SEVENTH EDITION

PRINCIPLES OF ENGINEERING ECONOMY

Includes The Tax Reform Act of 1986

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PREFACE

We are indeed grateful for the widespread acceptance of this book over a period of more than 50 years. It has been used in many hundreds of colleges and universities and scores of training programs in business and industry. The tendency of students to regard it as part of their basic equipment, for retention and later reference in professional or business life, has been a source of particular satisfaction.

Through successive editions we have emphasized that this is a book about a particular type of decision making. It explains the principles and techniques needed for making decisions about the acquisition and retirement of capital goods by industry and government. Normally, such decisions should be made on grounds of long-run economy. Because engineers make many such decisions and make recommendations for many others, the body of principles and techniques relating to them has been called *engineering economy*.

The same concepts and methods that are helpful in guiding decisions about investments in capital goods are useful in certain kinds of decisions between alternative types of financing (for example, ownership versus leasing) and in many personal decisions. Applications to these other areas of decision making are also discussed.

As in the past, our book may be used both as a text and as a reference. Experience has shown that its material is appropriate not only for engineering students but also for many students whose major interests are in economics, accounting, finance, or management. At the same time, it will serve as a working manual for engineers, management personnel, government officials, and others whose duties require them to make decisions about investments in capital goods.

The underlying philosophy regarding comparisons of alternatives is the same as in previous editions, and throughout, continued emphasis is placed on the following two important points:

It is prospective differences between alternatives that are relevant in their comparison.

The fundamental question regarding a proposed investment in capital goods is whether the investment is likely to be recovered plus a return commensurate with the risk and with the return obtainable from other opportunities for the use of limited

resources. The purpose of calculations that involve the time value of money should be to answer this question.

Just as in previous editions, the changes from the preceding edition have been made in part to improve the presentation of basic principles and in part to try to keep the treatment of various topics up to date. Some of the major changes are as follows:

1. The explanation of the relationship between economy studies and income taxation has been made more general. Now our intent is to present the subject in a way that will be useful to readers wherever income taxes are levied. Nevertheless, we continue to discuss relevant tax laws and regulations of the United States. In this edition we have added a new appendix that aims to give an up-to-date coverage of certain pertinent federal tax legislation.
2. The discussion of prospective price inflation has been expanded, particularly with reference to the interaction between inflation and economy studies.
3. Chapter order has been rearranged so that our introductory treatment of income taxes now precedes *all* of the chapters that explain techniques for economy studies.
4. The chapter on benefit–cost analysis has been expanded to introduce the subject of studies based on the concept of cost effectiveness.
5. The chapter on public regulation has been expanded to introduce the subject of government regulation of all types of private business. Special consideration still is given to the influence of regulatory policies on economy studies for privately owned public utility companies in the United States.
6. In the chapter on economy studies for replacements, our treatment of some of the older mathematical models has been shortened. This has made room for more detailed comments on certain popular types of errors in reasoning about replacement economy.
7. Our discussion has been expanded on the fallacy of using two interest rates during the same period of time in analysis of a cash flow time series.
8. In the 1980s in the United States and elsewhere, many college students who study engineering economy can look forward to paying substantial income taxes in the fairly near future. With this in mind we have expanded our coverage of the impact of income taxes on decision making by individuals.
9. There are now 500 problems, an increase of 18 per cent from the preceding edition. More than half are entirely new; many of the others have been substantially modified. Just as in the previous editions, answers are given to a number of representative problems, with the thought that this may be helpful to those persons who use the book for home study.

Our arrangement of chapters continues to be influenced by the fact that some introductory courses are too short to permit a full coverage of the subject. Most of the material in Chapters 1 through 17 is fundamental and should be included in any presentation of basic principles. The subject matter of Chapters 18 through 21 is appropriate for an elementary course if time permits but might also be deferred until an advanced course. Appendixes A through C cover topics that might be omitted in elementary college courses but should be included in advanced courses and in any presentation to persons in industry.

