PRINCIPLES OF ENGINEERING ECONOMY

EIGHTH EDITION

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This eighth edition is dedicated to the memory of William Grant Ireson who passed away during the final stages of its production. A dedicated teacher, Grant was admired and respected by engineering students around the world.

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Eugene L. Grant is Professor Emeritus of Economics of Engineering at Stanford University. He holds B.S. and C.E. degrees from the University of Wisconsin, an M.A. degree in Economics from Columbia University, and an honorary Doctor of Engineering from Montana State University. After serving in the U.S. Navy in World War I and with the U. S. Geological Survey thereafter, he joined the faculty of Montana State University in 1920 and left there with the rank of professor in 1930 to become Associate Professor of Civil Engineering at Stanford. Prior to becoming Professor Emeritus in 1962, he served as Executive Head of the Civil Engineering Department (1947–1956) and as Chairman of the Industrial Engineering Committee (1946–1952).

From 1941 to 1944, Professor Grant directed the Engineering, Science and Management War Training (ESMWT) program at Stanford University where, in conjunction with Holbrook Working, he helped develop an intensive short course in quality control by statistical methods for the key personnel of war industries. This became the model for a nationwide program of similar courses that were sponsored jointly by the War Production Board and the United States Office of Education; alumni of these courses formed the American Society for Quality Control in 1946.

Dr. Grant received the 1952 Shewhart Medal from ASQC and was awarded an honorary membership in 1968. In 1966 ASQC established an annual E. L. Grant Award for distinguished contributions to quality control education. He is one of three honorary academicians of the International Academy for Quality. In 1965, the Engineering Economy Division of the American Society for Engineering Education established an annual E. L. Grant Award for the best paper in each volume of *The Engineering Economist.* Professor Grant received the Founders Award from the American Institute of Industrial Engineers in 1965 and the Wellington Award in 1979. He received a Distinguished Service Citation from the University of Wisconsin College of Engineering in 1964. In 1987 he was elected to the National Academy of Engineering.

In addition to *Principles of Engineering Economy,* Professor Grant is the author of *Statistical Quality Control,* now in its sixth edition (McGraw-Hill, 1988) and coauthored since 1972 with R. S. Leavenworth, *Depreciation,* coauthored with P.T. Norton, Jr., and published by Ronald Press Co. (1949), and *Basic Accounting and Cost Accounting,* published by McGraw-Hill (1956 and 1964), the second edition of which he coauthored with L. F. Bell. He is coeditor with W. G. Ireson of *Handbook of Industrial Engineering and Management,* (Prentice-Hall, 1955 and 1971).

William Grant Ireson received his Bachelor of Science and Master of Science degrees in Industrial Engineering from Virginia Polytechnic Institute. After receiv-

ing his B.S. degree he was employed by Wayne Manufacturing Corporation. He returned to Virginia Polytechnic Institute as Instructor (1943) and left as Professor and Acting Department Head of Industrial Engineering (1948) to become Professor at Illinois Institute of Technology. In 1951 he accepted an invitation to become Acting Professor at Stanford University, half-time in Industrial Engineering and half-time in the Applied Mathematics and Statistics Laboratory.

In 1952 he became Professor and Chairman of the Committee of Industrial Engineering. The Department was established in 1954. He remained Department Head until 1975.

Since becoming Professor Emeritus (1981), he has been a consultant in Engineering Economics, Engineering Education, and Reliability to governments and business companies in the U.S., Mexico, Taiwan, Singapore, Bangladesh, and the People's Republic of China. Some of these assignments included from three-day to two-week intensive seminars, mostly for professional personnel.

From 1959–1960 he was on leave of absence from Stanford University to serve as consultant to the European Productivity Agency of the Organization for European Economic Cooperation, working with twelve countries of Western Europe. Over the period of 1958 to 1975 he had many consulting and research contracts with organizations including the United States Air Force Ballistic Systems Division and Space Systems Division; the United States Navy Special Projects Office under a CEIR contract; Pakistan Small Industries Corporation; Stanford Research Institute; United Nations Industrial Development Organization; California Water Service on Taxation Problems; Argonne National Laboratory; OAS Ford Foundation Grant; National Science Foundation Facilities Section; Contratora de Tamego, Ltd. (Portugal); and several business companies or government agencies in Virginia, Illinois, and California, as well as Mexico, Brazil, and several Asian countries.

