Period	Interest Is Calculated:
Semiannually	Twice per year, or once every six months
Quarterly	Four times a year, or once every three months
Monthly	12 times per year
Weekly	52 times per year
Daily	365 times per year
Continuous	For infinitesimally small periods

- In each chapter, a **Net Value** box provides a chapter-specific example of how the internet can be used as a source of information and guidance for decision making.

NET VALUE 1.1

Professional Engineering Associations

Each of the provincial engineering associations has a website that can be a good source of information about engineering practice. At time of publication, the engineering association websites are:

Alberta: **www.apegga.com**

British Columbia: **www.apeg.bc.ca**

Engineers Canada: **www.engineerscanada.ca**

Manitoba: **www.apegm.mb.ca**

New Brunswick: **www.apegnb.ca**

Newfoundland and Labrador: **www.pegnl.ca**

North West Territories & Nunavut: **www.napegg.nt.ca**

Nova Scotia: **www.engineersnovascotia.ca**

Ontario: **www.peo.on.ca**

Prince Edward Island: **www.engineerspei.com**

Quebec: **www.oiq.qc.ca**

Saskatchewan: **www.apegs.sk.ca**

These sites contain information such as recent salary surveys, the regional code of ethics along with disciplinary actions, job advertisements, member's directory, news releases and other useful information about the practice of engineering across Canada.

Engineers Canada is a National organization of the provincial and territorial and associations that regulate the profession of engineering in Canada. Their site contains information about the programs and services that Engineers Canada supports.

The Canadian Engineering Accreditation Board (CEAB), established by Engineers Canada, accredits undergraduate engineering programs to ensure they provide the academic requirements needed for becoming a licensed professional engineer in Canada.

- At the end of each chapter, a Canadian **Mini-Case**, complete with discussion questions, relates interesting stories about how familiar Canadian companies have used engineering economic principles in practice.

MINI-CASE 4.1

Rockwell International

The Light Vehicle Division of Rockwell International makes seat-slide assemblies for the automotive industry. It has two major classifications for investment opportunities: developing new products to be manufactured and sold, and developing new machines to improve production. The overall approach to assessing whether an investment should be made depends on the nature of the project.

In evaluating a new product, it considers the following:

1. *Marketing strategy:* Does it fit the business plan for the company?
2. *Work force:* How will it affect human resources?
3. *Margins:* The product should generate appropriate profits.
4. *Cash flow:* Positive cash flow is expected within two years.

In evaluating a new machine, it considers the following:

1. *Cash flow:* Positive cash flow is expected within a limited time period.
2. *Quality issues:* For issues of quality, justification is based on cost avoidance rather than positive cash flow.
3. *Cost avoidance:* Savings should pay back an investment within one year.

Additional Pedagogical Features

- Each chapter begins with a **list of the major sections** to provide an overview of the material that follows.
- **Key terms** are boldfaced where they are defined in the body of the text. For easy reference, all these terms are defined in a glossary near the back of the book.
- Additional material is presented in **chapter appendices** at the ends of Chapters 3, 4, 6, 8, 9, and 12.
- Numerous worked-out **Examples** are given throughout the chapters. Although the decisions have often been simplified for clarity, most of them are based on real situations encountered in the authors' consulting experiences.
- Worked-out **Review Problems** near the end of each chapter provide more complex examples that integrate the chapter material.
- A concise prose **Summary** is given for each chapter.
- Each chapter has 30 to 50 **Problems** of various levels of difficulty covering all of the material presented. Like the worked-out Examples, many of the problems have been adapted from real situations.
- A **spreadsheet icon** indicates where examples involve the use of spreadsheets, which are available on the Instructor's Resource Centre.
- **Tables of Interest Factors** are provided in Appendix A
- **Answers to Selected Problems** are provided in Appendix B.
- For convenience, a **List of Symbols** used in the book is given on the inside of the front cover, and a **List of Formulas** is given on the inside of the back cover.

Course Designs

This book is ideal for a one-term course, but with supplemental material it can also be used for a two-term course. It is intended to meet the needs of students in all engineering programs, including, but not limited to, aeronautical, chemical, computer, electrical, industrial, mechanical, mining, and systems engineering. Certain programs emphasizing public projects may wish to supplement Chapter 10, "Public Sector Decision Making," with additional material.

