EngineeringEconomics

FINANCIAL DECISION MAKING FOR ENGINEERS

SIXTH EDITION

Niall M. Fraser

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List of Symbols

$(A/F,i,N)$	sinking fund factor
$(A/G,i,N)$	arithmetic gradient to annuity conversion factor
$(A/P,i,N)$	capital recovery factor
$(F/A,i,N)$	uniform series compound amount factor
$(F/P,i,N)$	compound amount factor
$(P/A,g,i,N)$	geometric gradient to present worth conversion factor
$(P/A,i,N)$	series present worth factor
$(P/F,i,N)$	present worth factor
A	annuity amount, equivalent annual cost
A_C	current dollars in year N
A_{tot}	total annuity for arithmetic gradient to annuity conversion factor
A'	base annuity for arithmetic gradient to annuity conversion factor
AW	annual worth
B	present worth of benefits
BCR	benefit–cost ratio
BCRM	modified benefit–cost ratio
$BV_{db}(n)$	book value at end of period n using declining-balance method
$BV_{sl}(n)$	book value at end of period n using straight-line method
C	present worth of costs
CCA	capital cost allowance
CSF	capital salvage factor
CTF	capital tax factor
d	depreciation rate for declining-balance method
$D_{db}(n)$	depreciation amount for period n using declining-balance method
$D_{sl}(n)$	depreciation amount for period n using straight-line method
EAC	equivalent annual cost
ERR	external rate of return
E(X)	expected value of the random variable, X
F	future value, future worth
f	inflation rate per year
FW	future worth
g	growth rate for geometric gradient
i	current interest rate
I	interest amount
i'	real interest rate
I_c	compound interest amount

i_e	effective interest rate
i_s	interest rate per subperiod
I_s	simple interest amount
$i°$	growth adjusted interest rate
IRR	internal rate of return
$\mathbf{IRR_C}$	current dollar IRR
$\mathbf{IRR_R}$	real dollar IRR
i^*	internal rate of return
i_e^*	external rate of return
i_{ea}^*	approximate external rate of return
$I_{0,N}$	the value of a global price index at year N, relative to year 0
m	number of subperiods in a period
MARR	minimum acceptable rate of return
$\mathbf{MARR_C}$	current dollar MARR
$\mathbf{MARR_R}$	real dollar MARR
N	number of periods, useful life of an asset
P	present value, present worth, purchase price, principal amount
PW	present worth
$p(x)$	probability distribution
$\Pr\{X = x_i\}$	alternative expression of probability distribution
r	nominal interest rate, rating for a decision matrix
$R_{0,N}$	real dollar equivalent to A_N relative to year 0, the base year
S	salvage value
t	tax rate
UCC	undepreciated capital cost
X	random variable
π_{01}	Laspeyres price index

Engineering Economics

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Brief Contents

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Preface

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

There are several important stages involved in making a good decision. The viability stage identifies whether a solution to a problem is technically feasible. Appropriately, this is one of the many roles assigned to the engineer, who has the specialized training required to make such technical judgments. Another stage entails deciding which of several technically feasible alternatives is likely to be best. Deciding among alternatives often does not necessitate the technical competence needed to determine which alternatives are feasible, but it is equally essential in making the final choice. Engineers have found that choosing among competing alternatives can sometimes be more difficult than deciding what possibilities actually exist.

The role of engineers in Canadian society has changed over time. 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 mainly on the mathematics of the subject. Today, engineers are more likely to be involved in many stages of an engineering project, to be starting their own businesses, or to have varying levels of equity within an enterprise. Thus, they need to be acquainted with strategic methodology and policy issues.

This book is designed for teaching a course on engineering economics, and intended to match engineering practiced in Canada today. It recognizes the role of the engineer as a decision maker who has to make and defend sensible recommendations. Such choices 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 five previous editions. We have striven in every edition to meet and/or exceed the changing needs of our users. This has necessitated accommodating to an increasingly global perspective in business. Updates have also included changes in the expectations for engineering training, such as project management and case-based learning as required by the Canadian Engineering Accreditation Board, and responding to the fervent interest many engineering students now have in starting new innovative companies. Our adaptability and willingness to incorporate user input, is probably one of the many reasons this book has been the text of choice for Canadian educators for almost 20 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 of scenarios involving decisions that many students might face, such as renting an apartment, getting a job, or buying a car. Other references in the text are adapted from familiar sources such as Canadian newspapers and well-known Canadian companies.

