APPLIED SYSTEMS ANALYSIS

Engineering Planning and Technology Management

Richard de Neufville
Massachusetts Institute of Technology

McGraw-Hill Publishing Company
New York St. Louis San Francisco Auckland Bogotá Caracas Hamburg Lisbon London Madrid Mexico Milan Montreal New Delhi Oklahoma City Paris San Juan São Paulo Singapore Sydney Tokyo Toronto

CHAPTER 10

INTRODUCTION

10.1 PURPOSE

This introduction describes the overall features of evaluation. The objective is to put into context the specific approaches and techniques presented in subsequent chapters.

This chapter is unique compared with other discussions of evaluation. The basic argument is that different methods are suitable for different circumstances. It compares the various approaches to evaluation and suggests when each might be most suitable. This presentation is unique because other texts focus on particular approaches, such as engineering economy or decision analysis, and ignore the basic issue the analyst continually faces: what is the best approach to use for a specific problem?

This chapter sets the tone for the entire section on evaluation. The techniques are presented in relation to the issues they deal with rather than their disciplinary source. The idea is to provide the systems analyst with a synthesis of the methods that relates directly to the problems.

The chapter begins by defining the purpose of evaluation and the fundamental problem this creates for the analyst: the choice of the appropriate method. It next identifies and describes the major assumptions that can be made about a particular situation or investment that is to be evaluated. Finally, it matches the different evaluation techniques with the circumstances they deal with most effectively. This organization provides the analyst with useful guidelines for choosing which approach to use in any particular situation.

10.2 NATURE OF PROBLEM

The purpose of evaluation is to help decisionmakers choose among projects and strategies. It does this by estimating how much any choice may be worth.

Operationally, the task of evaluation consists of identifying the potential advantages and disadvantages of any action and comparing them in some specific way. Generally speaking, evaluation leads to either of two results:

1. The identification of worthwhile choices, in which the advantages are greater than the disadvantages.
2. The ranking of choices by some index of merit, which indicates the relative value of each project and thus, within the limits of its precision, also identifies the best choices.

Decisionmakers naturally would prefer evaluations that define the best choices clearly. But they must also have confidence that these rankings are a valid indication of the relative merit of the possible choices. These two criteria create a fundamental dilemma for the analyst. The problem lies in the fact that precision in the evaluation depends on the assumptions one makes about the situation. As a rule, precision is increased by making more simplifying assumptions. Conversely, however, more simplifying assumptions make the evaluation less realistic and the results less acceptable.

To illustrate the relationship between simplification, precision, and reality, consider an evaluation you might personally face. Suppose that you have savings you want to invest. You would have several possible choices, for example, a savings account from which you can withdraw at any time, fixed placements for a specified period, and investments in some business. In general, the evaluation of these choices can be seen as a complicated problem: the returns from any investment may be risky; you may also have several objectives, for example to make a profit, to protect your savings, and to maintain flexibility in their use. If you consider all the complications, the evaluation can be difficult and the results unclear. How, for instance, does one measure security or flexibility in the use of one's assets, and how does one balance these considerations against profits? If you simplify the question by focussing on monetary returns, then one can carry out a probabilistic analysis that is quite exact, even though the overlapping distributions of the returns from the different projects may not lead to an unambiguous ranking. Further simplifying the problem by assuming that the returns from the investments can be predicted does allow one to establish a single, clear ranking of the investments—but eliminating risk may seem too unrealistic and make the result unacceptable.

The primary objective of the analyst is to achieve the most useful evaluation possible, the one that ranks the choices most clearly, while maintaining sufficient realism. The difficulty in achieving this objective is that no one approach or technique of evaluation is best for all occasions. The techniques depend on the

nature of the assumptions made, and the legitimacy of the assumptions depends in turn on the context of the evaluation.

The first problem for the evaluator is, thus, to choose the method of evaluation suitable for the occasion. This requires the analyst to begin by thinking about the situation and which assumptions are realistic.

10.3 POSSIBLE ASSUMPTIONS

The assumptions that can legitimately be made about any situation depend on the context of the evaluation. They are defined by the nature of both the decisionmakers and the projects.

The range of assumptions can be broadly divided into two categories of

1. Comparability between the elements of any evaluation
2. Degree of uncertainty in the possible choices

Comparability is the greater issue as it enters into all aspects of the evaluation. It concerns the possibility of comparing

1. Objects over time
2. Quantities of objects at any single time
3. Different objects
4. The preferences of different decisionmakers

The consequences of any choice may be valued differently depending on when they occur. A given amount of money, for example, is generally more valuable now than in the future because we can invest it and make it grow into a larger amount. It is consequently not appropriate to compare monetary benefits and costs that occur at different times directly; they should be transformed to a comparable basis (See Chapters 11 and 12). Other consequences may be assumed to be comparable over time. A life saved through a safety program might be equally valuable to society whenever it occurs.

It may or may not be reasonable to assume that each unit of benefit or cost is equally valuable. A starving person would presumably value the first plate of food much higher than the second or third. But in other situations the decisionmaker may indeed value consequences linearly with quantity. For example, a manufacturer may consider each unit of production equally valuable, when they all sell for the same price (See Chapter 14).

Only in special situations may we realistically assume that different kinds of consequences of a choice are directly comparable. The value of investments in safety, health, and economy are not comparable in any obvious way. Think for example of how you would establish the value of a life, and then think whether any individual would accept this price as realistic. Or think of trying to evaluate different materials for constructing an automobile: On what basis can we compare ductility, strength and ease of fabrication? The consequences are most directly comparable when all of them have immediate economic implications in that they produce profits and losses (See Chapters 18, 19, and 20).