A course based on this book can be taught in the first, second, third, or fourth year of an engineering program. The book is also suitable for college technology programs. No more than high school mathematics is required for a course based on this text. The probability theory required to understand and apply the tools of uncertainty and risk analysis is provided in Chapter 12. Prior knowledge of calculus or linear algebra is not needed.

This book is also suitable for self-study by a practitioner or anybody interested in the economic aspects of decision making. It is easy to read and self-contained, with many clear examples. It can serve as a permanent resource for practising engineers or anyone involved in decision making.

Supplements

For Students

Companion Website (www.pearsoncanada.ca/fraser): We have created a robust, password-protected Companion Website to accompany the book. It contains the following items for students and instructors:

- *Practice Quizzes* for each chapter. Students can try these self-test questions, send their answers to an electronic grader, and receive instant feedback. These quizzes were revised for the fifth edition by Claude Théoret at the University of Ottawa.
- *Additional Challenging Problems* with selected solutions. These problems created by John Jones at Simon Fraser University, were provided on the CD-ROM in the previous edition.
- *Excel spreadsheets* for selected Spreadsheet Savvy discussions, examples (designated by a spreadsheet icon in the book), and problems.
- *Chapter 13*, *"Qualitative Considerations and Multiple Criteria"* from our Fraser et al., *Global Engineering Economics: Financial Decision Making for Engineers* Fourth Edition.
- *Extended Cases*
- *Interest Tables:*
  - Compound Interest Factors for Continuous Compounding, Discrete Cash Flows
  - Compound Interest Factors for Continuous Compounding, Continuous Compounding Periods
- *Glossary Flashcards*
- *Pearson eText.* Pearson eText gives students access to the text whenever and wherever they have access to the Internet. eText pages look exactly like the printed text, offering powerful new functionality for students and instructors. Users can create notes, highlight text in different colours, create bookmarks, zoom, click hyperlinked words and phrases to view definitions, and view in single-page or two-page view. Pearson eText allows for quick navigation to key parts of the eText using a table of contents and provides full-text search.

For Instructors

The following instructor supplements are available for downloading from a password-protected section of Pearson Canada's online catalogue (www.pearsoncanada.ca/highered). Navigate to your book's catalogue page to view a list of those supplements that are available. See your local sales representative for details and access.

Instructor's Solutions Manual. The Solutions Manual contains full solutions to all the problems in the book, full solutions to all the additional problems, model solutions to the extended cases on the Companion Website, teaching notes for the Mini-Cases, and Excel spreadsheets for selected examples and problems. This manual was created by the text authors.

Computerized Testbank (Pearson TestGen). This bank allows instructors to view and edit all questions, generate tests, print tests in a variety of formats, administer tests on a local area network, and have the tests graded electronically. The questions were revised for the fifth edition by Yuri Yevdokimov at the University of New Brunswick, Fredericton.

PowerPoint© Slides. PowerPoint slides have been created for each chapter and can be used to help present material in the classroom. They were revised for the fifth edition by Mark Thomas at Centennial College.

Image Library. We have compiled all of the figures and tables from the book in electronic format.

CourseSmart for Instructors. CourseSmart goes beyond traditional expectations—providing instant, online access to the textbooks and course materials you need at a lower cost for students. And even as students save money, you can save time and hassle with a digital eTextbook that allows you to search for the most relevant content at the very moment you need it. Whether it's evaluating textbooks or creating lecture notes to help students with difficult concepts, CourseSmart can make life a little easier. See how when you visit www.coursesmart.com/instructors.

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Pearson Custom Library. For enrollments of at least 25 students, you can create your own textbook by choosing the chapters that best suit your own course needs. To begin building your custom text, visit www.pearsoncustomlibrary.com. You may also work with a dedicated Pearson Custom editor to create your ideal text—publishing your own original content or mixing and matching Pearson content. Contact your local Pearson Representative to get started.

Acknowledgments

The authors wish to acknowledge the contributions of a number of individuals who assisted in the development of this text. First and foremost are the hundreds of engineering students at the University of Waterloo who have provided us with feedback on passages they found hard to understand, typographical errors, and examples that they thought could be improved. There are too many individuals to name in person, but we are very thankful to each of them for their patience and diligence.

