Norman N. Barish and Seymour Kaplan

ECONOMIC ANALYSIS FOR ENGINEERING AND MANAGERIAL DECISION MAKING

Second Edition

ECONOMIC ANALYSIS

For Engineering and Managerial Decision Making

SECOND EDITION

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PREFACE TO THE SECOND EDITION

The aims and underlying philosophy of this second edition are the same as those of the first edition, and its basic organization remains the same. As noted by a distinguished reviewer of this revision, "The reason that the original content can be retained so completely is that it was, in effect, 15 years ahead of its time . . . . When published in 1962 it was a giant stride forward over the micro-, business-, and engineering-economics texts then available. . . . The described procedures . . . were right on the edge of the state of the art. . . ."

In addition to updating the material in the first edition, numerous improvements and additions have been made: interest factors follow the ASEE standardized notation; a large number of new problems have been added; treatment of various subjects in decision making under risk and uncertainty, including coverage of decision trees, value of information, utility theory, and game theory, has been expanded; increased attention has been given to topics such as capital rationing models, input-output analysis, inflation, time series analysis, and forecasting; and new chapters have been added on benefit-cost studies and public utilities.

The book retains its comprehensive character, which provides flexibility for the instructor and a valuable reference source for students and practitioners.

Norman N. Barish

Seymour Kaplan

PREFACE TO THE FIRST EDITION

Making decisions is the key function in engineering and business activity. Most of the engineering and management decisions made in industry are or should be based upon economic analyses.

This book is directed to persons who are concerned with these economic analyses and aims to present the basic reasoning and methodology of various disciplines which are important in decision making. It is designed to be practical rather than theoretical. It is technique-oriented. Mathematical symbolism is kept as simple as possible and derivations or proofs are presented only if they are simple and will illuminate the subject matter.

The book has been planned as a college text for students of engineering, business, and economics for use in half-year or full-year courses which frequently bear such titles as engineering economy; managerial, industrial, or business economics; or business analysis. It has also been designed to be useful to operating executives and staff personnel. It can serve both groups as a reference book on the economic aspects of business decision making.

Although no specified background or courses are prerequisite for its use, it is anticipated that many students using this book will have completed courses in such subjects as accounting, economics and management, and probability and statistics. However, relevant aspects of all these subjects are presented in problem-oriented introductions throughout the text. Readers with no background in some of these areas should therefore be able to follow most of the text presentation. The Bibliography presents supplementary readings useful for those who desire further background in some of these areas. (In a few places, a knowledge of the calculus would be helpful, but the text can be readily followed omitting the mathematical derivations.)

The book is arranged to permit maximum flexibility in the choice of material and in the sequence of class presentation and to provide for its use in classes with students of different backgrounds. Sufficient material is included for courses and course sequences of varying length. Each section and chapter has been made as self-sufficient as possible.

1. Chapters 3 to 12 cover the fundamental material on project and equipment evaluation traditionally included in courses in engineering economy.
2. Chapter 19 and 20 are an extension of the traditional material on decision making under certainty to minimum-cost and maximum-profit determinations.
3. Chapters 16 to 18 cover the managerial economic problems of capital budgeting.
4. Chapters 13 and 21 to 26 examine the subject of risk, uncertainty, and intangibles in economic analysis. For those who desire to omit most of the material on probability and statistical techniques, the course coverage may be restricted to Chapter 13.
5. Chapters 27 to 35 are concerned with elements of economic measurement and analysis and with the managerial economic problems of forecasting sales, costs, and profits.

Each of these groups (and sections of them) may be included in or excluded from course coverage depending upon the objectives of the course and the background of the student.

I am grateful to the many business organizations and executives with whom I have been associated and who have contributed directly and indirectly to whatever value this book may have as well as to those who have permitted me to use illustrations included in this book. I am indebted to Professor Sir Ronald A. Fisher, F.R.S., Cambridge, and to Dr. Frank Yates, F.R.S., Rothamsted, also to Messrs. Oliver & Boyd, Ltd., Edinburgh, for permission to reprint Table 24 in the Appendix from their book *Statistical Tables for Biological, Agricultural and Medical Research*, and to Stephen T. Heinaman and the Armstrong Cork Company for permission to reproduce forms for evaluating capital expenditures. I am particularly grateful to Miss Justine L. Schmalzl for her capable and invaluable assistance in the preparation of text, tables, and charts. I am indebted to Norbert Hauser for reading the entire manuscript and offering helpful comments. I wish to thank Professors Eugene D. Homer, Arthur Lesser, Jr., and Wallace J. Richardson as well as Messrs. Harold Greenberg and Irwin Greenberg for reading and commenting on various sections of the book and Miss Betty Kiernan for typing the manuscript.