Different decisionmakers or different parts of a community may, finally, have quite different tastes. When should we assume that it is reasonable to perform an evaluation with only one set of preferences? Clearly when we are concerned with a single decisionmaker. Possibly when we are working with a company or agency whose members are agreed on common goals. At other times it would be unreasonable to assume we can directly compare the preferences of various groups concerned with a decision. This topic is covered in more advanced texts (See Chapter 21).

The question of uncertainty cuts across these issues of comparability. The essential issue here is whether the evaluation assumes that the consequences of any choice can be predicted sufficiently accurately in advance. If yes, the analyst can work with a limited description of each choice. But if not, as is often the case (See Chapter 15), the consequences of each choice should be described by probability distributions, and the calculations become much more extensive. This extra effort limits—due to constraints on budget and time—the depth of analysis that may be devoted to other issues. It also changes the nature of the evaluation.

Taken as a whole, the set of assumptions that can be made about a situation defines the complexity and nature of the evaluation. It also defines the approach that should be taken.

10.4 HIERARCHY OF METHODS

The available methods for evaluation are based in three different disciplines: engineering, economics, and operations research. Each of these traditions focuses on a separate set of issues. Each is therefore appropriate for different kinds of problems.

The most basic approaches to evaluation are those of engineering economy. The essential issue here is how to compare money over time. The techniques consist of simple formulas, presented in Chapter 11. The pivotal parameter in this approach is the discount rate, which is the means of establishing the comparisons over time. Chapter 12 discusses the choice of this quantity. Engineering economy leads to a variety of related criteria of evaluation, such as the benefit-cost ratio, and these are presented in Chapter 13. This entire body of methods assumes that all parties to the evaluation agree on a single objective, that its valuation is linear with quantity, and that the consequences can be predicted. Generally these consequences are valued in terms of money, but sometimes, when the possible choices are all directed toward a single objective, for example the number of lives saved by different safety programs, the benefits may be numbered in terms of that objective. Engineering economy is most obviously suitable for situations

in which the various projects have predominantly financial effects. Among these would be investments that either reduce costs or produce marketable goods, such as factories, transportation, energy conservation and production, et cetera.

Recently, operations research has led to the development of decision analysis. This method focuses on the existence of uncertainty about the descriptions of the consequences of any choice. Since the planning and design of engineering systems inherently involves considerable uncertainty about both costs and effects, as Chapters 14 and 15 indicate, decision analysis is a most useful technique. It provides an effective means to represent the choices and the risk, to calculate the preferred choice at any time (see Chapter 16), and to define optimal strategies over time (Chapter 17). Decision analysis is the only approach to evaluation that is really suitable when uncertainty is a major factor.

Operations research has also led to a parallel development of practical methods of dealing with the lack of comparability between different quantities of any item, that is, the nonlinearity of their values. These methods are developed for both single and multiple attributes in the three chapters on utility functions, Chapters 18, 19, and 20. Utility functions are often presented integrally with decision analysis in theoretical texts, but as these techniques address quite different issues, applicable in different circumstances, they are developed separately here.

Welfare economics also deals with nonlinear valuations of consequences. The principal method here is that of "social cost-benefit analysis," an extension of ordinary benefit-cost analysis. (The term cost-benefit is due to the fact that the techniques were first put into practice in Britain!) The calculations are direct, once the preferences of a group are defined. The particular contribution of this approach is that it exploits the characteristics of the nonlinear functions to define optimal policies analytically, and that these solutions provide quite practical guidelines. This is a most useful result and makes this the procedure of choice when values are nonlinear and uncertainty is not an issue. For situations involving multiple parties with different preferences, finally, there are no operational techniques. The problem is too complicated to permit satisfactory analytic solutions except in simple textbook examples. Work in economics and operations research, however, has led to some guidelines that are useful to the analyst. These two topics are covered in more advanced texts (See Chapter 21).

The relative position of the different approaches to evaluation are summarized in Table 10.1. They form a hierarchy from the simplest techniques of engineering economy, which are only legitimate if strict conditions can be accepted, to the most general concepts of welfare economics.

Each of the major approaches and issues in evaluation are presented in detail in the following chapters:

Engineering Economy: 11 to 14
Decision Analysis: 15 to 17
Nonlinear Valuation: 18 to 21

TABLE 10.1
Hierarchy of evaluation techniques

Approach		Assumptions made				Operational characteristics
Disciplinary basis	**Evaluation method**	**Time value**	**Uncertain consequences**	**Nonlinear values**	**Multiple decisionmakers**	
Engineering economy	Benefit-cost, etc.	X				Easy formulas
Operations research	Decision analysis	X	X			Probabilities inaccurate Computations easy
Operations research	Decision analysis with utility	X	X	X		Utilities approximate
Economics	Social cost-benefit analysis	X		X		Value data difficult to obtain
Economics	Welfare economics	X		X	X	Only general guidelines available

Because the presentation aims to develop a synthesis between the several techniques of evaluation, the organization does not divide the detailed material into conventional bundles. For example, texts in both economics and decision analysis discuss nonlinear valuation of preferences using their own approaches and little, if any, reference to the alternative. Here both possibilities are presented together so that the analyst can see the relative strengths of each and choose between them as the occasion warrants. The chapters on decision analysis focus on methods of dealing with uncertainty. This differs from a conventional treatment in that it incorporates methods of assessing the uncertainty, but leaves the methods for obtaining the nonlinear values to the subsequent section.