Other individuals who have contributed strongly to previous editions of the book include Irwin Bernhardt, May Tajima, Peter Chapman, David Fuller, J.B. Moore, Tim Nye, Ron Pelot, Victor Waese, Yuri Yevdokimov, and Peggy Fraser.

During the development process for the new edition, Pearson Canada arranged for the anonymous review of parts of the manuscript by a number of very able reviewers. These reviews were extremely beneficial to us, and many of the best ideas incorporated in the final text originated with these reviewers. We can now thank them by name:

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Prashant Mhaskar	McMaster University
Juan Pernia	Lakehead University
Claude Théoret	University of Ottawa
Frank Trimnell	Ryerson University
Yuri Yevdokimov	University of New Brunswick, Fredericton

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To all of the above, thank you again for your help. To those we may have forgotten to thank, our appreciation is just as great, even if our memories fail us. Without doubt, some errors remain in this text in spite of the best efforts of everyone involved. To help us improve for the next edition, if you see an error, please let us know.

Niall M. Fraser
Elizabeth M. Jewkes

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CHAPTER 1

Engineering Decision Making

ENGINEERING ECONOMICS IN ACTION, PART 1A

Naomi Arrives

Naomi's first day on the job wasn't really her first day on the job. Ever since she had received the acceptance letter three weeks earlier, she had been reading and rereading all her notes about the company. Somehow she had arranged to walk past the plant entrance going on errands that never would have taken her that route in the past. So today wasn't the first time she had walked through that tidy brick entrance to the main offices of Canadian Widgets—she had done it the same way in her imagination a hundred times before.

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"Yes. That's where we'll start you out, anyhow. It's a good way for you to learn how things work around here. We've got some projects lined up for you already, and they involve some pretty big decisions for Canadian Widgets. We'll keep you busy."

1.1 Engineering Decision Making

Engineering is a noble profession with a long history. The first engineers supported the military using practical know-how to build bridges, fortifications, and assault equipment. In fact, the term *civil engineer* was coined to make the distinction between engineers who worked on civilian projects and engineers who worked on military problems.

In the beginning, all engineers had to know were the technical aspects of their jobs. Military commanders, for example, would have wanted a strong bridge built quickly. The engineer would be challenged to find a solution to the technical problem, and would not have been particularly concerned about the costs, safety, or environmental impacts of the project. As years went by, however, the engineer's job became far more complicated.

All engineering projects use resources, such as raw materials, money, labour, and time. Any particular project can be undertaken in a variety of ways, with each one calling for a different mix of resources. For example, an incandescent light bulb requires inexpensive raw materials and little labour, but it is inefficient in its use of electricity and does not last very long. On the other hand, a high-efficiency light bulb uses more expensive raw materials and is more expensive to manufacture, but consumes less electricity and lasts longer. Both products provide light, but choosing which is better in a particular situation depends on how the costs and benefits are compared.

Historically, as the kinds of projects engineers worked on evolved and technology provided more than one way of solving technical problems, engineers were more often faced with having to choose among alternative solutions to a problem. If two solutions both dealt with a problem effectively, clearly the less expensive one was preferred. The practical science of engineering economics was originally developed specifically to deal with determining which of several alternatives was, in fact, the most economical.

Choosing the least expensive alternative, though, is not the entire story. Though a project might be technically feasible and the most reasonably priced solution to a problem, if the money isn't available to do it, it can't be done. The engineer has to become aware of the financial constraints on the problem, particularly if resources are very limited. In addition, an engineering project can meet all other criteria, but may cause detrimental environmental effects. Finally, any project can be affected by social and political constraints. For example, a large irrigation project called the Garrison Diversion Unit in North Dakota was effectively cancelled because of political action by Canadians and environmental groups, even though over $2 000 000 000 had been spent.

Engineers today must make decisions in an extremely complex environment. The heart of an engineer's skill set is still technical competence in a particular field. This permits the determination of possible solutions to a problem. However, necessary to all engineering is the ability to choose among several technically feasible solutions and to defend that choice credibly. The skills permitting the selection of a good choice are common to all engineers and, for the most part, are independent of which engineering field is involved. These skills form the discipline of engineering economics.

