Gerald W. Smith

Engineering Economy

FOURTH EDITION

ANALYSIS OF CAPITAL EXPENDITURES

Economy FOURTH EDITION

ANALYSIS OF CAPITAL EXPENDITURES

Gerald W. Smith

IOWA STATE UNIVERSITY PRESS, AMES, IOWA

GERALD W. SMITH is Professor of Industrial Engineering at Iowa State University, where he received his Ph.D. degree. He has served in virtually all the offices of the Engineering Economy Division of ASEE, including the chairmanship. In 1964 he was Iowa State's representative at the General Electric Professor's conference; in 1968–1971 he was designated Iowa State's Alcoa Professor; in 1969 he was recipient of the E. L. Grant Award for best paper in *The Engineering Economist* and in 1970–1976 he served that journal as associate editor for book reviews; he has also served on the editorial board of *IIE Transactions.* He and his graduate students contribute gratis their efforts in the annual publication *Engineering Economy Abstracts,* which he originated. In 1974 he received the Iowa State University Faculty Citation; in 1981 he received the Outstanding Teacher award from Iowa State's College of Engineering; in 1986 the Engineering Economy Division of the Institute of Industrial Engineers named him recipient of the Wellington Award for Outstanding Contributions in Engineering Economy. He has consulting and industrial experience and is a registered professional engineer.

First edition, 1968
Second edition, 1973
Third edition, 1979
Fourth edition, 1987

Library of Congress Cataloging-in-Publication Data

Smith, Gerald W.
Engineering economy.

Bibliography: p.
Includes index.
1. Engineering economy—United States. 2. Capital investments—United States. 3. Capital budget—United States. 4. Depreciation allowances—United States. I. Title.
TA177.4.S57 1987 658.1'52 87-2751
ISBN 0-8138-0553-8

Engineering Economy

ANALYSIS OF CAPITAL EXPENDITURES

Preface

> Planning without action is futile,
> action without planning is fatal.
>
> AUTHOR UNKNOWN

THIS BOOK deals with the concepts, principles, techniques, and reasoning applicable to the planning of long-term facilities. The planner may be a manager of capital equipment, an engineer responsible for its design, a citizen acting on behalf of the community, an entrepreneur concerned about a project's impact, or a consultant acting on behalf of a client. The frequent role of the engineer and the objective of long-term economy are responsible for the widely used title "Engineering Economy." The book is intended as both a textbook and reference for students of engineering, management, business, and economics as well as practitioners who are already involved as decision-making planners.

Engineering economy relates or applies many concepts from economics, mathematics, accounting, statistics, and management; the text provides enough detail of these topics to be self-sufficient. For those who wish to pursue such topics more fully, a number of helpful references are noted in the Selected References.

The general plan of the book is to begin with very restrictive mathematical models of reality, then to relax these restrictions one at a time to focus attention on the primary topic at hand. To continue this process generally requires that succeeding chapters *not* repeat all the complicating factors of reality; thus the section on capital budgeting forsakes the more complex models of income tax, economic life, risk, and obsolescence so that the reader may concentrate upon the topic at hand. The problems of real life that *do* include simultaneous consideration of such factors are accompanied by monetary consequences that can justify a depth of study far beyond the practical limits of the classroom.

The audience to whom this book is addressed varies considerably in background, needs, and time available for its study. An attempt has been made to achieve some flexibility in meeting the varying needs of readers by the inclusion of material a teacher may choose to include or exclude, according to the purposes and nature of the course involved. Sufficient material is offered for a two-term course. In an introductory one-term course the first eleven chapters may provide most of the coverage. Problems 20-4 and 20-5 (a capital budgeting game) have proved so popular as concluding sessions that we especially recommend your consideration of them. Sample assignment sheets are available from the author.