The authors wish to thank many of the users of the *Sixth Edition* for helpful suggestions for changes and improvements. In this connection we want to make special mention of help from Professors James Burns, Timothy Lowe, Ralph Swalm, and Robert C. Waters, and from Messrs. Lawrance F. Bell, John F. Roberts, and William M. Vatavuk.

In preparing this *Seventh Edition*, we have been mindful of the responsibility imposed by the success of its predecessors and have made every effort to provide the reader with a body of knowledge that can be carried well into the future.

Eugene L. Grant
W. Grant Ireson
Richard S. Leavenworth

In this Revised Printing, Appendix F has been completely rewritten to reflect the impact of certain changes in the income tax laws of the United States.

October, 1986

E. L. G.
W. G. I.
R. S. L.

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PART I

SOME BASIC CONCEPTS IN ENGINEERING ECONOMY

1

DEFINING ALTERNATIVES AND PREDICTING THEIR CONSEQUENCES

*As the correct solution of any problem depends primarily on a true understanding of what the problem really is, and wherein lies its difficulty, we may profitably pause upon the threshold of our subject to consider first, in a more general way, its real nature; the causes which impede sound practice; the conditions on which success or failure depends; the directions in which error is most to be feared.—A. M. Wellington**

The practice of engineering involves many choices among alternative designs, procedures, plans, and methods. Since the available alternative courses of action involve different amounts of investment and different prospective receipts and disbursements, the question "Will it pay?" is nearly always present. This question may be broken down into subsidiary questions.

For example, there are the often-quoted three questions that were asked by General John J. Carty when he was chief engineer of the New York Telephone Company in the early years of the present century. He applied these questions to the many engineering proposals that came before him for review:

1. Why do this at all?
2. Why do it now?
3. Why do it this way?

Why do this at all? Shall a proposed new activity be undertaken? Shall an existing activity be expanded, contracted, or abandoned? Shall existing standards or operating procedures be modified?

Why do it now? Shall we build now with excess capacity in advance of demand, or with only sufficient capacity to satisfy the demand immediately in prospect? Are the costs of capital and other business conditions favorable to a present development?

*A. M. Wellington, *The Economic Theory of Railway Location*, 2d ed. (New York: John Wiley & Sons, Inc., 1887), p. 1.

Why do it this way? This choice among alternative ways of doing the same thing is common to all types of engineering activity.

This book deals with certain principles and techniques that are useful in securing rational answers to questions of this type. The central problem discussed in the book is how we may judge whether any proposed course of action will prove to be economical in the long run, as compared to other possible alternatives. Such judgment should not be based on an unsupported "hunch"; it calls for an economy study. An economy study may be defined as a comparison between alternatives in which the differences between the alternatives are expressed so far as practicable in money terms. Where technical considerations are somehow involved, such a comparison may be called an engineering economy study. In most cases, the engineering economy studies discussed in this book deal with the evaluation of proposed investments.

Management's Responsibility for Decisions on Plant Investment

The earliest book on engineering economy was Wellington's *The Economic Theory of Railway Location*. Wellington wrote in a missionary spirit in a day when investments in railway plant in the United States were greater than the aggregate of all other investments in industrial assets. Railway location obviously is a field in which many alternatives are likely to be available. Nevertheless, Wellington observed what seemed to him to be an almost complete disregard by many locating engineers of the influence of their decisions on the prospective costs and revenues of the railways. In his first edition (1877) he said of railway location, "And yet there is no field of professional labor in which a limited amount of modest incompetency at $150 per month can set so many picks and shovels and locomotives at work to no purpose whatever."

Although salary rates and many other things have changed since Wellington's time, the type of problem that he recognized is an ever-present one in an industrialized civilization. If, in a business enterprise or in government, many important decisions that in the aggregate can have a major influence on the success (and sometimes on the survival) of the enterprise are badly made by persons of "modest incompetence," these bad decisions are not primarily the fault of those persons; they are the fault of management.