1.2 What Is Engineering Economics?

Just as the role of the engineer in society has changed over the years, so has the nature of engineering economics. Originally, engineering economics was the body of knowledge that allowed the engineer to determine which of several alternatives was economically best—the least expensive, or perhaps the most profitable. In order to make this determination properly, the engineer needed to understand the mathematics governing the relationship between time and money. Most of this book deals with teaching and using this knowledge. Also, for many kinds of decisions, the costs and benefits are the most important factors affecting the decision, so concentrating on determining the economically "best" alternative is appropriate.

In earlier times, an engineer would be responsible for making a recommendation on the basis of technical and analytic knowledge, including the knowledge of engineering economics, and then a manager would decide what should be done. A manager's decision could be different from the engineer's recommendation because the manager would take into account issues outside the engineer's range of expertise. Recently, however, the trend has been for managers to become more reliant on the technical skills of the engineers, or for the engineers themselves to be the managers. Products are often very complex, manufacturing processes are fine-tuned to optimize productivity, and even understanding the market sometimes requires the analytic skills of an engineer. As a result, it is often only the engineer who has sufficient depth of knowledge to make a competent decision.

Consequently, understanding how to compare costs, although still of vital importance, is not the only skill needed to make suitable engineering decisions. One must also be able to take into account all the other considerations that affect a decision, and to do so in a reasonable and defensible manner.

Engineering economics, then, can be defined as the science that deals with techniques of quantitative analysis useful for selecting a preferable alternative from several technically viable ones.

The evaluation of costs and benefits is very important, and it has formed the primary content of engineering economics in the past. The mathematics for doing this evaluation, which is well developed, still makes up the bulk of studies of engineering economics.

However, the modern engineer must be able to recognize the limits and applicability of these economic calculations and must be able to take into account the inherent complexity of the real world.

1.3 Making Decisions

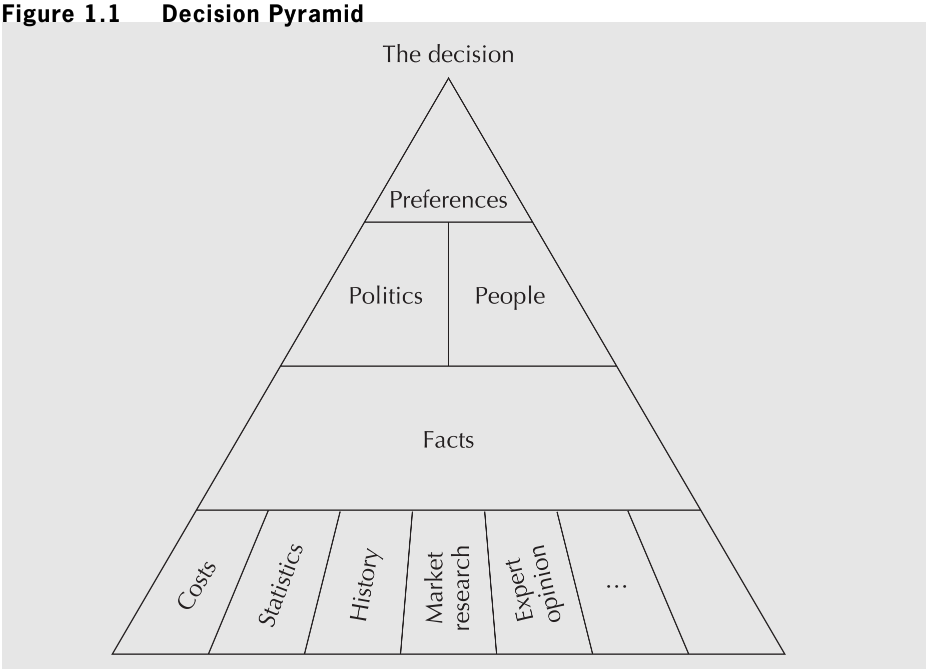
All decisions, except perhaps the most routine and automatic ones or those that are institutionalized in large organizations, are made, in the end, on the basis of belief as opposed to logic. People, even highly trained engineers, do what feels like the right thing to do. This is not to suggest that one should trust only one's intuition and not one's intellect, but rather to point out something true about human nature and the function of engineering economics studies.

Figure 1.1 is a useful illustration of how decisions are made. At the top of the pyramid are preferences, which directly control the choices made. Preferences are the beliefs about what is best, and are often hard to explain coherently. They sometimes have an emotional basis and include criteria and issues that are difficult to verbalize.