In response to the enthusiastic comments of teachers and students, graphic presentations in this edition have been further utilized in the development of concepts. In addition to cash flow diagrams, break-even charts, decision trees, net present value (*PEX*) diagrams, sensitivity studies, utility functions, and probabilistic cash flows, readers will find many original graphic presentations:

- Corporate flows of cash.
- Network diagrams used to develop conditional decision responses under unspecified rate of return requirements.
- Relation of the multialternative net present value diagram to network diagram decisions.
- Probabilistic before-tax and after-tax cash flows.
- Summary of the Monte Carlo simulation of multivalued inputs.
- Determination of expected utility for probabilistic cash flows that are continuous functions.
- "Economic package" determinations, including decision tree analyses and the role of "expansion rate" and "economies of scale."
- "Marginal investment opportunity curve" for various decisions on economic package; deferred investment; optimal timing of acquisition, retirement, or replacement.
- Life cycle of a capital expenditure as a multistage series of sequential commitment decisions with time-variant "escape" costs. Time-variant avoidable (controllable) annual cost and the sunk cost concept.

Other unique features include:

- Early and continuing emphasis is placed on the integration of

accounting information with the decision needs of the feasibility study, including the unifying perspective of the "sources and application of funds statement."

- The specially designed format of the compound interest tables, with a proven advance in symbol systems, provides both mnemonic and dimensional analysis aids in computation.
- The conversion between continuous cash flows and end-of-year cash flows is reduced to a simple convenient form not found in other texts.
- Depletion and depreciation are treated in a manner relevant to current business decisions.
- A newly developed approach to income tax computation simplifies and shortens analyses involving debt financing.
- Multioutcome (risk and uncertainty) analyses involving discrete or continuous probability functions are summarized in convenient form for expected outcome and expected utility criteria.
- The relevance of "marginal opportunity cost" as empirical evidence of the capital budgeting cutoff rate is stressed in the examples of many chapters, thus emphasizing the "system" impact of such decisions.
- Capital expenditure decisions are portrayed as imperfectly reversible, multistage, sequential decisions and permit the reader a depth of understanding and intuitive "feel." Probabilistic treatment of the risk of premature retirement is similarly treated.
- Typical contemporary treatment of optimal service life (economic life) is restricted to the case where acquisition age is zero. That constraint as well as those relating to revenue level and duration are removed, thus permitting determination of optimal acquisition age and optimal retirement age.
- A noncomputer capital budgeting game permits students to gain insights through a brief encounter with capital budgeting decisions and cash flows in a realistic dynamic context.
- Stochastic dominance concepts provide a helpful screening mechanism for eliminating inferior alternatives *prior* to further analysis. "Risk-adjusted rate of return" is a logical outgrowth of utility of money and rate of return concepts.
- Emphasis is given to the operational nature of a capital budgeting system, even when such problems as heterogeneity, project indivisibility, time-variant cutoff rates, and prerequisite projects appear.

In this fourth edition we have attempted to integrate more fully the role of the personal computer in the broad spectrum of capital expenditure analyses. Rapid growth in its availability, affordability, breadth of use, and ease of use are well documented. Spreadsheet analyses are illustrated in many chapters. Teachers are encouraged to use the illustrations as guides for student assignments that are tailored to the available facilities and prevailing circumstances. Students may wish to develop a collection of these spreadsheet applications for future professional and personal use. Computer programs and worksheets may thus fill a role similar to the collection of notes and books that the engineering graduate takes to professional practice.

Ever-changing rules for the computation of income tax, depreciation, depletion, and the like create both the need and data for changes incorporated in this fourth edition. Federal budget tendencies have provided the cover color cue.

The objectives of the book and course should be not only to bring its reader to a point of competent analysis but also to help the reader recognize unsound reasoning, criteria, methods, or criticism and to respond to their defects.

I am indebted to my students whose enthusiasm for the subject has made its teaching a pleasure. I am grateful for the opportunity of association with the engineers and managers of public utility companies whose experience with capital expenditure planning has made obvious the increasing stake of the firm and of the nation. I owe much to the students, business executives, and colleagues with whom I have been privileged to associate for their insights into new challenges and unsolved problems. I wish to thank Dr. Clair G. Maple for the derivation which led to his interesting discovery that capital recovery factors for group properties following the Iowa Type S_x survivor dispersions can be expressed as a Bessel function. I also wish to thank Professors Arthur Lesser, Jr., Loran E. Mohr, Jean C. Hempstead, and Edward J. Carney for reading and commenting upon sections of the book. I owe much to Professors J. K. Walkup and J. P. Mills for their guidance.