He has been consultant in Engineering Education to universities in Nigeria, Saudia Arabia, Singapore, Hong Kong, Mexico, and Korea. For his assistance in developing and establishing the Korean Advanced Institute of Science (KAIS) between 1971 and 1978, he was awarded the Order of Civil Merit by the Government of South Korea, presented by the President of South Korea in 1981.

Other honors include Tau Beta Pi, Phi Kappa Phi, Sigma Xi, Alpha Pi Mu, Virginia Polytechnic Institute Honors Scholarship, Air Force Scroll of Appreciation (1959), American Society for Quality Control Eugene L. Grant Medal for Advancement of Quality Control Education, American Society for Quality Control Reliability Education Advancement Award, Institute of Industrial Engineers Gilbreth Award, Institute of Industrial Engineers Special Citation for Outstanding Contributions in Engineering Economics, and Stanford University Tau Beta Pi Professor of the Year. Upon his becominig Professor Emeritus in the Department of Industrial Engineering and Engineering Management at Sstanford in 1981, a fellowship covering tuition and expenses for graduate students in the IE-EM Department was established with the name of W. Grant Ireson Fellowship.

In addition to *Principles of Engineering Economy*, which he has co-authored since its fourth edition, Professor Ireson is coeditor with Eugene L. Grant on the first and second editions of *Handbook of Industrial Engineering and Management*, (Prentice-Hall, 1955 and 1971), and author of *Factory Planning and Plant Layout*, (Prentice-Hall, 1952). He was Editor of *Reliability Handbook* (McGraw Hill, 1966), and coeditor in 1987, and was also a Series Editor in Management Science and Industrial Engineering for Prentice-Hall. He is currently Editor-in-Chief of *Reli-*

ability Review. Many of his articles in various professional journals, as well as several of his books, have been translated into Spanish and languages of the Middle East.

Richard S. Leavenworth received his Ph.D. degree in industrial engineering from Stanford University in 1964. After two years at Virginia Polytechnic Institute and State University as an Assistant Professor, he joined the faculty of the University of Florida where he is presently Professor Emeritus of Industrial and Systems Engineering. In 1970 he was voted Outstanding Professor in the College of Engineering by the Inter-Fraternity Council and was a semifinalist for the Standard Oil Good Teaching Award. He has served as Acting Chairman of the department and as Assistant Dean for Planning and Analysis and has been a member of the University Senate. In addition to service on numerous department, college, and university committees, he chaired the College of Engineering Committee on the Doctor of Engineering degree.

Dr. Leavenworth's research, sponsored in part by the Office of Naval Research, has resulted in technical reports and publications in the *Journal of Quality Technology, Naval Research Logistics Quarterly,* and *Transactions* of the Institute of Industrial Engineers. He has developed a number of courses for in-plant training and has presented seminars and short-courses nationally and internationally. His consulting and training activities have included organizations such as the U. S. Department of Commerce, the General Electric Company, Manhattan Industries, the Florida Department of Transportation, USDA Food Safety Inspection Service, Harris Corporation, the Tennessee Valley Authority, and Naval Aviation Depot, Jacksonville, Florida.

In addition to *Principles of Engineering Economy,* he is coauthor with E. L. Grant of *Statistical Quality Control,* now in its sixth edition (McGraw-Hill, 1988). Both texts have been translated into Spanish and are widely distributed through International Students Editions.

He has been very active in the Institute of Industrial Engineers, having served in a number of positions including Region Vice-President and Vice-President for International Operations and as Editor, *The Engineering Economist.* In 1984 he was presented the Quality Control and Reliability Engineering Division Award of Excellence. He is a Fellow of the Institute of Industrial Engineers and Senior Member of the American Society for Quality Control. He is a member of the American Society for Engineering Education and is a Registered Professional Engineer in California and Florida. Also, he has been elected to Tau Beta Pi, Sigma Xi, and Alpha Pi Mu honor societies.