Content and Organization

Since the mathematics of finance has not changed dramatically over the past number of years, there is a natural order to the presentation of 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 continually reminded that the eventual decision depends not only on the cash flows, but also relies on less easily quantifiable considerations related to business policy, social responsibility, and ethics.

Chapters 2 and 3 present tools for manipulating monetary values over time. Chapter 2 also explains the idea of depreciation. 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 focusing on two aspects of business. The first half of the chapter discusses financial accounting and the role of financial statements. The second half provides information about the uses of a business plan and how to write one.

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 presents the fundamentals of project management. It is intended to impart an appreciation of the phases that all engineering projects pass through, and to meet the requirements of the CEAB.

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 sixth edition:

- We have introduced a new segment in each chapter called Case-in-Point. Each Case-in-Point features a circumstance appropriate to the chapter material, and raises difficult and sometimes unanswerable questions. They provide an opportunity for the individual student to challenge their own thinking. They also are ideal material for initiating lively class discussions intended to enhance the students' understanding of the core topics as well as broaden their perspectives generally.

- The material in Chapter 2 has been enriched with a section on depreciation (formerly part of Chapter 6 in the previous edition). Depreciation is a practical and easy subject, and its inclusion helps balance the relatively dry basic principles and necessary fundamentals that otherwise form Chapter 2. This provides a prelude, and allows for the accommodation of the new material presented in Chapter 6.
- A completely new section has been added to Chapter 6 on business plans. Many engineers are now very interested in forming their own companies as a student or shortly after graduation. Comprehensive examples are provided in this chapter to assist students with the foundations for proposing and structuring viable business plans.
- 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 other supporting 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 receiving 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 helped 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 learnt 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."

- **Case-in-Point** boxes present material relevant to the appropriate chapter. The issues raised can be difficult, curious, and possibly disquieting. There may be no obvious "right" answer or "correct" application of principles. Students are invited to challenge rigidity and encouraged to exercise flexibility in their problem solving approaches. The questions posed are intended to be thought provoking, with the hope of inspiring lively classroom discussions and perhaps reflective contemplation. Ideally the boxes will enrich the students' understanding of the core topics and broaden their general perspectives.

CASE IN POINT 1.1 Loss of Life in Engineering Projects

Whenever an engineering project is undertaken, there are always safety risks. Injuries and accidents are often unavoidable. Although sometimes large projects are completed without loss of life, there is always the chance that the decision of proceeding with an engineering project will result in one or more deaths.

For example, a rule-of-thumb for building skyscrapers once was that one could expect to lose one life per floor of the building. This was borne out with the John Hancock Building in Chicago as late as 1970: it has 100 floors and 109 lives were lost building it. Similarly, for the construction of aqueduct tunnels to New York City in the 1930's, the rule was to expect one life lost per mile of tunnel.

In modern times, the safety record for engineering projects has improved considerably. In building the CN Tower, for example, only one man died. Three people died building the Confederation Bridge. However, no matter how careful people are, most engineering projects are dangerous, and people will likely perish.

Discussion Questions

1) What is an acceptable death rate for an engineering project?
2) How can an engineer know whether to approve a project that is sure to cause deaths that would otherwise not occur?
3) How can an engineer decide how much money to spend on improving safety in an engineering project?

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

CLOSE-UP 2.1 Financial Terminology

Annual Percentage Rate of Charge: An effective interest rate for the entire year that a borrower will pay to banks or financial institutions for a loan or on credit card debt.

Disbursement: Money paid out or spent.

Fixed term investment: An investment mechanism in which the investor is paid his/her initial investment, plus a specific amount of interest after a fixed period. The investor cannot withdraw his or her money before the fixed period without facing penalties.

GIC: A Guaranteed Investment Certificate is a specific fixed-term investment, usually issued by a Canadian bank or trust company.

Receipt: Money received or earned.

- 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:

Newfoundland and Labrador: **www.pegnl.ca**
Nova Scotia: **www.engineersnovascotia.ca**
Prince Edward Island: **www.engineerspei.com**
New Brunswick: **www.apegnb.com**
Quebec: **www.oiq.qc.ca**
Ontario: **www.peo.on.ca**
Manitoba: **www.apegm.mb.ca**
Saskatchewan: **www.apegs.sk.ca**
Alberta: **www.apega.com**
British Columbia: **www.apeg.bc.ca**
Northwest Territories & Nunavut: **www.napeg.nt.ca**
Engineers Canada: **www.engineerscanada.ca**

These sites contain information such as recent salary surveys, the regional code of ethics along with disciplinary actions, job advertisements, members' 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 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. *Workforce:* 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.

