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2012-09-21

Engineering Project Appraisal (2nd. ed)

Martin G. Rogers
Martin Rogers, Martin.rogers@dit.ie

Aidan Duffy
Dublin Institute of Technology, aidan.duffy@dit.ie

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Chapter 1

Decision Making and Project Appraisal

1.1 Decision making context

Let us firstly discuss the identity of the decision maker. In answer to the question as to whether individuals or organisations make decisions, it is a widely held view that managerial decision making is essentially an individual process, but one which takes place within an organisational context. Therefore, while the decision maker is central to the process, any given decision made may influence other individuals and groups both within and outside the organisation, as well as having the potential to influence the surrounding economic, social and technical environment within which they all operate.

In the particular context of engineering project appraisal, complex decisions may need to be resolved involving not only the definition and evaluation of alternative actions, but also the resolution of how the chosen project should be physically undertaken. Such complex decisions, often involving the expenditure of vast amounts of money, are rarely taken by one single individual decision maker, such as a government minister, a technical expert or an administrator. Even if the final legal responsibility does lie with one specific individual, the decision will only be taken after consultation between this designated individual and other interested parties. For example, the final decision regarding whether a major highway project will proceed is the responsibility of the relevant government minister. However, his or her decision is made only after a consultation process with interested parties has been completed, usually by means of a formal public inquiry at which all affected parties are represented. Such a decision could in some cases be the ultimate responsibility of a collection of individual decision makers, such as a cabinet of government ministers or an elected or appointed body. Groups seeking to directly influence the decision maker, such as professional representative institutions or local community groups, could be directly affected by the decision. All these 'actors' are what Banville *et al.* (1993) call primary stakeholders in the decision process. They have a pre-eminent interest in the outcome of the process and will intercede to directly influence it. Also,

Engineering Project Appraisal: The Evaluation of Alternative Development Schemes, Second Edition.
Martin Rogers and Aidan Duffy.
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there are third parties to the decision, such as environmental and economic pressure groups that are affected only in general terms by the decision. Termed secondary stakeholders, they do not actively participate in making the decision. Their preferences, however, must be considered.

In such complex cases, it is usual for one of the primary stakeholders central to the decision process to be identified and designated as the decision maker. In the context of the appraisal, therefore, the decision is, in effect, reduced to an individual process. The diverse backgrounds and differing perspectives of the various stakeholders may mean that not all can benefit directly from the decision-making procedure. This chosen stakeholder, as the designated decision maker, then plays a critical part in the process. In some circumstances, however, he or she may only be a spokesperson for all the stakeholders, both primary and secondary. Whatever the relative influence of the various actors, the process requires that a decision maker be identified, even if the objectives specified by the chosen party are those commonly held or assumed to be commonly held by the entire group of stakeholders.

Although the actual process of decision making is generally carried out by the designated decision maker, in certain complex and/or problematic situations it is more usual for it to be undertaken by a separate party who is expert in the field of decision theory. This person, called the facilitator or the analyst, can work alone or as leader of a team. The function of the analyst is to explain the mechanics of the decision process to the decision maker, obtain all required input information and interpret the results, possibly with the use of decision models, in an easily understandable way.

For the purposes of this book, it will be assumed that the decision maker is an individual, responsible for each step in the decision process, with the ability to directly influence the decision-making procedure.

1.2 Techniques for decision making

A decision is only needed when there is a choice between different options. Such a choice can be made using either a non-analytic or an analytic technique. The first type is used for less important, relatively trivial decisions. The second type is required for more complex decisions involving the irreversible allocation of significant resources. These techniques justify greater input in terms of time and expense on the part of the decision maker.

1.2.1 Non-analytical decision making

Some decisions are made without conscious consideration, on the basis that they are perceived by the decision maker as being ‘right’. These are intuitive in nature and reflect an ingrained belief held by the decision maker in relation to the situation

under examination. There is, however, the danger that the decision environment may have changed and that new conditions could now prevail, resulting in the decision maker's intuition being misplaced and incorrect. For this reason, decisions based on intuition should only be used with extreme care, in matters where the outcome is of small consequence.

The other type of decision in this category – judgemental decisions – are more 'rational' or reasoned in their approach than the first type. They are appropriate only for those decisions that recur. The decision maker consciously reasons out the probable outcomes of the possible alternatives using his or her judgement, which has been developed from past experience and general knowledge. He or she selects the alternative that he or she believes will deliver the most desirable outcome. For a large organisation where the same types of decision tend to recur very frequently, these types of decision can be very useful. The similarity between these frequently occurring decision situations allows the effective use of 'programmed' decisions where, like a computer-based algorithm, the selection of options is highly structured and consists of an ordered sequence of clearly defined steps. An example of such a programmed decision is the use of a code of practice by a structural engineer to design a reinforced concrete building. Because the set of design decisions is standard for such a process, the code of practice provides a guide for the designer regarding the major decisions that should be made and the sequence in which they should be addressed. Professional judgement alone is inadequate for this decision process, as such a problem can be very complicated. Because the code of practice is used successfully by structural engineers on a daily basis to design reinforced concrete structures, they have the confidence that using this 'programme' as a framework for their design decision will result in a properly designed building. Such codes of practice are not static, unchanging documents, but are amended as technological advances dictate. In general terms, within this type of decision, the 'programme' must be altered to take account of situational changes, be they alterations in the economic, social or technological environment.

It is important, therefore, to distinguish between a programmed decision and a non-programmed decision. As previously defined, a programmed decision is applied to structured or routine problems, involving repetitive work and relying primarily on previously established criteria. Many of the problems at the lower levels of organisations are often routine and well defined, requiring less decision discretion and analysis. (For example, a relatively junior engineer in the organisation would be competent to carry out the structural design procedure referred to in the previous paragraph.) These are classified as 'non-analytical' decisions. Non-programmed decisions, on the other hand, are used for new, unstructured and ill-defined situations of a non-recurring nature, requiring substantial analysis on the part of the decision maker. Because of the unstructured nature of such decisions, managers, as they become more senior, are increasingly involved in these types of decisions (Figure 1.1).