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CHAPTER
ONE

THE DECISION PROCESS

Economic analysis for engineering economy and management decision making encompasses the rational, scientific methods of analysis which are available to engineers and staff management personnel. This volume emphasizes the quantitative aspects of decision making because they are most amenable to scientific treatment.

The success of an enterprise or organization depends upon how effectively the managers and engineers do the following:

1. Decide what needs to be done and how and when
2. Administer the persons and groups in the enterprise who will carry out the decisions

We are concerned in this book with the first of these tasks, with the decisions which the engineers and managers of business enterprises and other organizations must recommend and make.

Engineering and Managerial Economic Decisions. The methods of analysis considered in this book are applicable to a large variety of engineering and economic decisions. For example: What should be the economic objective of the enterprise? its scope? its policies? its organizational structure? its systems? its strategies? its pricing procedures? What are the best sizes, numbers, and locations of servicing facilities for repairing the company's products? Should a fleet of delivery trucks be leased or bought?

Which research projects should be undertaken and how much should be invested in each? Which alternative engineering design should be chosen? Should production planning be performed manually or by means of a high-speed digital computer? If a computer system is desirable, which of the available computers should be chosen?

Is centralized or decentralized control of inventories more desirable? Should larger quantities of raw materials and parts be purchased at one time? Should a larger safety stock of finished goods be maintained? How many finished-goods warehouses should be constructed and where should they be located?

How large should the capital budget of the company be? Which investment proposals should be included? Should a proposed new venture be established? Should plant capacity be expanded? If yes, how much excess capacity should be built now to meet future anticipated needs? Should new labor-saving automation equipment be purchased? If yes, which of the competing types should be chosen?

These are just a few of the types of questions which are amenable to solution by the analytic methods discussed in this book. The analyses and evaluations to reach decisions on these questions can be very simple or very sophisticated. How well these analyses and evaluations are made will affect the future welfare of the business and will determine the quality of the engineering design.

This discussion of problems requiring decisions has been stated in terms which are applicable to business enterprises. However, many of these same questions and the methods of analysis and evaluation apply equally to activities in government and nonprofit organizations.

Importance of Economic Considerations. The significance of economic considerations in engineering decision making was recognized over a half century ago by one of the first writers of a text on the subject:†

> Every engineering structure, with few exceptions, is first suggested by economic requirements, and the design of every part, excepting few, and of the whole is finally judged from the economic standpoint
>
> It is therefore apparent that the so-called principles of design are subordinate to the principles which underlie economic judgment
>
> This important fact usually escapes the student of engineering because, while he may have seen hundreds of books on the principles of design and his time is largely employed in studying these principles and their applications, he has seen not one book devoted to the principles which underlie economic judgement, and his books and his instructors merely mention these in passing

Uneconomic "Modern" Decisions. Many computer systems have been adopted by company managements in recent years based upon evaluation studies which indicated that tangible costs would be reduced, or remain the same, or just increase slightly. The incentive behind the adoption of some of these systems has been the desire of company executives to have the "most modern, advanced data-processing system." There are numerous explanations for the errors of evalu-

† John Charles Lounsbury Fish, *Engineering Economics*, 2d ed., McGraw-Hill Book Company, New York, 1923, preface to the 1st ed

ation which have been made in many of these cases and many of these will be discussed later However, it will be useful to review two factors briefly

Many of the problems and complications of actual operation are not envisioned by the systems planners prior to the installation of the computer system Why? Sometimes equipment used in the system does not perform to design specifications In other cases, the people familiar with the machine capabilities are not familiar enough with procedural requirements and the people who know the procedural requirements do not know the machine capabilities

Another factor in some cases is that, with the use of some of the modern data-processing and electronic equipment, the incremental costs of producing reports are low and the ability of the equipment to produce these reports swiftly is high. Under these conditions, reports of limited usefulness have sometimes proliferated because they have been easily available from data already coded and stored in readily usable form The natural tendency to increase the number of reports is encouraged by the great effectiveness of this new equipment. The result is the continuance on a regular basis of reports with limited or no usefulness or only a one-time usefulness.