A Conceptual Framework for the Presentation of Engineering Economy

The first two chapters of this book introduce a number of concepts that the authors believe are important in decision making—particularly so with reference to decisions about proposed investments in physical assets. The reader will doubtless observe that these concepts are not mutually exclusive; some of them overlap a bit. Throughout the remainder of the book, the application of these concepts is discussed and illustrated in various ways, often with reference to specific examples that involve numerical solutions in the comparison of alternatives.

In these two initial chapters, each concept is first stated in italics and then expanded by means of a short discussion. Some of the discussions contain descriptions of cases chosen to illustrate specific points. These early examples are intentionally brief; the desired points in this initial presentation can be made without giving all the details needed for a formal analysis and a numerical solution.

Recognizing and Defining Alternatives

1. *Decisions are among alternatives; it is desirable that alternatives be clearly defined and that the merits of all appropriate alternatives be evaluated.*

There is no need for a *decision* unless there are two or more courses of action possible. However, many decisions are, in effect, made by default; although many alternatives exist, the decision maker fails to recognize them and considers only one possible course of action.

In many other instances, formal consideration is given to several alternatives. Nevertheless, an unwise decision is finally made (or recommended) because of an analyst's failure to examine an alternative that is superior to any of the ones selected. It is obvious that a poor alternative will appear to be attractive if it is compared with alternatives that are even worse.

Frequently, one alternative is to do nothing, i.e., maintain the existing conditions. This alternative is sometimes overlooked or ignored.

A Case of a Failure to Recognize the Existence of Any Alternatives. An industrial concern owned a "total energy system" which had been operated for many years to furnish steam for heating, for operation of steam-driven pumps and steam-driven air compressors, and for generation of the electricity needed in the plant for lighting and for the operation of small motors. An increase in the concern's volume of business finally increased the demands for compressed air and for electric energy above the capacity of the existing plant.

Without any engineering survey of the situation, the general manager of the plant contracted to purchase from the local electric light and power company the excess of his needs for electric energy above the amount that could be generated in his existing plant. To meet the increased needs for compressed air, he bought a large electrically driven air compressor.

His decision proved to be a costly one. The air compressor purchased was a large single unit; it turned out that it was operated most of the time at a very small fraction of its capacity and at a correspondingly very low efficiency. The amount of energy purchased was too low to bring the unit rate into the lower blocks of the power company's rate schedule. No reduction was possible in labor cost for operation of boilers, prime movers, compressors, and pumps, or in the fuel and maintenance costs of the old and inefficient prime movers.

Finally, after a long period of uneconomical operation, an engineering economy study was made to discover and evaluate the possible alternatives. This study made it clear that there were a number of plans that would have been more economical than the one that had been adopted. Steam capacity might have been increased by the addition of new boilers and the old ineffi-

cient prime movers might have been replaced by modern efficient ones of greater capacity. Or the old prime movers might have been shut down with all electric energy requirements purchased from the power company, permitting all the steam generated to be used for operation of steam-driven compressors and pumps and for heating. Or the compressors and pumps might have been electrified and all electric energy requirements then purchased, with boilers operated for steam heat only in cold weather.

Some Cases of Failure to Consider Appropriate Alternatives. In a certain study of alternate highway locations, Proposal A required a major improvement of an existing interstate highway. Proposal B called for an entirely new location that would relegate the existing road chiefly to the service of local traffic. A prospective favorable consequence of the new location was to make possible the development of new economic activity in a certain area not now served by an adequate highway. This consequence, included in the economic analysis as a "benefit" for B but not for A, was a major factor in the analyst's recommendation favorable to proposal B. The analyst failed to recognize that the same benefit could be obtained by making a relatively small additional investment to add to Proposal A a low-cost secondary road that would serve the new area.