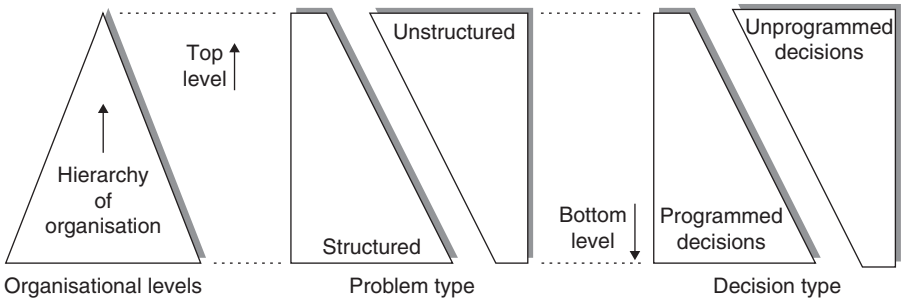

Figure 1.1 Types of problems and decisions at different levels of the organisation.

1.2.2 Analytical decision making

Non-programmed decisions are thus complicated in nature, involving a large number of factors where only correct actions will give rise to the desired results, and correct actions call for correct decisions carried out within an analytical framework. The probability of the correct choice being made in such situations is greatly increased by adopting a 'reasoned' or 'rational' approach that provides the appropriate analytical structure within which a coherent decision can be formulated.

1.2.3 Reasoned choice

The 'reasoned choice' model of individual or group decisions provides a technical foundation for non-programmed, non-recurring decisions (Zey, 1992). It comprises the following steps:

- *Recognising the problem*. The decision maker ascertains that a problem exists and that a decision must be reflected on.
- *Identifying goals*. The decision maker details the desired result or outcome of the process.
- *Generating and identifying options*. Different potential solutions are assembled prior to their evaluation.
- *Information search*. Characteristics of the alternative solutions are sought by the decision maker.
- *Assessing information on all options*. The information necessary for making a decision regarding the preferred option is gathered together and considered.
- *Selection of preferred option*. A preferred option is selected by the decision maker for implementation in the future.
- *Implementing the decision*. The chosen option is brought to completion.
- *Evaluation*. The decision is assessed after its implementation in order to evaluate it on the basis of its achieved results.

Clear rationality, where a judgement is arrived at following a sequence of deliberately followed logical steps, lies at the basis of this model for decision making.

1.2.4 Classical rational decision making

The principles of reasoned choice have been adapted into an analytic technique, called the rational approach, which has a specific application in the evaluation of project options at the planning stage of a proposed engineering scheme. The proper planning of a major engineering project requires a set of procedures to be devised which ensure that available resources are allocated as efficiently as possible in its subsequent design and construction. This involves deciding how the available resources, including manpower, physical materials and finance can best be used to achieve the desired objectives of the project developer. Systems analysis can provide such a framework of procedures in which the fundamental issues of design and management can be addressed (de Neufville & Stafford, 1974). Engineering systems analysis provides an orderly process in which all factors relevant to the design and construction of major engineering projects can be considered. Use of the process has the following direct impacts on the coherent and logical development of such a project:

- The process forces the developer/decision maker to make explicit the objectives of the proposed system, together with how these objectives can be measured. This has the effect of heightening the developer's awareness of his or her overall core objectives.
- It provides a framework in which alternative solutions will be readily generated as a means to selecting the most desired one.
- Appropriate methodologies for decision making will be proposed within the process for use in choosing between alternatives.
- It will predict the major demands which will be placed on the facility under examination through the interaction of the various technical, environmental and social criteria generated by the process. These demands are not always detected in advance.

The planning of major engineering projects is, therefore, a rational process. It involves a project's developer acting or deciding rationally in an attempt to reach some goal that cannot be attained without some action. He or she must have a clear awareness of alternative paths by which agreed goals can be achieved within the limitations of the existing environment, and must have both the information and the ability to analyse and evaluate options in light of the goals sought. Within the rational model, therefore, appropriate future action by the developer is determined by using the available scarce resources in such a way that his or her aims and objectives are maximised. It is a problem-solving process which involves closing the gap between the developer's objectives and the current situation by means of the developmental project in question, the 'objectives' being, for example, a more coherent transport infrastructure, a better quality rail service or a more efficient and cleaner water supply system.

The basic rational procedure can be represented by five fundamental steps. They constitute the foundation of a systematic analysis and are summarised in Table 1.1.

Table 1.1 Steps in the rational decision making process.

Step	Purpose
Definition of goals and objectives	To define and agree the overall purpose of proposed project
Formulation of criteria/measures of effectiveness	To establish standards of judging by which the options can be assessed in relative and absolute terms
Generation of alternatives	To generate as broad a range of feasible alternatives as possible
Evaluation of alternatives	To evaluate the relative merit of each option
Selection of preferred alternative/group of alternatives	To make a final decision on the adoption of the most favourable option as the chosen solution

Define goals and objectives

Goals can be seen as conceptual statements that set out in detail the intended long-term achievements of a proposed plan. They articulate the social values to be used within the planning process. Initially, they may only exist in outline form. Considerable data collection and evaluation may need to be undertaken and existing problems may need to be addressed before the goals can be precisely defined. Goals are, by their nature, abstract, and must therefore be translated into quantitatively based measurable objectives. These will form the basis for the criteria used within the process for evaluating alternative options. No appraisal process should proceed without an explicit statement of the objectives of the proposed undertaking. All analyses have a set of objectives as their basis. Much of the value of the planning process lies in the identification of a clear set of objectives.