To thank my wife for her typing is unduly restrictive; so finally, to my family, I acknowledge the value of the quiet, understanding, and encouragement they so patiently supplied.

GERALD W. SMITH

Contents

I

Enterprise Decision Making and Action in the Management of Capital Equipment

THE monogram of our national initials, which is the symbol of our monetary unit, the dollar, is almost as frequently conjoined to the figures of an engineer's calculations as are the symbols indicating feet, minutes, pounds, or gallons.

HENRY R. TOWNE in a paper before the American Society of Mechanical Engineers in 1886

1

Capital Expenditures and Analysis for Economy

Design for Function: Design for Economy

The engineer is a designer; what is designed—structures, processes, circuits, mechanisms, production environments, or systems of people and facilities—is dependent upon the engineer's specialization.

A design must accomplish some function and therefore meet the test, Does it work? However natural in logic, the test is nonetheless insufficient in scope. The majority of basic science, engineering science, and engineering analysis and design courses in the engineer's education are devoted to the study and understanding of *functional* aspects of design. We agree that function is a *primary* criterion of design but note that it is not a *unique* criterion. Even when an engineer is asked to design a system whose only specifications appear to be functional, it is most improbable that system cost is inconsequential. With economy as one criterion of design, the engineer's task becomes one of finding the best way to achieve the functional goal. This means the engineer (and facility manager too) must *search for, recognize, and generate alternatives* and also *compare and evaluate* them. This book deals primarily with this latter need—the principles, concepts, techniques, factual data, and methods by which alternatives can be compared and evaluated. Both search and comparison stages must be properly performed if meaningful results are to be produced.

Interestingly enough there is a tendency for the functional and economic criteria of a given design or facility to move from predominantly functional to predominantly economic with time. Even though efforts to travel through space are now primarily a search for a *way* to do so, the years ahead will see increasing effort

to make space travel more *economic*. Digital computers have evolved in this manner; the cost per unit of memory or per unit of internal speed continues to decline.

It seems unlikely that dependence upon an engineer's intuitive regard for cost is reasonable. Engineering economy concepts are an essential element in the engineering science background upon which the engineer bases designs. Criteria of design include function and economy as well as other criteria such as time, safety, and reliability.

Illustration of the Relationship of Function and Economy

One of our nation's problems is that of assurance of an adequate supply of water that is both potable and palatable. In response to this need experimental efforts have included the design of facilities for conversion of seawater. Todays plants meet the functional criteria; these are largely experimental, however, because present methods of seawater conversion do not yet satisfy certain *economic* criteria.

One problem of the electric utility is that costly generating facilities must be sufficient to meet peak demand; during off-peak hours a portion of high-cost facilities are therefore idle. The natural suggestion here is the storage of electric energy. For many years we have been capable of storing electric energy as chemical energy via batteries; this, however, is not a satisfactory answer to the problem because, though functional, it is uneconomical. In an alternative storage method, off-peak energy is used to pump water to an elevated reservoir; the process is reversed at peak load times, thus converting energy from electric to potential, then to electric again. This system has been found to meet the criteria of both function and economy in a number of applications.

Role of the Engineer

Decisions involve alternatives. Even the single investment opportunity requires acceptance or rejection. The specialized training and knowledge of the engineer is often required to properly describe alternatives and to make estimates with regard to them. The ensuing economic comparisons are not exclusively an engineering activity.

Decisions among alternatives can be made from the viewpoint of an engineer in the midst of design, or a manager acting upon a number of investment opportunities and alternatives within each opportunity. The engineer has a role in this latter viewpoint also since estimates, judgments, and alternatives are

involved in opportunities having technical considerations. The organization of this book is based more on the latter viewpoint, although some examples will reflect the former.