In another case, an irrigation district was having great difficulty with the maintenance of a number of flumes in its main canal. The district's consulting engineer estimated a cost of $1,200,000 for a proposed plan of flume replacement. When the district's commissioners tried to sell the district's bonds for this amount, the bond house that they approached sent its engineer to investigate. This engineer suggested that the investment might be reduced and a more permanent ditch obtained by substituting earth fills for many of the low flumes that needed replacement. This plan was later carried out at a cost of about $400,000.

Improved Analytical Procedures as a Possible Alternative to Investments. Sometimes when an unsatisfactory condition is under review and an investment in fixed assets is proposed to correct this condition, no thought is given to possible methods of improving the condition without a substantial investment.

For example, new machinery may be proposed to reduce high labor costs on a certain operation. Work simplification methods based on motion study may provide an alternative way to reduce these costs. As another example, new machinery may be proposed to reduce the percentage of spoilage of a manufactured product that must meet close tolerances. Possibly the same result might be obtained through the use of the techniques of statistical quality control.

A number of organizations have reported that the analysis of procedural problems preparatory to the purchase or lease of a large, high-speed computer has resulted in the improvement of existing procedures to the point that the computer could not be justified. The introduction of a computer always requires the careful analysis of the problems to be solved on it in order to

translate each problem into language the computer can understand. Such analysis frequently reveals flaws in the current procedures that could have been eliminated without waiting until the lease or purchase of a computer was proposed.

In the public works field, also, proposed investments may have alternatives that are not obvious at first glance. For instance, the cost of flood damage may be reduced by investment in flood protection reservoirs, levees, and channel improvement. This cost may also be reduced by a system of flood zoning that prevents certain types of land use where there is a likelihood of flooding. Moreover, the cost of flood damages often may be reduced by an improved system of flood forecasting accompanied by an effective system of transmitting the forecasts to people in the area subject to flood.

Imperfect Alternatives Are Sometimes the Most Economical. The satisfaction of the engineer's sense of perfection is not a necessary prerequisite for the most economical alternative. Sometimes it happens that a careful study will show that an alternative that at first was summarily rejected affords the most economical solution of a given problem.

An illustration is the case of a geographically diversified group of public utility companies that needed to buy a great many poles. Poles came in a number of classes, AA, A, B, C, D, E, F, and G, depending upon the top diameter and the butt diameter. The past practice of these companies in pole selection had been based on their experience of what had proved to be satisfactory rather than on any considerations of theoretical design, and usually had involved purchasing no poles below class B.

It was then decided to analyze pole requirements on the basis of such factors as the expected storm loads in different areas and the importance of each pole line to the entire system. This analysis showed that many of the lighter grades of poles that had not previously been purchased were satisfactory for certain conditions. Savings were effected because cheaper poles were used in many cases. Additional savings resulted because the distribution of pole requirements among all of the classes made it possible to use a "wood's run" of poles, so that lumber companies were able to set a lower price on poles A and B than was possible when they had trouble in selling their lower classes.

The Common Condition of the Existence of Major Alternatives and Subsidiary Alternatives. Earlier in this chapter, we cited a "hunch" decision by the manager of a factory that had a total energy system. When it was finally recognized that this was an uneconomical decision, an engineer was called in to survey the situation and make recommendations.

The engineer examined the factory's past requirements for the relevant services—heat, pumping, compressed air, and electricity. After consideration of the trend of growth of production and of some changes in production methods that seemed to be in prospect, a forecast was made of the needs for these services for several years to come. With this forecast as a basis, prelimi-

nary designs were then made for meeting the expected needs by each of the possible alternatives recognized. For each alternative, approximate estimates were made of the immediate investment required and of the annual expenditures necessary in the future. With these estimates, the engineer was able to make a preliminary comparison of the long-run economy of the several alternative plans (including as one plan a continuance of the existing scheme), and to select those that seemed to justify detailed study.

Of all the alternatives given preliminary study, two appeared to be much more economical than any of the others. One was a plan to modernize the power plant by the purchase of one or more steam turbines; the other was a plan for the electrification of the compressors and pumps and the purchase of all power. Each of these plans was given detailed study with complete designs, and with careful estimates of investment costs and operation and maintenance costs.