The process will generate different classes of objectives that may be potentially conflicting. For example, within the planning of major transport infrastructure, the designer may have to reconcile the maximisation of economic and technical efficiency with the minimisation of social and environmental impact. These objectives will each have their own merits, and must be considered by their own individual set of criteria.

In an engineering context, the determination of broad objectives, such as the relief of traffic congestion in an urban area or changing the method by which domestic waste is disposed of, is seldom within the design engineer's sole remit. Their setting predominantly takes place at what is termed 'systems planning level' where input is mainly political in nature, with the help and advice of senior technical experts, some of whom will be professional engineers. The objectives serve to define the 'desired situation' that will transpire as a direct result of the construction of the proposed facilities.

Establish criteria

Defining the planning problem involves identifying the actual gap between the 'desired situation', as defined by the set of objectives derived, and the current situation, and

assembling a range of measures designed to minimise or even close that gap. The ultimate aim of the process is thus to develop a grasp of the relative effectiveness with which these selected alternatives meet the derived set of objectives. Measures of performance, or criteria, must therefore be determined. They are used as 'standards of judging' in the case of the options being examined. Preferably, each criterion should be quantitatively assessed, but if, as with some social and environmental criteria, they cannot be assessed on any cardinal scale, it should nonetheless be possible to measure them qualitatively on some graded comparative scale.

The selection of criteria for the evaluation of alternatives is of crucial importance to the overall process because it can influence to a very great extent the final design. This selection process is also of value because it decides to a large degree the final option chosen. What may be seen as most desirable from the perspective of one set of criteria may be seen as much less so using another set of criteria. Thus the selection of the preferred design may hinge on the choice of the criteria for evaluation.

Identify alternative courses of action

Given that the ultimate end point of the process is to identify a preferred solution or group of solutions, it is logical that the decision maker should invest substantial effort in examining a broad range of feasible options. It would not be possible to subject all feasible options to a thorough analysis. Moreover, because resources for the analysis are never limitless, the decision maker must always be selective in the choice of options to be considered within the process. The decision maker must pay particular attention to identifying those alternatives that are shown to be most productive in achieving objectives, while ensuring that effort spent on the analysis of a given alternative does not exceed its anticipated benefits. This process should result in the drawing up of a set of alternative proposals, each of which would reasonably be expected to meet the objectives stated. There is seldom a plan for which reasonable alternatives do not exist.

Evaluate the alternatives

The relative merit of each option is determined on the basis of its performance against each of the chosen criteria. Each alternative is aligned with its effects, economic costs and benefits, environmental and social impacts, and functional effectiveness. This process is usually undertaken using some form of mathematical model. Selecting the appropriate model for the decision problem under consideration is a key step in the evaluation process. In the case of complex engineering projects where numerous alternatives exist and where so many variables and limitations need to be considered, it is at this point in the planning process that the application of decision-aid techniques becomes helpful. Ultimately, people make decisions. Computers, methodologies and other tools do not. But decision-aid techniques and models do assist engineers/planners in making sound and defendable choices.

Selection/recommendation

This is the point at which a single plan or shortlist of approved plans is adopted as most likely to bring about the objectives agreed at the start of the process. This is the real point of decision making, where a judgement is made on the basis of the results of the evaluation carried out in the previous step. As expressed above, because decisions are made by people, value judgements must be applied to the objectively derived results from the decision-aid model within the evaluation process. Political considerations may have to be allowed for, together with the distribution of the gains and losses for the preferred alternatives among a range of incident groups affected by the proposed facilities. The act of selection must, therefore, not be seen solely as a technical problem. This step within rational planning is the point in the process at which the final decision is actually taken.

1.2.5 Behavioural decision making

Although the reality of the decision situation may dictate otherwise, rationality assumes that, in order to arrive at the optimum solution for the planning problem under consideration, the decision maker must have:

- Complete information regarding the decision situation, that is why the decision is necessary, what stimulus initiated the process, and how it should be addressed.
- Complete information regarding all possible alternatives.
- A rational system for ordering alternatives in terms of their importance.
- A central goal that the final choice will be arrived at in such a way that maximises the economic benefit to the developer.

The basic, central assertion of this theory is that the decision maker, possessing complete knowledge of the problem, can, within the appraisal process, select the option which best meets the needs and objectives of the developer. This approach, termed optimisation, is strongly influenced by classical economics, and assumes that the decision maker is unerringly rational and devoid of personal preferences, motives and emotions. Since this is, in reality, unlikely to be the case, the behavioural model takes account of the imperfections likely to exist in the environment surrounding the planning process for engineering projects. Its originator, Herbert Simon (1976), recognised that full rationality did not accurately describe actual decision-making processes. In contrast to strict classical rationality, behavioural decision theory makes the following assumptions regarding the decision process:

- Decision makers have incomplete information in relation to the decision situation.
- Decision makers have incomplete information on all possible project options.
- Decision makers do not have the capacity or are not prepared to fully foresee the consequences of each option considered.

Simon notes that decision makers are, in reality, limited by their value systems, habits and skills as well as by less-than-perfect levels of knowledge and information.

He believes that, while decision makers seek to behave in a rational goal-oriented manner, their rationality has limits. They can be rational in striving to achieve a set of objectives only to the extent that:

- they have the ability to pursue a particular course of action;
- their concept of the end-point of the process is correct; and
- they are correctly informed regarding the conditions surrounding the choice.

Simon called this concept 'bounded rationality'. A decision maker is rational only within the boundaries laid down by the above limiting internal and external factors. Given that these limitations of information, time and certainty may, in practice, hinder a manager from being completely rational in his decision making, the manager may, as a result, decide to 'play it safe' rather than strive to arrive at the 'best' solution. Simon called this practice 'satisficing', where, rather than searching exhaustively for the best possible solution, a decision maker will search only until an option that meets some minimum standard of sufficiency is identified.