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,** like the one shown here, indicates where examples or problems involve spreadsheets, which are available on the Companion Website.
- **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 appropriately 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 necessary.

This book is also suitable for self-study by a practitioner or individuals 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.
- *Additional Challenging Problems* with selected solutions.
- *Spreadsheet Savvy* contains features which indicate elements of Excel related to the chapter material. It shows 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.
- *Excel spreadsheets* for selected Spreadsheet Savvy discussions, examples 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 online 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.

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 available supplements. 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 Test Bank. Pearson's computerized test banks allow instructors to filter and select questions to create quizzes, tests, or homework. Instructors can revise questions or add their own, and may be able to choose print or online options. These questions are also available in Microsoft Word format.

PowerPoint© Slides. PowerPoint slides have been created for each chapter and can be used to help present material in the classroom.

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

Learning Solutions Managers. Pearson's Learning Solutions Managers work with faculty and campus course designers to ensure that Pearson technology products, assessment tools, and online course materials are tailored to meet your specific needs. This highly qualified team is dedicated to helping schools take full advantage of a wide range of educational resources, by assisting in the integration of a variety of instructional materials and media formats. Your local Pearson Canada sales representative can provide you with more details on this service program.

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Peter Wylie	University of British Columbia, Okanagan Campus
Michael Bennett	University of Ontario Institute of Technology
Soha Eid Moussa	University of Guelph

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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 despite the best efforts of everyone involved. Please help us improve the next edition by notifying us of any errors. Thank you.

Niall M. Fraser
Elizabeth M. Jewkes
Mehrdad Pirnia

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CHAPTER

1

Kali9/E+/Getty Images

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 receiving 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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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, engineers only needed to know 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 with the costs, safety, or environmental impacts of the project. However, over time the engineer's job has become 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, asphalt roofing is inexpensive and easy to install, but it has negative environmental impacts and low durability. Slate roofing uses more expensive raw materials and can be difficult to install but is environmentally friendly and lasts longer. Both choices provide secure protection for a building, but choosing which is better in a particular situation depends on how the costs and benefits are compared.

Historically, as the kind of projects engineers worked on evolved, and technology provided more than one way of solving technical problems, engineers were more frequently faced with choosing 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 anticipated to be the most economical.

Choosing the least expensive alternative is not the only consideration. Even when a project may be technically feasible and the most reasonably priced solution to a problem, if adequate funding is not available, it cannot be done. The engineer has to be aware of the financial constraints on the problem, particularly if resources are very limited, and should take into account, to the degree possible, unpredictable events. For example, Darlington Nuclear Station's estimated cost was $3.9 billion in late 1970s, but after construction started in 1981, the projected cost increased to $7.4 billion. However the project actually had a final cost of $14.4 billion. The cost overruns on this project were due to the Chernobyl disaster (resulted in more expensive safety reviews), high interest rates, an economic recession, and multiple management errors (such as ordering wrong equipment, which put labor on hold for 6 months).

Another factor to consider is that an engineering project can meet all other criteria, but may cause detrimental environmental effects. The Garrison Diversion Unit was a $2 billion water diversion project that was cancelled in the 1960's because it would bring salty water and foreign fish species into Canada. Finally, any project can be affected by social and political constraints. For example, the Spadina Expressway was to be built to connect downtown Toronto to the 401 expressway north of the city but was cancelled in 1971 due to public opposition. The small part that was completed is now called the Allen Expressway. Another cancelled Toronto project was the Pickering Airport, to be build east of the city.

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, within a set of moral, social, environmental, and political criteria. 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 correctly, 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 vitally important, is not the only skill needed to make suitable engineering decisions. One must also be able to assess other significant considerations affecting the decision, and do so in a reasonable and defensible manner. Hence, engineering economics can be defined as the science dealing with techniques of quantitative analysis, useful in selecting a preferable alternative from several technically viable ones. It is a special area of the social science called economics and can also be considered as field of finance as it applies to engineering.

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.