The next tier is composed of politics and people. Politics in this context means the use of power (intentional or not) in organizations. For example, if the owner of a factory has a strong opinion that automation is important, this has a great effect on engineering decisions on the plant floor. Similarly, an influential personality can affect decision making. It's difficult to make a decision without the support, either real or imagined, of other people. This support can be manipulated, for example, by a persuasive salesperson or a persistent lobbyist. Support might just be a general understanding communicated through subtle messages.

The next tier is a collection of facts. The facts, which may or may not be valid or verifiable, contribute to the politics and the people, and indirectly to the preferences. At the bottom of the pyramid are the activities that contribute to the facts. These include a

Figure 1.1 Decision Pyramid



history of previous similar decisions, statistics of various sorts, and, among other things, a determination of costs.

In this view of decisions, engineering economics is not very important. It deals essentially with facts and, in particular, with determining costs. Many other facts affect the final decision, and even then the decision may be made on the basis of politics, personality, or unstated preferences. However, this is an extreme view.

Although preferences, politics, and people can outweigh facts, usually the relationship is the other way around. The facts tend to control the politics, the people, and the preferences. It is facts that allow an individual to develop a strong opinion, which then may be used to influence others. Facts accumulated over time create intuition and experience that control our "gut feeling" about a decision. Facts, and particularly the activities that develop the facts, form the foundation for the pyramid in Figure 1.1. Without the foundation, the pyramid would collapse.

Engineering economics is important because it facilitates the establishment of verifiable facts about a decision. The facts are important and necessary for the decision to be made. However, the decision eventually made may be contrary to that suggested by analysis. For example, a study of several methods of treating effluent might determine that method A is most efficient and moderately priced, but method B might be chosen because it requires a visible change to the plant which, it is felt, will contribute to the company's image in environmental issues. Such a final decision is appropriate because it takes into account facts beyond those dealt with in the economic analysis.

ENGINEERING ECONOMICS IN ACTION, PART 1B

Naomi Settles In

As Naomi and Clement were walking, they passed the loading docks. A honk from behind told them to move aside so that a forklift could get through. The operator waved in passing and continued on with the task of moving coils of sheet metal into the warehouse. Naomi noticed shelves and shelves of packaging material, dies, spare parts, and other items that she didn't recognize. She would find out more soon enough. They continued to walk. As they passed a welding area, Clem pointed out the newest recycling project at Canadian Widgets: the water used to degrease the metal was now being cleaned and recycled rather than being used only once.

Naomi became aware of a pervasive, pulsating noise emanating from somewhere in the distance. Suddenly the corridor opened up to the main part of the plant and the noise became a bedlam of clanging metal and thumping machinery. Her senses were assaulted. The ceiling was very high and there were rows of humpbacked metal monsters unlike any presses she had seen before. The tang of mill oil overwhelmed her sense of smell, and she felt the throbbing from the floor knocking her bones together. Clem handed her hearing and eye protectors.

"These are our main press lines." Clem was yelling right into Naomi's ear, but she had to strain to hear. "We go right from sheet metal to finished widgets in 12 operations." A passing forklift blew propane exhaust at her, momentarily replacing the mill-oil odour with hot-engine odour. "Engineering is off to the left there."

As they went through the double doors into the engineering department, the din subsided and the ceiling came down to normal height. Removing the safety equipment, they stopped for a moment to get some juice at the vending machines. As Naomi looked around, she saw computers on desks more or less sectioned off by acoustic room dividers. As Clem led her farther, they stopped long enough for him to introduce Naomi to Carole Brown, the receptionist and secretary. Just past Carole's desk and around the corner was Naomi's desk. It was a nondescript metal desk with a long row of empty shelving above. Clem said her computer would arrive within the week. Naomi noticed that the desk next to hers was empty, too.

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"Am I sharing with someone?" she asked.

"Well, you will be. That's for your co-op student."

"My co-op student?"

"Yep. He's a four-month industrial placement from the university. Don't worry, we have enough to do to keep you both busy. Why don't you take a few minutes to settle in while I take care of a couple of things? I'll be back in, say, 15 minutes. I'll take you over to human resources. You'll need a security pass, and I'm sure they have lots of paperwork for you to fill out."