In the context of the planning of a major engineering project, decision makers may practise satisficing for a variety of reasons. A lack of willingness to ignore their own personal motives and objectives may lead to an inability on their part to continue the search after the first minimally acceptable option is identified. They may be unable to evaluate large numbers of options and/or criteria. Subjective considerations, such as the actual selection of criteria for evaluation, often intervene in decision situations. For all such reasons, the process of satisficing thus plays a major role in engineering decision making.

1.2.6 Irrational decision making

Both the classical and behavioural theories assume that the decision process involves at least some degree of rationality. Here, options are again generated and evaluated prior to the decision. In this instance, however, the decision maker is assumed to act in an irrational manner, with the final choice made prior to the initial generation of development options.

This model, termed the implicit favourite approach, was put forward by Soelberg (1967). It assumes that the decision maker does not search for the best option or even one that 'satisfices'. The process is only used as a vehicle for confirming that the initial favourite was the best option available, with spurious and sometimes irrelevant criteria of evaluation being invented to justify the final selection.

It is generally believed that unusual non-recurring decision problems will most often give rise to this type of solution in situations where the decision maker may not have ready-made rules and guidelines at his or her disposal for establishing and evaluating options. It has been found that the more political a decision, the more likely that the irrational model will be used. Political groupings may champion a particular option that they perceive as being to their own benefit. These groups will try to convince others of the chosen option's merits relative to the others under

consideration. If the power position of the group pushing a particular option is strong enough, the opinions of others may not even be taken into consideration within the decision process.

1.2.7 Political involvement in the project planning process

In the context of a major engineering development project, the rational view of the planning process incorporates political involvement at two steps:

(1) The determination of community goals is assumed to be the responsibility of political representatives.
(2) The decision/selection process is usually viewed as primarily a political process, with elected representatives acting on the basis of information and advice from professional engineers and planners.

This perspective makes certain assumptions regarding the environment within which the decision is made:

- A set of community values and policies exist which is consistent with the goals and objectives of the proposed project.
- The project options are developed in response to rationally determined needs.
- The decision makers are primarily influenced by the rational evaluations of the various project options put forward by the technical experts.

Routine decisions, handed down on a day-to-day basis by those agencies responsible for the planning of engineering development projects, are generally resolved within a 'rational' framework. In many cases such decisions are taken by the professionals within the planning agency, with the political actors merely ratifying their actions. For extraordinary engineering planning decisions, Banks (1998) believes a form of irrational decision making, which he terms the 'political planning process', prevails in the case of 'one-off' extensive and complex engineering projects. The process is described as 'proposal oriented' rather than comprehensive, beginning with a specific development proposal rather than the definition of a broad set of goals and objectives that the chosen project must fulfil. Banks describes such a process as disjointed and confused, with different actors having different concerns and disagreement arising primarily out of people's lack of understanding of the decision problem. The process itself may be crisis oriented if the project being proposed is one of many such schemes within the political arena, in which case it will only be addressed if the problems which the proposal is intended to solve have reached crisis point.

Banks notes that the political planning process involves the following elements:

- A project proposal is made regarding a specific engineering development project. Specific projects such as the construction of a mass transit system for a given urban area or a toll-bridge connecting two major motorway networks could be proposed.

- The promoter of the proposal attempts to gather support for it through political influence, compromise or the manipulation of public opinion. Success in this regard could depend on the developer's ability both to gather political support from other parties in the planning process and to amend his proposal where necessary to gain additional support.
- A decisive action occurs, such as the decision of the planning authority or appeals board, to authorise a particular project. This may occur at either central or local government level.
- If the decision is favourable, the project is implemented. If it is unfavourable, the project is modified and then reintroduced at the first opportunity. Proposals of this type are rarely abandoned outright – it can fail many times, but it need only succeed once.

These steps are summarised in Table 1.2.

Banks' view is that the rational process can be incorporated into the political planning process as a means of persuasion. The professionals, such as planners and engineers, will tend to study the proposal within a structured rational framework, and the results of this work will be used within the overall political planning process to justify the project. The problem with this mixing of the two processes occurs where the two conflict with each other. For example, if a comprehensively rational decision process is followed by the professionals involved and results in a decision being reached that is incompatible with the more 'political' concerns of both local authority management and the members of the planning appeals board, it will lead to a divisive and unsatisfactory conclusion to the process.

Table 1.2 Steps in the political decision making process.

Step	Purpose
A proposal is made	To define the project as specific and non-choice based
The developer attempts to gather support for it	To generate political momentum in favour of the proposal
A decisive action occurs	To locate the point in the process at which approval/non-approval actually occurs
Resubmission if first submission rejected	If approval is not gained, the ability to continually amend and resubmit the proposal until consent is obtained.

1.3 Primacy of the rational model

The existence of 'non-rational' decision processes of the type outlined by Banks must be acknowledged. Such theories offer a useful insight into how, in a particular environment where political considerations tend to dominate,

certain one-off, non-recurring project proposals gain approval via this process. However, for the purposes of this book, it will be assumed that the appraisal of engineering projects takes place within a format, overseen by planning specialists, where rational decision making, be it classical or behavioural, is the primary methodology at the basis of decision making. Within Banks' political planning process model, rational planning is seen as secondary and supplementary to the main process, used by the project promoters as a means of persuasion. Its use as a means of justifying proposals is seen primarily as a political asset rather than as a coherent logical tool for decision making. From the perspective of the professional engineer, it seems appropriate to assert the primacy of the rational model, on the basis of its logical foundation and its wide level of acceptance as an appropriate decision-making technique for use within this sphere of work. Within the rational model, the pivotal step is the evaluation or appraisal process where the relative merit of each proposal is determined. The main purpose of the succeeding chapters within this text is to explain the workings of various appraisal methodologies of direct use to planning engineers.