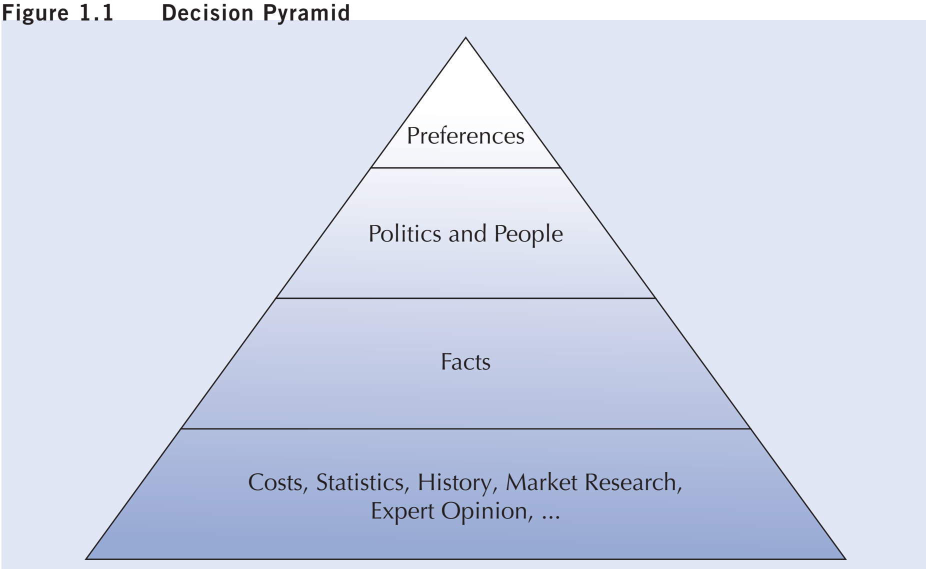
1.3 Making Decisions

All decisions, except perhaps the most routine and automatic ones or those that are institutionalized in large organizations, are likely made on the basis of beliefs as opposed to logic. Individuals, even highly trained engineers, often do what "feels right." This is not to suggest intuition instead of intellect should be trusted, but rather to point out the reality of 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 or persuasive personality can significantly affect decision making. It is difficult to implement a decision without the support, either real or imagined, of other people. Support might just be a general understanding

Figure 1.1 Decision Pyramid



communicated through subtle messages. This support can be manipulated, for example, by a convincing salesperson or a persistent lobbyist.

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 constitute the facts. These include a history of previous similar decisions, statistics of various sorts, and, among other things, a determination of costs.

In this view of decisions, engineering economics could be incorrectly seen as 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 may be chosen because it requires a visible change to the plant that could contribute positively to the company's image on 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 unrecognizable items. 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 discarded.

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 further, 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.

"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 full-time operator busy providing the giant coils of metal, removing the waste skeleton scrap, and stacking blanks in racks for transport to the next operation.

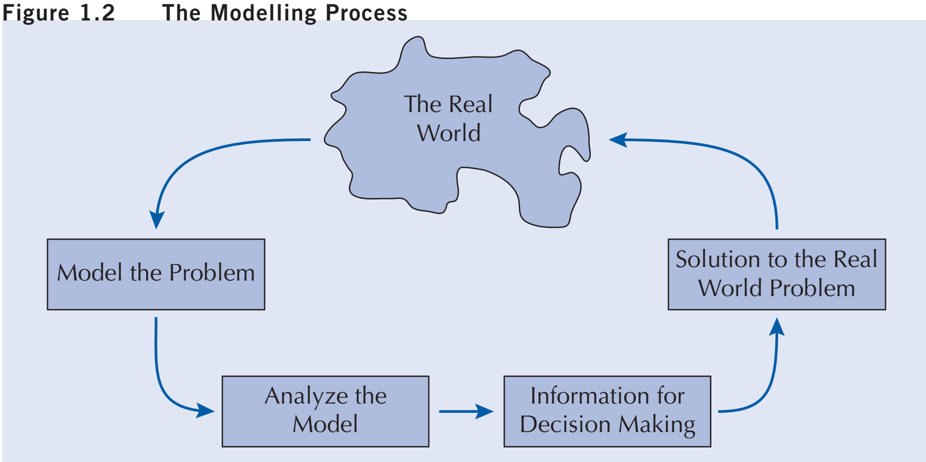
This gives a description of a manufacturing process that is reasonably complete in that it permits one to visualize the process. But it is not absolutely complete. For example, how large and thick were the blanks? How big was the metal bin? How heavy was the press? How long did it take to change a die? 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. In 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. 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

Figure 1.2 The Modelling Process



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 and 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 demonstrated in Figure 1.2 highlights 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. However, this information is related back to the real problem, to take into account aspects of the real world issue 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. Alternately, 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 car should Ben buy?