These uneconomic "modern" decisions illustrate three points·

1. Decisions made on the basis of modernity, progressiveness, rules of thumb, and hunch can be uneconomic.
2. Engineering and economic analyses for decision making should be entrusted only to qualified analysts who are aware of both the system requirements and the machine capabilities.
3. Administrative performance after decisions have been reached can alter the relative economy of operations. Effective managerial control is usually essential to insure that anticipated cost savings are obtained and that anticipated economic advantages are achieved

Economic Evaluation of Existing Company Policies. Many companies have over the years developed policies in various areas of their operations which function as guideposts for decision making. Some of these policies were valid when they were first established years ago but have lost their validity because of changed conditions. Others were never good policies and were continued because their economic implications were never carefully estimated.

Examples of the former type of policies are these: maintain a complete line of products to meet customer requirements (valid when the product line was relatively small); make all appointments to supervisory and managerial positions by promotion (valid when the organization was small and specialized technical or managerial skills were not required).

Examples of the latter types of policies are these: maintain inventory levels on all items so as never to be out of stock (usually unachievable, resulting in uneconomically high inventory levels); maintain employment at stable levels, smoothing out all seasonal and cyclical demand fluctuations by varying the stock level (absolute stability of employment is not always economically justifiable).

The economic effects of all company policies on current and future operations should be periodically evaluated to ascertain whether the policies should be continued or amended

Rational Objectives. Successful economic decision making may involve very simple procedures in one case and very complex technical ones in another However, some basic elements are common to all economic analyses

A first, and crucial, step in any economic evaluation is a logical statement of the objectives to be achieved When the relative importance of these objectives has been determined, they will furnish the basis for establishing the criteria for the desirability of alternative proposals A rational set of objectives is therefore of pivotal importance in engineering and economic decision making.

Data Collection. It is necessary to collect data on the environment in which the various alternative proposals will operate. These data are of three types: quantitative data based on observations which describe organizational, financial, procedural, physical, and operational relationships and flows; qualitative data based on observations which describe these relationships and flows, and data based upon the opinions, intuition, and personal judgment of experts with experience These types of data have been presented in descending order of general usefulness in economic analysis. Quantitative data are most amenable to scientific analysis Qualitative data do not usually permit as rigorous analytic manipulation nor as definite a conclusion. Data based on personal opinions have been frequently found to be unconsciously biased and unreliable for many reasons, some of which can be explained by statistical probability and psychology.

A critical approach is necessary in gathering data. The engineering and economic analyst must always be silently critical and skeptical of all alleged facts. A statement is considered suspect until it is proved true. A well-executed analysis will not be worth the paper it is written on if it is based on incorrect or incomplete data

The problem of obtaining correct data is complicated because there may be a number of different answers to the same question, for example, how is a certain activity performed?

1 The way the supervisor thinks it is done
2 The way the employee thinks the supervisor wants it done
3 The way the supervisor tells the employee to do it
4 The way the instruction manual says it should be done
5. The way it is actually done

People mislead not only from malicious intent: they sometimes are misinformed themselves; they sometimes do not desire to admit their ignorance and therefore guess at the answer. Written information may be incorrect because it is out of date The only answer to the accuracy problem is to double-check all crucial information by actual observation whenever possible.