1.4 Decision-making conditions

While we can assume that decision making is, in effect, an individually-based process, and that it takes place, from the planning engineer's perspective, within a rational format, the environmental conditions surrounding it can vary markedly. Virtually all decisions are made under conditions of at least some uncertainty. The extent will range from relative certainty to great uncertainty. There may also be certain risks associated with making decisions. There are thus three categories of environmental conditions: certainty, risk and uncertainty.

1.4.1 Certainty

Very few decisions are made under conditions of certainty. This state, therefore, never truly exists. The complexity of an engineering project, together with the cyclical nature of the economic environment surrounding it, makes such a condition unattainable. It defines an idealised situation where all project alternatives and the conditions surrounding them are assumed to be known with complete certainty. Suppose an engineering contractor is awarded a project ahead of the other tendering companies on the basis of its bid. While this decision to award may appear to approach the condition of complete certainty, each of the contractors may have written non-identical cost increase clauses into their respective contracts so that the engineer making the decision to award may not be 100% certain of the relative conditions associated with each alternative bidder.

1.4.2 Risk

In a risk situation, the outcomes of the decision are random, with the probabilities of each outcome being known. Under these conditions, the availability of each project option and its potential pay-offs and costs are all associated with probability estimates. The probability in each case indicates the degree of likelihood of the outcome. The key element in decision making under a state of risk is the accurate determination of the probabilities associated with each project alternative. The probabilities can be determined objectively using either classical probability theory or statistical analysis, or subjectively using the experience and judgement of the decision maker. The values derived can then be used in a rationally based quantitative approach to decision making.

1.4.3 Uncertainty

In the context of an engineering project, the vast majority of decision making is carried out under conditions of uncertainty. Because of the complex and dynamic nature of the technology associated with present day engineering projects, the decision maker does not know what all the options are, the possible risks associated with each, or what the results or consequences of each will be. In such a situation, the decision maker has a limited database, is not certain that the data are completely reliable and is not sure whether the decision situation will change or not. Moreover, the interaction between the different variables may be extremely difficult, if not impossible, to evaluate.

Consider the environmental appraisal of an engineering development project. Because of the complexity of criteria relating to the estimation of noise and air pollution valuations, the database compiled by environmental specialists for each impact may be incomplete and there may be no guarantee that the values measured will not change with time. The accuracy and reliability of the data are therefore in question, and this uncertainty must be reflected in the decision process.

Under these conditions, if decision making is to be perceived as effective, the decision maker must seek to acquire as much relevant information as possible, approaching the situation from a logical and rational perspective. Explicit estimates of the levels of uncertainty associated with criterion estimates, together with judgement, intuition and professional experience will be of central importance to the decision making process.

Both the newness and the complexity of the rapidly changing technology associated with modern engineering development projects tend to induce uncertainty in their evaluation.

Many of the models outlined in this book as aids to the decision maker in the process of appraisal take explicit account of the levels of uncertainty associated with the relative evaluations of the competing proposals under consideration.

1.5 Project planning process

Accepting the importance of the rational model, certain steps within it are of particular importance in the context of examining an engineering development project. Assuming that such a proposed project will be planned in a logical manner, in an environment where some uncertainty/risk may exist, the three main steps in the process can be identified as:

- Identifying the project options.
- Identifying the criteria for evaluation.
- The appraisal process in which a preferred option is identified.

While the appraisal process may be the most important, the proper execution of the two preceding stages is of vital importance to the success of the overall process, as they provide an invaluable platform for effective appraisal. Let us look at each of these stages in some detail.

1.5.1 Identifying project options

A central objective of a given decision situation is the identification of feasible options. The term 'feasible' refers to any option that, upon preliminary evaluation, presents itself as a viable course of action, and one that can be brought to completion given the constraints imposed on the decision maker, such as lack of time, information and resources.

Finding sound feasible options is an important component of the decision process. The quality of the final outcome can never exceed that allowed by the best option examined. There are many procedures for both identifying and defining project options. These include:

- Drawing on the personal experience of the decision maker himself as well as other experts in the field.
- Making comparisons between the current decision problem and ones previously solved in a successful manner.
- Examining all relevant literature.

Some form of group brainstorming session can be quite effective in bringing viable options to light. Brainstorming consists of two main phases. Within the first, a group of people put forward, in a relaxed environment, as many ideas as possible relevant to the problem being considered. The main rule for this phase is that members of the group should avoid being critical of their own ideas or those of others, no matter how far-fetched. This non-critical phase is very difficult for engineers, given that they are trained to think analytically or in a judgemental mode (Martin, 1993). Success in this phase requires the engineer's judgemental mode to be 'shut down'. This phase, if properly done, will result in the emergence of a large number of widely differing options.

Proposed option vs. an accepted 'tried and tested' solution	Better	Worse
Construction cost	✓	
Maintenance Cost		✓
Visual appearance		✓
Technical innovation		✓

Table 1.3 Example of T-Chart.

The second phase requires the planning engineer to return to normal judgemental mode to select the best options from the total list, analysing each for technological and economic practicality. This is, in effect, a screening process that filters through the best options. One such method is to compare by means of a T-chart each new option with an existing, 'tried-and-tested' option that has frequently been used in previous similar projects (Riggs *et al*., 1997). The chart contains a list of criteria which any acceptable option should satisfy. The option under examination is judged on the basis of whether it performs better or worse than the conventional option on each of the listed criteria. An example of a T-chart is given in Table 1.3.

In the example shown in Table 1.3, the proposed option would be rejected on the basis that, while it had a lower construction cost, its maintenance costs and visual appearance, together with its relatively limited degree of technical innovation, would eliminate it from further consideration.

The above example illustrates a very preliminary screening process. A more detailed, finer process would contain percentages rather than checkmarks. The level of filtering required would depend on the final number of project options the decision maker wishes to bring forward to the full evaluation stage.