Table 1.1 Buying a Car

	1980 Chevrolet Corvette	2011 Toyota Corolla	2011 BMW 5-Series
Purchase	$12 000	$9000	$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 optimal. As it turns out, under most circumstances, the Corvette is best. However, when 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 some vagueness 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 $9000 and perhaps impossible to raise $25 000. The Corvette might be the best value, but if the money is not available to take advantage of the opportunity, it could be irrelevant. In order to do an economic analysis, we may assume he has adequate funds.

If an economic model is judged appropriate, does it 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 might be essential for the car to be reliable (especially during the Yukon winter). The operating costs for the Corvette are high, reflecting the need for more maintenance than with the other cars. Also, there are indirect effects of potential inconvenience and low reliability that may be difficult to capture as a dollar value.

If Ben were very tall, he would be extremely uncomfortable in the compact Toyota Corolla. Hence, 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, the number of potential unknowns and intangibles make it almost impossible for anyone but Ben himself to make such a personal decision. An outsider can point out the results of a quantitative analysis given certain assumptions but cannot authoritatively determine the best choice for him. ■

1.5 The Moral Question: Three True Stories

Complex decisions often have an ethical component. Recognizing this component is important for engineers since society relies on them for so many things. The following three anecdotes concern real companies—although names and details have been altered for anonymity—and illustrate some extreme examples of the forces acting on engineering decision making.

EXAMPLE 1.2

The process of making sandpaper is similar to that of making a photocopy. A two-metre-wide roll of paper is coated with glue and given a negative electric charge. It is then passed over sand (of a particular type) that has a positive charge. The sand is attracted to the paper and sticks on the glue. The fact that all the bits of sand have the same type of charge ensures that the grains are evenly spaced. The paper then passes through a long, heated chamber to cure the glue. Although the process sounds fairly simple, the machine that does this, called a maker, is very complicated and expensive. One such machine, costing several million dollars, can support a factory employing hundreds of workers.

Preston Sandpapers, a subsidiary of a large firm, is located in a small town. Its maker was almost 30 years old and desperately needed replacement. However, rather than replace it, the parent company might have chosen to close down the plant and transfer production to one of its sister plants located in a different country.

The chief engineer had a problem. The costs for installing a new maker were extremely high, and it was difficult to justify a new maker economically. However, if he could not do so, the plant would close and hundreds of workers would be out of a job, including perhaps himself. What he chose to do was lie. He fabricated figures, ignored important costs, and exaggerated benefits to justify the expenditures. The investment was made and the plant is still operating. ■

EXAMPLE 1.3

Hespeler Meats is a medium-sized meat processor specializing in deli-style cold cuts and European processed meats. Hoping to expand its product offerings, it decided to add a line of canned pâtés. The company was eligible for a government grant to cover some of the purchase price of the necessary production equipment.

Government support for manufacturing is generally fairly sensible. Support is usually not given for projects that are clearly very profitable, since the company should be able to justify such an expense itself. Also, logically support is not usually given for projects that are clearly not very profitable because taxpayers' money should not be wasted. Government support is generally directed at projects that the company would not otherwise undertake but that have good potential to create jobs and expand the economy.

Hespeler Meats had to provide a detailed justification for the canned pâté project in order to qualify for a government grant. Its problem was it had to predict both the expenditures and receipts for the following five years. This was a product line with which it had no experience and that had not been offered in North America by any meat processor. The company had absolutely no idea what its sales would be. Any numbers picked would be guesses, but to get the grant it had to give defendable figures.

What it did was select an estimate of sales that, given the equipment expenditures expected, fell exactly within the range of profitability that made the project suitable for government support. Hespeler Meats got the money. As it turned out, the product line was a flop and the canning equipment was sold as scrap five years later. ■

EXAMPLE 1.4

When a large metal casting is made, as for the engine block of a car, it has only a rough exterior and often has flash—ragged edges of metal formed where molten metal seeped between the two halves of the mould. The first step in finishing the casting is to grind off the flash and to grind flat surfaces so that the casting can be held properly for subsequent machining.

Galt Casting Grinders (GCG) made the complex specialized equipment for this operation. It had once commanded the world market for this product but lost market share to competitors. The competitors did not have a better product than GCG but were able to increase market share by adding fancy display panels with coloured lights, dials, and switches that looked very sophisticated.

GCG's problem was that its idea of sensible design was to omit the features the competitors included (and the customers wanted). GCG reasoned that these features added nothing to the capability of the equipment but contributed considerably to the manufacturing and maintenance costs that would be borne by the purchaser. The company deemed it unwise, and poor engineering design, to make such unnecessarily complicated displays, so it made no changes.

GCG went bankrupt several years later. ■