Clem left. Naomi sat and opened the briefcase she had carefully packed that morning. Alongside the brown-bag lunch was her engineering economics textbook. She took it out and placed it on the empty shelf above the desk. "I thought I might need you," she said to herself. "Now, let's get this place organized!"

1.4 Dealing With Abstractions

The world is far more complicated than can ever be described in words, or even thought about. Whenever one deals with reality, it is done through models or abstractions. For example, consider the following description:

> Naomi watched the roll of sheet metal pass through the first press. The die descended and punched six oval shapes from the sheet. These "blanks" dropped through a chute into a large metal bin. The strip of sheet metal jerked forward into the die and the press came down again. Pounding like a massive heart 30 times a minute, the machine kept the operator busy full-time just providing the giant coils of metal, removing the waste skeleton scrap, and stacking blanks in racks for transport to the next operation.

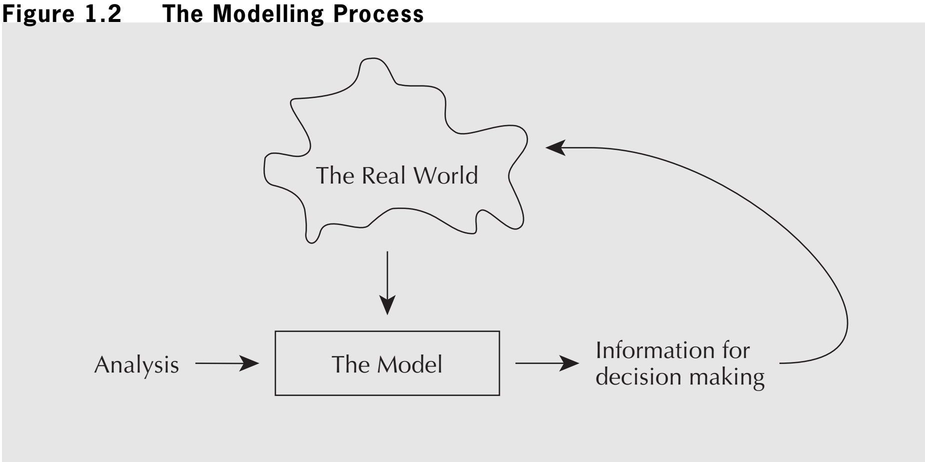
This gives a description of a manufacturing process that is reasonably complete in that it permits one to visualize the process. But it is not absolutely complete. For example, how large and thick were the blanks? How big was the metal bin? How heavy was the press? How long did it take to change a die? These questions might be answered, but no matter how many questions are asked, it is impossible to express all of the complexity of the real world. It is also undesirable to do so.

When one describes something, one does so for a purpose. In the description, one selects those aspects of the real world that are relevant to that purpose. This is appropriate, since it would be very confusing if a great deal of unnecessary information were given every time something was talked or written about. For example, if the purpose of the above description were to explain the exact nature of the blanks, there would be considerably less emphasis on the process and many more details about the blanks themselves.

This process of simplifying the complexities of the real world is necessary for any engineering analysis. For example, in designing a truss for a building, it is usually assumed that the members exhibit uniform characteristics. However, in the real world these members would be pieces of lumber with individual variations: some would be stronger than average and some would be weaker. Since it is impractical to measure the characteristics of each piece of wood, a simplification is made. As another example, the various components of an electric circuit, such as resistors and capacitors, have values that differ from their nominal specifications because of manufacturing tolerances, but such differences are often ignored and the nominal values are the ones used in calculations.

Figure 1.2 illustrates the basic process of modelling that applies in so much of what humans do, and applies especially to engineering. The world is too complicated to express completely, as represented by the amorphous shape at the top of the figure. People extract from the real world a simplification (in other words, a model) that captures information useful and appropriate for a given purpose. Once the model is developed, it is used to analyze a situation and perhaps make some predictions about the real world. The analysis

Figure 1.2 The Modelling Process



and the predictions are then related back to the real world to make sure the model is valid. As a result, the model might need some modification so that it more accurately reflects the relevant features of the real world.