1.5.2 Identifying attributes/criteria of evaluation

Attributes represent the characteristics associated with the essential features of a proposed development. Any given option being considered must perform positively with respect to these features if it is to have any hope of fulfilling the overall objectives for the project as laid down by the decision maker. Once these attributes can be measured or scaled in some way, they are termed criteria. Generating criteria will thus provide a means of evaluating the extent to which each option under consideration achieves the objectives set down. They provide a tool for the comparison of project options.

The characteristics of the decision making environment may vary substantially, and this may be reflected in the decision criteria used. Within a complex engineering development, criteria may vary from well defined quantitative attributes, such as economic and financial viability, to ones that are extremely difficult to define and quantify, such as morale and environmental welfare. Many of the more straightforward decision problems involve quantitative, monetary-based criteria that can be

understood, defined and measured with relative ease. Many view criteria that can be expressed in monetary terms as the most important within a decision problem, given that selecting the most efficient option that will make the best use of limited resources is the primary concern of the decision maker. Grant *et al*. (1990) believe, therefore, that, where possible, all criteria should be expressed in monetary terms, and that the primary criterion should be monetary-based. Criteria that are not reducible to monetary figures are considered, but their role in the decision process is a secondary one.

This primary concern with monetary attributes or attributes that can be easily converted to monetary units lies at the basis of most texts on engineering economics. The ability to score the total performance of each project option on a single scale – usually a monetary value – has the great advantage that an 'optimum' solution can be found. The most often used method of project appraisal that uses the principle of optimisation is Cost–Benefit Analysis (CBA), which is one of a number of monetary-based methods described in detail later in the book. The decision process in such instances constitutes an economic evaluation. Non-economic-based consequences of the project are assumed to be of lesser importance to the decision maker.

However, more complex decision problems may involve attributes that prove difficult to define and measure. Examples of these are levels of passenger comfort and safety on a proposed transport system and the effects of a highway project on the cultural heritage of the area. These attributes are termed 'intangible' or 'qualitatively based'. Within an appraisal process where the measures of the relative effectiveness of the project options are not just economic but also possibly technical, social and environmental, a wide range of criteria, some monetary, some non-monetary but quantitative, and others purely qualitative must be taken into account. This can only be achieved within a multi-attribute or multicriteria decision-making format. Multicriteria decision models integrate quantitative and qualitative criteria to produce an aggregate performance measure using a 'compromise' technique which ranks or scores each option on the basis of a trade-off of its performances relative to the other options on each of the decision criteria.

Whether the criteria for assessment are purely economic or cover a wide range of objectives, the success of the evaluation process depends on being able to select and define criteria relevant to the appraisal process. Criteria can be developed by studying the relevant technical literature, by examining written details of similar decision situations or by asking the opinions of people with expertise in the relevant field. A number of formal methodologies for compiling a list of decision criteria exist.

Consumer surveys

Those who will be the eventual users of the development being proposed are one of the most logical sources of information regarding attributes to be used in an appraisal of competing options. For example, before deciding on a new mass transit system for a city, it is wise to ask the inhabitants what features of such a system they consider to be most important. However, certain care must be taken with the responses, as consumer tastes are open to manipulation and can change rapidly over time. Their

stated behaviour towards the proposed development may vary greatly from how they actually react to the finished product.

Technical documents

Handbooks or government guidelines may exist in the relevant area on the attributes that must be taken into account when a development in a particular discipline of engineering is proposed. For example, in the water engineering area, the Battelle System (Dee, 1973) supplies a list of 78 economic, social and environmental criteria that must be considered when an option for a given water resources project is being assessed. Such information, used alongside the opinion of experts in the relevant field of engineering, can result in the compilation of a complete and exhaustive list of criteria relevant to the decision problem.

Delphi Method

The Delphi Method combines opinions into a reasoned and logical consensus. It requests and collates, in a systematic manner, opinions from experts regarding the correct decision criteria for appraising the proposed development. Initially, a precisely prepared questionnaire is given to a panel of experts from the professional specialties relevant to the problem. Replies to the questionnaires must contain answers with written supporting reasons for them. These reasons are summarised by a moderator/facilitator who gives them to the full panel for consideration. Full anonymity with regard to the source of each written response is maintained at all times. This iterative process is continued until the exchange of arguments and the transfer of knowledge results in a consensus being formed.

Overview

Whether the criteria are purely economic, or are more widely based, taking into account environmental and technical concerns, those finally selected for use in the appraisal process should be:

- measurable on some scale, be it quantitative or qualitative (measurability in monetary terms is only required for a purely economic appraisal);
- complete and exhaustive, covering all aspects of the decision problem;
- mutually exclusive, allowing the decision maker to view the criteria as separate entities, thereby avoiding ‘double-counting’;
- restricted to performance attributes of real importance to the decision problem.

1.5.3 Methods for engineering project appraisal

Assuming that the rational model forms a basis for this appraisal procedure, and that all options and decision criteria have been identified, the most important stage within this process is the actual common evaluation of the individual project options. For the

engineer involved in assessing the relative merits of the individual proposals, a properly structured evaluation is central to the overall success of the appraisal. The remainder of this book concentrates on the models that might be used by the planning engineer to assess each of the options under consideration. These models fall into two categories as mentioned briefly above: the first based on optimisation, and the second based on compromise. They are distinguished by the set of rules they employ to make the decision.

A set of rules, which can also be called an evaluation method, is required to interpret the criterion valuations for each alternative considered. This set is a procedure that enables the pros and cons of alternative projects to be described in a logical framework so as to assess their various net benefits. They transform the facets of each proposal, as expressed within the agreed measure (or measures) of performance, into statements of its net social benefits.

The evaluation method must provide an insight into the formal relationships between the multiple aspects of alternatives as expressed in their performance on the decision criteria. The challenge is to develop an evaluation procedure appropriate for both the decision problem under consideration and the available information. It must be readily understandable to those involved in the decision process. The set of decision rules at the basis of the evaluation process is of vital importance.