Role of the Manager

Our nation's productive facilities change in response to the affluence of people and to the technology of innovators. As productive facilities evolve from a dependence upon manual effort to a reliance upon mechanized, automated, computer-controlled systems, the responsibility of the manager changes from a person-oriented to a machine-oriented role. In response to this changing role the manager must learn:

1. To interview, screen, and select equipment just as effectively as one should interview, screen, and select people.
2. That, like people, equipment has both desirable and undesirable characteristics to be weighed.
3. To ask the right questions concerning the prospective equipment; acquisition is a somewhat irreversible process. Once an equipment is "hired," "firing" it generally involves substantial economic penalty.
4. That some "team" concepts are equally applicable to equipment (selecting a team of nine excellent first basemen certainly must fail to optimize a team's baseball prospects).
5. To assign carefully, according to ability, the task of production to the various items of equipment.
6. To devise systems of periodic checkups to verify that the equipment is still adequate and appropriate.
7. To be aware of new (equipment) talents that will be available in the forseeable future.

We have in mind the manager of fixed assets, that is, plant and equipment. The decisions of managers of inventory are treated in other books (especially those of operations research); the decisions of managers of cash (comptroller and/or treasurer) are deferred to texts in the appropriate area of finance, control, or budgeting, except as they have relevance to the capital expenditure decision.

Objectives of Analysis

The ultimate objective of analysis is action. Action comes as a result of implementing a managerial decision. Frequently that decision is one of accepting or rejecting an investment opportu-

nity and is based on a comparison that identifies the best of the alternatives. For an action required by legal, franchise, humanitarian, or other overriding considerations, "best" may simply be the loss-minimizing alternative. Economic analysis permits identification of the best alternative and sometimes reveals economic feasibility; by this means, analysis facilitates managerial decision making and can ultimately lead to prescription of a course of action.

Consider next the question of how we might describe *best* or *good enough* in more meaningful ways. Approaching this question from the viewpoint of the enterprise, we can see that our response is dependent upon the objectives of the enterprise as well as the political and economic structure of the nation.

Objectives of the Enterprise

If a comparison of alternatives is to yield results, the objectives by which the alternatives are to be evaluated must be specified. Possibilities include:

1. Maximize profit.
2. Minimize cost.
3. Maximize the benefit-cost ratio.
4. Maximize profit rate.
5. Minimize risk of loss.
6. Maximize safety.
7. Maximize quality of service.
8. Maximize sales.
9. Minimize cyclic fluctuations of the firm.
10. Minimize cyclic fluctuations of the economy.
11. Maximize growth rate of the firm.
12. Maximize prestige of the firm.
13. Maximize service to community needs by providing both money and people.
14. Maximize economic, physical, and psychological security of employees by recreation facilities, counseling services, challenging roles, generous wages, and so forth.
15. Create an optimal "public image."

In any specific decision it is unlikely that we can simultaneously satisfy more than one of these objectives. In general, analyses in this book will be based on the first objective, maximization of profit. In public projects this is equivalent to maximizing the amount by which annualized benefits exceed annualized costs.

Utility of money concepts, consideration of nonmonetized factors, and certain mechanisms in the capital budgeting process treated later will permit some relaxation of the apparent narrowness of our objective. The triple limitations of available time, money, and information may lead to decisions that approach rather than reach our objective.

Capital Expenditure or Investment Opportunity Alternatives

A capital expenditure opportunity is one that requires a nontrivial present cash outlay and offers hope of future benefits extending over two or more years. This description is broad enough to include many research, training, and advertising expenditures. Consider the many alternative equipment and facility possibilities in such problems or purposes as:

1. Alleviation of a shortage of potable water.
2. Fastening of two materials.
3. Systems of communication.
4. Production of a certain item.
5. Harnessing natural sources of energy.
6. Fabrication of a geometric shape.
7. Transportation of people from suburb to city to suburb.
8. Manufacture of a gear.
9. Reduction in the danger of flood.

Suboptimization and the Accept-reject Decision

The majority of capital expenditure decisions of this book appear to be made on a one-by-one basis and as such suggest the possibility of nonoptimality from the viewpoint of the firm. In fact, however, the acceptance decision is a *preliminary* one (perhaps from a departmental viewpoint) with further screening and review to follow. Later, from a company viewpoint, the same projects will be reexamined (1) by a number of upper management persons each having familiarity with special considerations of the overall system; (2) simultaneously with many other projects so that a *balance* of interrelated projects can be attained, with approval tending to be based on company rather than department or project considerations; and (3) for consistency with long-range operating and financial plans of the company. It will be shown later that even the economic aspects of accept-reject decisions are not entirely separable from the overall capital budgeting decisions.