Determining the Alternatives. When engineering and business decisions are made logically, they always involve an evaluation of alternative courses of action As much as possible all alternative courses of action should be considered and evaluated Otherwise the evaluation may suggest an alternative as optimum which is only the best among those alternatives considered, but is not the best of all possible ones The best decision may then be missed

Alternative courses of action are determined at all levels in an organization by operating and supervisory as well as staff research and engineering personnel Alternatives for accomplishing the objectives of the study also suggest themselves to an analyst at the same time as the data are being gathered, analyzed, and evaluated Not only should alternatives be considered which are available with existing technology but, in some cases, it may be feasible to consider the research and development of new technology or the modification of existing facilities

If an engineer is told that a particular part should be fabricated either using aluminum or brass, it is easier to just compare the aluminum alternative vs the brass one, than to consider other possibilities. Plastic, for example, might be preferable to both aluminum and brass but will not enter the decision process unless the engineer makes it his business to search for additional alternatives. Often, the number of alternatives which can be generated depends on how much time one is willing to spend thinking about them. Time spent in this way may be a good investment but naturally is limited in most decision-making environments by practical considerations

A possible simplified procedure for developing alternatives is shown in Figure 1-1 Once a need for a problem solution is perceived, it is useful to question whether the perceived problem is a real problem It may turn out that the perception was based on incomplete or incorrect information For example, my plant security manager tells me that there have been repeated attempts to enter the skylight of a warehouse where expensive inventory items are stored His information is based on the fact that the existing automatic burglar alarm system has been activated on numerous occasions. He has recommended that a 24-hour guard be posted at the warehouse At first appearance there definitely seems to be a security problem However, after further investigation it turns out that the alarms were set off by birds, attracted to the skylight by heat The need for additional security, based on the existing information, does not exist

When a problem does exist, the decision maker should determine whether it is temporary or permanent. A problem which will disappear in a week will require a different approach (need different alternatives) than a similar one which will last into the forseeable future This is a rather obvious point but it is one which is often overlooked

Once a complete set of alternatives has been found, a systematic means of comparison should be used In making the comparisons it is important to consider keeping any existing system as one of the alternatives. Many analysts automatically assume that if replacements for an existing system are being considered the existing system should automatically be discarded. This is obviously an incorrect procedure