If the conditions for the classical rational model are assumed to exist, then the chosen option emerging from this process can be designated the 'single best' of all the competing proposals. It is thus deemed the optimum choice. For the principle of optimisation to be at the basis of the decision taken, the decision maker must assume that the different objectives of the proposal, as stated through their relevant measures of performance, can be expressed in a common denominator or scale of measurement. This allows the loss in one objective to be directly evaluated against the gain in another. This idea of compensatory changes is central to many of the models used within engineering appraisal. The optimising principle is very elegant, providing a straightforward tool for the evaluation of alternative strategies on the basis of their economic benefit to society. In the case of CBA, the contribution of each alternative to the community is expressed in monetary terms.

Within the context of many engineering development projects, however, the decision maker may have limited knowledge regarding the decision situation, the available alternatives or the decision criteria to be used within the appraisal. In such instances, the optimising principle is rather limited, since the specification of a function expressing total benefit to society presumes the possession of complete information about all possible combinations of actions, about the relative trade-offs between actions, and about all constraints prevailing in the decision making process.

Given the somewhat limiting nature of these constraints on finding solutions to real-life and often complex engineering problems, certain circumstances exist where the so-called 'compromise' principle should be considered (Van Delft & Nijkamp, 1977). It stems from Simon's concept of 'bounded rationality' referred to earlier (Section 1.2.5), where the rational model must operate within the limitations

imposed on the decision maker by lack of information in certain vital areas. It assumes the existence of a variety of decision criteria, not all measurable in a common denominator. The principle states that any viable solution has to reflect a compromise between various priorities, while the various discrepancies between actual outcomes and aspiration levels are traded off against each other by means of preference weights. The quality of each option can only be judged in relation to multiple priorities, so that a desired alternative is one that performs comparatively well according to these priorities. The compromise principle is particularly relevant for option evaluation/choice problems leading to multicriteria analyses. Given the potential complexity of the planning process for major engineering projects, such multicriteria methodologies can provide a useful resource for decision makers in the completion of their task.

Optimising methods

In situations where this analysis is predominantly an economic one, computations are performed on each of the alternatives in order to obtain one or more measures of worth for each. Engineering economics provides techniques that result in numerical values termed measures of economic worth. These, by definition, consider the time value of money, an important concept in engineering economics that estimates the change in worth of an amount of money over a given period of time. Some common measures of worth are:

- Net Present Value (NPV)
- Benefit/Cost Ratio (B/C)
- Internal Rate of Return (IRR)

In economic analysis, financial units (Euro/Pounds/Dollars) are used as the tangible basis of evaluation. With each of the above 'measure of worth' techniques, the fact that a quantity of money today is worth a different amount in the future is central to the evaluation.

Within the process of actual selection of the best option in economic terms, some criterion based on one of the above measures of worth is used to select the chosen proposal. When several ways exist to accomplish a given objective, the option with the lowest overall cost or highest overall net income is chosen. While intangible factors that cannot be expressed in monetary terms do play a part in an economic analysis, their role in the evaluation is, to a large extent, a secondary one. If, however, the options available have approximately the same equivalent cost/value, the non-economic and intangible factors may be used to select the best option.

Multicriteria methods

Within the context of the 'compromise' principle, multicriteria decision aid gives project planners some technical tools to enable them to solve a decision problem where several often conflicting and opposite points of view must be taken into

account within the decision process (Rogers *et al*., 1999). With such complex infrastructural planning problems, in many cases no single option exists which is the best in economic, technical and environmental terms. Furthermore, criteria from such diverse sources are seldom measurable in a common denominator. As a result, direct comparison of scores from different attributes becomes more complex. Hence the optimisation techniques available within operations research, referred to above, are not applicable to this problem type. The word 'optimisation' is inappropriate in the context of this type of decision problem. It may be virtually impossible to provide a truly scientific foundation for an optimal solution/decision. Multicriteria methods based on the compromise principle provide tools and procedures to help us attain the 'desired situation', as expressed in the set of objectives, in the presence of ambiguity and uncertainty. However refined our models may be, we must recognise that no amount of data will remove the fundamental uncertainties which surround any attempt to peer into the future. Multicriteria methods do not yield a single, 'objectively best' solution, but rather yield a kernel of preferred solutions or a general ranking of all options. They are the most readily applicable models to problems of option choice within civil engineering where it is virtually impossible to provide a scientific basis for an optimal solution. Solving such a multicriteria problem is, therefore, not searching for some kind of 'hidden truth', as Vincke (1992) put it, but rather helping the decision maker to master the complex data involved in a decision problem in such areas and advance towards a solution. This process involves compromise, and depends to a great extent both on the personality and experience of the decision maker and on the circumstances in which the decision-aiding process is taking place. However complete the information, the need for personal judgement and experience in the making of project planning decisions remains.

1.6 Example of a decision process

The project appraisal techniques described within this book are divided into two broad categories:

(1) Purely monetary-based evaluations.
(2) Multicriteria evaluations.

The methods in the first category require the monetary evaluation of all criteria relevant to the decision. The second category contains those methods that enable the evaluation of a potentially diverse range of attributes ranging from economic to social, environmental and technical criteria. Within this group, each criterion does not have to be measurable in monetary terms. Any scale that differentiates the performance of a number of options on the criterion in question, whether qualitative or quantitative, is permissible.

Before going into the details of these methods in the succeeding chapters, brief descriptions of typical decision problems solved using the two method types are given in the case studies in Sections 1.6.1 and 1.6.2. Both cases detail the data at the

basis of the problem in question and outline the final decision taken. In neither case is the actual method for directly appraising the relative merit of the alternative proposals on the basis of the chosen decision criteria actually described. The methods of project appraisal detailed in the succeeding chapters of this text will attempt to provide the reader with the means of:

- selecting the appropriate appraisal methodology;
- collating all relevant information on the available options and their performance on each of the decision criteria chosen; and
- translating this information into a measure of the relative performance of the project options.