As is characteristic of all economy studies to determine general policy, each of these designs involved numerous subsidiary alternatives, and each selection between subsidiary alternatives required a subsidiary economy study. For example, in the first alternative what type and size of turbines should be selected? How many should there be? What boiler pressures should be used? Should the power generation be combined with other steam requirements by selecting turbines that exhaust at pressures that permit the use of their exhaust steam for other purposes? In the second alternative, several different possible rates were offered by the power company. "Primary" power could be taken at 23,000 volts, requiring the customer to install transformers for stepping down the voltage and, of course, to take the transformer losses involved; a variation of this was an off-peak rate that restricted the power that could be used in certain specific hours of certain months. Two other different rates were available under which the power company supplied electricity at the voltages at which it was ultimately to be used. The electrification of compressors and pumps involved several possible alternative designs.

What Alternatives Are "Appropriate" for Evaluation? Costs for design, estimating, and analysis are involved whenever an additional alternative is to be reviewed. Clearly a balance is required between the possible advantages to be gained from evaluating more alternatives in any given case and the expenses (including sometimes the adverse consequences of time delays) incident to the evaluation. It is reasonable to try to avoid the costs of examining alternatives that have no merit.

The statement (on page 5) that the merits of all appropriate alternatives should be evaluated obviously leaves room for interpretation of the word *appropriate*. In most instances, as in the case cited of the engineer's study of the total energy system, preliminary economic evaluation will serve to eliminate many alternatives that are physically possible. Detailed study can be limited to those alternatives that have appeared to be best in the preliminary comparison.

The Need to Consider Consequences

2. *Decisions should be based on the expected consequences of the various alternatives. All such consequences will occur in the future.*

If there were no basis for estimating the results of choosing one proposed alternative rather than another, it would not matter which alternative was chosen. But in most proposals that involve investments in physical assets by business enterprises or by governmental bodies, it is possible to make estimates of differences in consequences. Clearly, rational decisions among alternatives should depend on prospective consequences to the extent that consequences can be anticipated. Because the consequences of a decision are necessarily *after* the moment of decision, this estimation always applies to the future.

As will be brought out by a variety of examples throughout this book, some types of consequences of investment decisions can be forecast with a fair amount of justifiable confidence, particularly if adequate effort is devoted to the job of estimation. In contrast, other consequences are inherently difficult to forecast. For example, other things being equal, consequences that are expected in the fairly distant future are harder to forecast than those in the near future. Moreover, some types of prospective consequences are fairly easy to quantify in a way that makes them commensurable with one another. But there may also be prospective consequences that are difficult or impossible to quantify in this way.

The Critical Issue of Consequences to Whom

3. *Before establishing procedures for project formulation and project evaluation, it is essential to decide whose viewpoint is to be adopted.*

The majority of the examples and problems in this book deal with economy studies for competitive business enterprise. In these studies we shall assume that the analysis is to be made primarily from the point of view of the owners of the enterprise.

The matter is a bit more complicated in economy studies for privately owned public utility companies that operate under the rules of rate regulation that have developed in the United States. We explain in Chapter 20 that the common practice of trying to minimize "revenue requirements" when choosing among design alternatives is, in effect, taking the viewpoint of the customers of a utility company. We also note certain circumstances in which such a customers' viewpoint may be insufficient or inappropriate.

The choice of viewpoint is much more complicated in economy studies made for governmental bodies. In many types of economy study for public works, it clearly is undesirable to restrict the viewpoint to the financial position of the particular governmental unit that is involved. We shall see first in Chapter 9 and later in Chapter 19 that, in principle, many such economy studies ought to be made considering prospective consequences "to whomsoever they may accrue." We shall also see that, because of their diffused nature, consequences are often much harder to estimate and evaluate in government projects than in private enterprise.