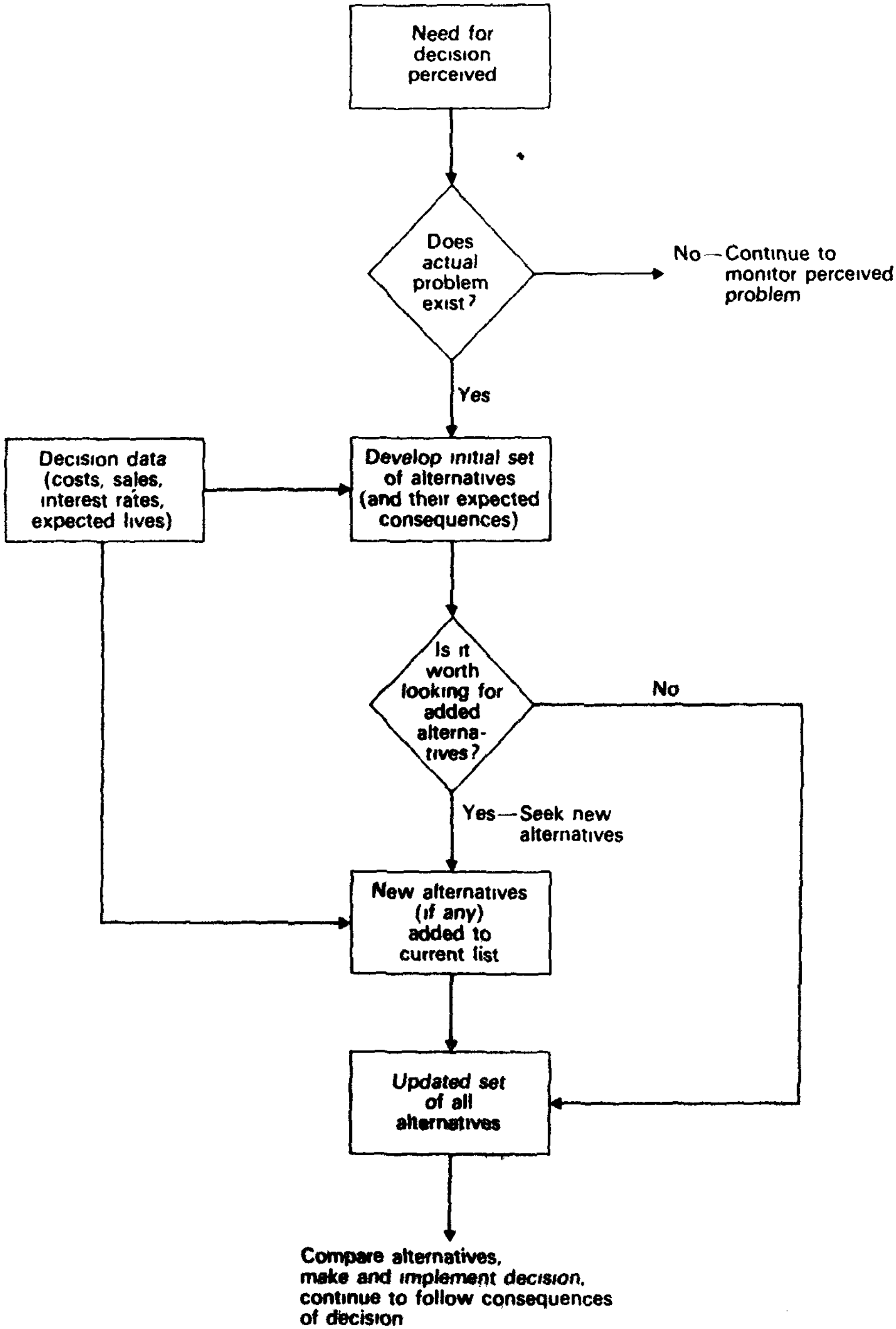

Figure 1-1 A possible plan for developing alternatives

A common method for comparing alternatives is to do pairwise comparisons. This is especially useful when the alternatives are mutually exclusive (only one can be chosen) and exactly one must be chosen. Suppose there are four, called A, B, C, and D We can select the one with the least cost, which might be C, and compare it against the one with the next smallest cost, say B. The preferred alternative, would then be compared with the next lowest cost alternative, A. The "winner" would then be compared with the last contender, D, and a final selection made. This methodology simplifies the analysis in that only two alternatives are being compared at each stage of the decision process.

It is important that alternative possibilities be considered separately as well as in combination with each other This should reduce a source of error in economic evaluations which has in the past crept into the economic justification for computer installations Let us suppose that there is a noncomputer system for performing a task which is better than the presently used noncomputer system. Then, logically, the economy of the computer system should be compared with this better noncomputer method as well as with any other possible alternatives The study preliminary to a computer application will frequently disclose possibilities for major systems improvements and savings which are not necessarily tied to use of the computer The alternative of a computer installation should not be credited with these savings

Decision-making Costs. For many engineering and business decisions, dollar income and costs provide convenient measures for summarizing the potential future performance of alternative courses of action However, costs as determined by the usual accounting systems, which are designed to measure past occurrences rather than future prospects, are not always suitable for decision-making purposes We must therefore examine how accounting costs have been determined before using them in economic analysis The handling of depreciation, interest, profits, and income taxes in economy analyses must receive careful consideration Potential pitfalls from using sunk (past) costs to estimate future expected cost should be avoided

Evaluating Investment Proposals. When all the significant effects of an investment proposal can be estimated in dollars, a tangible analysis of the worth of the proposal can be made Annual-cost comparisons are the most commonly used and are easily understood in industry because the format is analogous (but only in some respects) to a forecasted profit and loss statement. Present-worth and premium-worth calculations are useful for comparisons of certain kinds of long-term investment proposals Rate-of-return determinations provide a measure of profitability which is quite universal in its applicability to all kinds of investment proposals Rate-of-return evaluation is especially useful in overall capital-budgeting procedures Equal-cost determinations are helpful when we are uncertain about the correct value to use for one important factor in our dollar analysis They are also useful for evaluating the sensitivity of a decision to changes in the expected value of one important factor. Payout determinations are especially valuable when a business is short of capital funds and desires to make investments in which the funds will be recovered rapidly Special evaluation techniques have been developed for use in the governmental sector (benefit-cost analysis) In public utility decision making the tangible analysis of the worth of proposals also has some special characteristics

Capital management represents a central decision-making function in the enterprise What are the investment opportunities in the firm? What are the sources of capital funds? Which investment opportunities should be undertaken and which sources of funds utilized to finance these investments to promote the profitability and long-range growth of the enterprise? Capital-budgeting procedures should be designed to provide rational answers to these questions

Minimum Costs or Maximum Profits. Many decisions which involve the choice of the size or the amount of an activity or a facility may be handled by determining the size or amount which will result in a minimum-cost point. Other decisions involving the allocation of limited resources may be determined by programming these resources to achieve a minimum-cost or maximum-profit objective.