PREFACE

We are indeed grateful for the widespread acceptance of this book over a period of nearly 60 years. It has been used in many hundreds of colleges and universities and in scores of training programs for 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 special 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 the 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 also are 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. Also, it can 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, a 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. Although the coverage of topics has been maintained, the number of chapters has been reduced by combining some closely related topics. Topics have been structured into four parts: basic concepts, principles, and mathematics; procedures and methods for evaluating alternatives; techniques for handling special situations; and special applications.
2. The use of computers, specialized computer programs, and spreadsheets in the evaluation of engineering alternatives has been introduced into a number of chapters. Many examples of spreadsheet tables are illustrated, and general instructions for setting up worksheets are given.
3. We have continued the policy of keeping the explanation of the relationship between economy studies and income taxes in the main body of the text in Chapter 9 relatively general. Up-to-date coverage of certain pertinent U. S. federal tax legislation is given in Appendix F where it can be changed from time to time as necessary. The numerous changes in U. S. tax laws since 1981 have proven that this approach is useful. The intention in Chapter 9 is to present the subject in a way that will be useful to readers wherever income taxes are levied.
4. The two introductory chapters, which covered the basic principles of economic decision making, have been combined into a single entity. These 10 principles deserve thorough discussion and constant reiteration throughout the course.
5. The two chapters covering the formulas of financial mathematics and examples of cash flow equivalence conversions have been combined. We believe it is more efficient to deal with numerical examples at the same time that formulas are being developed than to treat them sequentially.
6. Discussions and problems dealing with personal finance have been collected into identified areas within many chapters. Students and practitioners alike will find these discussions and examples useful in their personal lives and thus will find the subject matter interesting and immediately useful in decision making.
7. The material on handling multiple alternatives by rate of return and benefit/cost ratio methods has been combined into those respective chapters. It is believed that this approach is more efficient when an instructor is picking and choosing topics to include or exclude from a particular course.
8. Since they are closely interrelated, the topics of capital budgeting and choosing a minimum attractive rate of return have been combined and placed in Part III.
9. There are now 476 problems in the book of which more than one half are entirely new or 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. The material in Chapters 1 to 10 (Parts I and II) is fundamental and should be included in any presentation of basic principles. However, some instructors may prefer to emphasize the tax material in Appendix F instead of some of the detail covered in Chapter 9. The subject matter of Chapters 11 to 15 (Part III) is appropriate for an elementary course if time permits but should be included in an advanced course. Chapters 16 and 17 are recommended for advanced study and for courses pre-

sented to persons in affected industries. Appendixes A to C cover topics that might be ommitted in elementary college courses but should be included in advanced courses and in any presentation to persons in industry.

We thank many of the users of the *Seventh Edition* as well as other reviewers for helpful suggestions and improvements. In this connection we want to make special mention of help from Professors Ralph Swalm, Robert C. Waters, Joseph E. Gust, Jr., Henry A. Wiebe, Henry A. Kallsen, and T. G. Eschenback and from Messrs. John F. Roberts, William M. Vatavuk, and the late Lawrance F. Bell.

In preparing this *Eighth 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

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PART I

SOME BASIC CONCEPTS IN ENGINEERING ECONOMY

- *PRINCIPLES OF ECONOMIC CHOICE*
- *THE CONCEPT OF EQUIVALENCE*
- *FINANCIAL MATHEMATICS AND PROBLEM SOLVING*

1

BASIC PRINCIPLES OF ECONOMIC CHOICE

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[1]

Management's Responsibility for Investment Decisions

Formulation of a company's or government agency's capital budget is one of its most vital tasks in implementing strategic management decisions. Usually approved on an annual basis, the capital budget determines the physical parameters within which the company or agency will have to operate and attempt to prosper for years if not decades into the future. The highway, rail, air transport, utility, energy, etc., systems that make up the infrastructure of an industrialized nation are the result of thousands of strategic management decisions made over many years and implemented through the capital budgeting process. In many cases, the implementation of these strategic decisions requires the technical advice and expertise of engineers. Engineers not only provide technical inputs but frequently are responsible for estimating and evaluating costs and benefits to be expected from various courses of action. This service is called an engineering economy study.

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 the 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

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

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.

Although it is unlikely that new engineering graduates will be involved in the formulation of great strategic decisions, they may often become involved in the myriad of tactical decisions that impact on the implementation of strategic decisions. The strategic decision to increase productivity and improve quality, for example, provides a skeleton. The tactical decision to renovate a plant or build a new one, including all the subsidiary decisions in choosing equipment, puts the flesh and muscle on the skeleton.

Engineering's Responsibility for Investment Decisions

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? Should a proposed new activity be undertaken? Should an existing activity be expanded, contracted, or abandoned? Should existing standards or operating procedures be modified?

Why do it now? Should 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?

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. In most cases, the engineering economy studies discussed in this book deal with the evaluation of proposed investments.

A Conceptual Framework for the Presentation of Engineering Economy

The first chapter of this book introduces 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.

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, that is, maintain the existing conditions. This alternative is sometimes overlooked or ignored.

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 an 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 favorable recommendation for proposal B. The analyst failed to recognize that the same benefit could be obtained by adding a relatively small investment to Proposal A for 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 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 on 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 consider-