The process illustrated in Figure 1.2 is exactly what is done in engineering economics. The model is often a mathematical one that simplifies a more complicated situation but does so in a reasonable way. The analysis of the model provides some information, such as which solution to a problem is cheapest. This information must always be related back to the real problem, however, to take into account the aspects of the real world that may have been ignored in the original modelling effort. For example, the economic model might not have included taxes or inflation, and an examination of the result might suggest that taxes and inflation should not be ignored. Or, as already pointed out, environmental, political, or other considerations might modify any conclusions drawn from the mathematical model.

EXAMPLE 1.1

Naomi's brother Ben has been given a one-year assignment in Whitehorse and he wants to buy a car just for the time he is there. He has three choices, as illustrated in Table 1.1. For each alternative, there is a purchase price, an operating cost (including gas, insurance, and repairs), and an estimated resale value at the end of the year. Which should Ben buy?

Table 1.1 Buying a Car

	1980 Corvette	2007 Toyota Corolla	2007 BMW 5-Series
Purchase	\$12 000	\$7000	\$25 000
Operation	\$400/month	\$300/month	\$450/month
Resale	\$13 000	\$5000	\$23 000

The next few chapters of this book will show how to take the information from Table 1.1 and determine which alternative is economically best. As it turns out, under most circumstances, the Corvette is best. However, in constructing a model of the decision, we must make a number of important assumptions.

For example, how can one be sure of the resale value of something until one actually tries to sell it? Along the same lines, who can tell what the actual maintenance costs will be? There is a lot of uncertainty about future events that is generally ignored in these kinds of calculations. Despite this uncertainty, estimates can provide insights into the appropriate decision.

Another problem for Ben is getting the money to buy a car. Ben is fairly young and would find it very difficult to raise even $7000, and perhaps impossible to raise $25 000. The Corvette might be the best value, but if the money isn't available to take advantage of the opportunity, it doesn't matter. In order to do an economic analysis, we may assume that he has the money available.

If an economic model is judged appropriate, does that mean Ben should buy the Corvette? Maybe not.

A person who has to drive to work every morning would probably not want to drive an antique car. It is too important that the car be reliable (especially in the Yukon in the winter). The operating costs for the Corvette are high, reflecting the need for more maintenance than with the other cars, and there are indirect effects of low reliability that are hard to capture in dollars.

If Ben were very tall, he would be extremely uncomfortable in the compact Toyota Corolla, so even if it were economically best, he would hesitate to resign himself to driving with his knees on either side of the steering wheel.

Ben might have strong feelings about the environmental record of one of the car manufacturers and might want to avoid driving that car as a way of making a statement.

Clearly, there are so many intangibles involved in a decision like this that it is impossible for anyone but Ben himself to make such a personal choice. An outsider can point out to Ben the results of a quantitative analysis given certain assumptions, but cannot authoritatively determine the best choice for him. ■

SPREADSHEET SAVVY

A spreadsheet program is a useful way of performing calculations that are more complex than can be easily handled using a calculator. In particular, a spreadsheet program allows you to organize data into a grid and perform simultaneous calculations on rows, columns, or other subsets of the data. Spreadsheet programs are used extensively by engineers and are particularly helpful for engineering economics calculations. In this book, we will focus on the popular Microsoft Excel, but other spreadsheet programs have similar functionality.

A sample Excel spreadsheet is shown below. Each cell in the spreadsheet contains either a value (such as a number or text) or a formula. Text was entered into cells A1 and A2 to label rows 1 and 2. Then the integers 1 through 5 were entered into cells B2 through F2. Row 2 computes the cumulative sum of the values in row 1. The summation starts by entering "=B1" in cell B2. Proceeding to the right, cell C2 is the sum of B2 and C1, cell D2 is the sum of C2 and D1, and so forth.

	A	B	C	D	E	F
1	Numbers	1	2	3	4	5
2	Cumulative Sum	1	3	6	10	15

In normal use of a spreadsheet, the calculation result (as shown in row 2) appears by default. If you wish to display the formulas in a spreadsheet, click on the Formulas tab and select Show Formulas. The formulas for the above spreadsheet are as follows:

	A	B	C	D	E	F
1	Numbers	1	2	3	4	5
2	Cumulative Sum	=B1	=B2+C1	=C2+D1	=D2+E1	=E2+F1

To return to the default display, go back to the Formulas tab and click on Show Formulas again.