Risk, Uncertainty, and Intangibles. We can classify engineering and business decisions as to whether the conditions under which the decision is made are certain, risky, uncertain (partial or complete), or both risky and uncertain. Risk exists when each alternative will lead to one of a set of possible outcomes and there is a known probability of each outcome. Uncertainty exists when the probabilities of these outcomes are completely or partially unknown For example, if one alternative is to install an automatic-control device to correct a quality defect and if there is a known probability that such a device will correct this trouble only one time in 10, the conditions are risky. If the probability that it will correct the defect is unknown or only partially known, the conditions are uncertain as well as risky

In actual fact, all economic analyses are made under conditions of risk and uncertainty to varying degrees. Evaluations of the relative desirability of alternatives require estimates of present conditions as well as forecasts of future events, which involve risks and uncertainties. Yet none of the methods of analysis thus far mentioned explicitly take account of risk and uncertainty.

To take account of risk explicitly, we need to apply theories of statistics, probability, utility theory, probability distributions, sampling, and confidence limits. Decision theory and game theory can be used when complete uncertainty is present or when decisions must be made against opponents who can employ strategies of their own.

When the data describing important environmental relationships are not available, experimentation may be desirable to obtain required quantitative data Unfortunately, it is frequently difficult and prohibitively expensive to arrange many of the types of experiments required in economic analysis. The use of models and Monte Carlo simulations of actual operating conditions can sometimes be helpful in developing data. Monte Carlo techniques may be helpful with models of situations in which risk is present. Analytic queuing models can be useful in waiting-time problems.

When we cannot measure the risks and uncertainty in an economic analysis, they become intangible factors in the evaluation In addition, there may be significant factors involved in the decision which cannot be quantified into dollars or another common denominator It may be very difficult to devise adequate, scientific methods for evaluating these intangibles

Economic and Business Forecasting. All the decisions we have been discussing affect future events Therefore, no mathematical calculation, however sophisticated, erudite, and accurate, can be better than the validity and reliability of the forecasted data used in the analysis. The forecasted revenues and costs will depend upon the future state of the company, the industry or industries, and the economy. To assist in this forecasting, it is helpful to have an understanding of the economics of the firm and its relationship to other firms in the same, competing, and complementary industries Time-series and correlation analysis are useful tools for the econometric task of measuring the nature of the demand for various products and services as well as forecasting future values for various factors Mathematical models of the economy provide a different approach to economic forecasting. Index numbers and other measures of the economy are helpful in forecasting future economic activity and sales of a company's product

Available methods of forecasting future requirements for the goods and services of a company are varied, but they are all fraught with large possibilities for error It is well to use as many different independent approaches as possible to check one against the other in an attempt to discover the sources of any mistakes.

If we have developed a forecast of sales and can determine how our costs will vary in the short run with changes in output rate, we can forecast our short-run profits. We can also use this short-run revenue-cost comparison (break-even analysis) In public utility decision making the tangible analysis of the worth of long run a company can vary other factors in addition to output rate. The long-run cost function shows the average cost of producing a product or service, assuming that the correct size of facility has been chosen, and is useful for making facility-size-and-location decisions.

Cost of Data Gathering, Analysis, and Evaluation. We are confronted with the problem of making a decision on how much cost and effort it is economical to spend to make the economic decision. Data gathering, analysis, and evaluation are expensive It is not economic to attempt to collect all the information which might be pertinent to an optimum solution and make all of the analyses and evaluations of all the alternatives which may conceivably yield useful results.

What are some of the factors which will determine the amount of data gathering, analysis, and evaluation which is desirable?

A decision on whether or not to research, develop, manufacture, and market a proposed new line of products may or may not be more important to the future welfare of the business than a decision on a proposed change in the product-warranty policy. Other things being equal, a decision on whether or not to invest $500 in laborsaving equipment which will yield a prospective return of 20 percent is not as crucial as whether or not to invest $500,000 in laborsaving equipment which will yield the same prospective rate of return. Obviously, more time and