These three steps lie at the basis of project appraisal.

1.6.1 Case study 1: Economic analysis of alternative port access routes for a major city

A municipal authority wishes to evaluate the economic performance of a number of highway options for providing better access for heavy vehicles to the port area. The objective of the road is to reduce the negative effects on the city centre arising from the heavy vehicle traffic travelling to the port area from the outskirts of the city. Four options are assessed:

(1) A 'do minimum' traffic management option involving the banning of trucks from some roads in the city centre (Option 1).
(2) A new north–south tunnel connecting the existing orbital motorway system to the port area (Option 2).
(3) A new east–west tunnel connecting the port to an existing dual carriageway (Option 3).
(4) A new overground highway running east–west along an existing rail corridor adjacent to an existing canal (Option 4).

Each of the four options is assessed on the basis of the following nine economic consequences/criteria:

(1) Car-user time savings
(2) Heavy vehicle time savings
(3) Public transport time savings
(4) Car operating cost savings
(5) Heavy vehicle operating cost savings
(6) Accident cost savings
(7) Capital costs
(8) Maintenance costs
(9) Operating costs.

All nine can be assessed in monetary terms. The first six are benefits and will thus have a positive monetary value, while the last three are costs and have a negative valuation.

For each option, its score on each of the economic criteria is discounted to a present worth. They are then added up to give an overall net present worth for the option in question. The following estimates of net worth for each of the options are obtained from the appraisal process:

- Option 1: –£40 million
- Option 2: +£100 million
- Option 3: +£50 million
- Option 4: +£66 million

On the basis of the economic evaluation, Option 2 is chosen as the best performing proposal.

1.6.2 Case study 2: Multicriteria analysis of alternative waste management strategies for a region

The regional government of a country in Western Europe wishes to devise a new waste management strategy, involving better use of existing incineration facilities and the possible construction of new ones. The objective of any new strategy is not only to put the process of waste management on a firmer economic footing, but also to have regard to the environmental and social effects of the strategy. The problem is thus a multicriteria one rather than purely economic. Five strategies are assessed:

(1) Constructing a number of new waste incineration plants and importing waste from other countries to subsidise their construction (strategy 1).
(2) Constructing a number of new waste incineration plants with no import of foreign waste (strategy 2).
(3) Maximising the transportation of waste between existing facilities in the region (strategy 3).
(4) Decentralising waste facilities to the outlying areas of the region (strategy 4).
(5) Rationalising the number of existing waste management facilities (strategy 5).

Each of the five options is assessed on the basis of the following nine economic, technical, social/political and environmental factors:

(1) Quantity of waste transported and distance travelled (environmental)
(2) Energy use (environmental)
(3) Impact of gas emissions (environmental)
(4) Cost (economic)
(5) Flexibility of strategy to possible increases in quantity of waste produced (technical)
(6) Flexibility of strategy to possible decreases in quantity of waste produced (technical)

(7) Level of overcapacity resulting from strategy (technical)
(8) Level of local opposition to strategy (political)
(9) Dependency of strategy on supply of imported waste (political)

Of the nine, one is assessed in monetary terms, six in quantitative, non-monetary units, and two on a qualitative scale. This diversity of assessment necessitated the use of a compromise-based rather than an optimising technique, with the overall performance of the strategy options based on their comparative performance on each of the decision criteria. An option's overall performance entailed trading-off its good performance on one criterion against its relatively weak performance on another. This analysis requires information on the relative importance to the decision makers of the nine criteria considered.

An analysis of the relative performance of the options on each of the decision criteria yields the following ranking:

- First: strategy 5
- Second: strategy 4
- Third: strategy 3
- Fourth: strategy 1
- Fifth: strategy 2

Strategy 5, involving the rationalising of existing incineration facilities, performs very well relative to the other options, with strategy 4 also scoring strongly. Both options are presented by the decision maker as viable solutions to the responsible government minister.

1.7 Summary

Within this first chapter we have defined project appraisal, identified the broadly rational planning framework within which it operates and outlined the potential level of certainty/uncertainty/risk associated with the environment within which it takes place. Two distinct types of appraisal systems are defined: one a purely economic analysis with its basis in classic rationality, and the other based in bounded rationality with the ability to encompass more broadly based environmental, technical and political concerns in addition to the basic economic factors. The first set of techniques – the optimising methods – makes assumptions regarding the level of completeness of information available and allows a precise measure of the relative performance of the different options on a common monetary scale. The second set of techniques – the compromise-based methods – makes far fewer demands on the quality of information available. However, this offers an evaluation procedure which, while being more inclusive than the first set, is more likely to supply a preferred option which performs 'well' relative to the others, rather than one which is identified as the optimal or 'single best' option.

1.8 Review of succeeding chapters

Part I of the book, comprising Chapters 1 to 10, details the basic tools and methodologies required by a decision maker to perform an 'optimising' economic appraisal. Chapter 2 specifies the basic tools required to carry out this process. The time value of money, interest rates and time equivalence are defined and explained in detail. Chapters 3 to 6 detail four methods for computing the economic worth of a stream of cash flows arising during the life of a project. Chapter 3 deals with the computation of present worth for such a stream. Life cycle cost analysis and payback period are also explained. Chapter 4 explains the computation of equivalent annual worth. The importance of the economic lives assigned to the options being compared within this computation is emphasised. Chapter 5 deals with rate of return computations both for a single project and when a number of competing options are being compared. In the case of competing projects, the way in which the method is employed will depend on whether the options are independent or mutually exclusive. Use of the benefit/cost ratio technique is also subject to these conditions. It is dealt with in Chapter 6 along with the topics of depreciation and taxation. Chapter 7 is of central importance within Part 1. It introduces Cost–Benefit Analysis (CBA), the main method of economic appraisal for public projects, and illustrates how the four basic methods for computing economic worth explained in the early chapters – present worth, rate of return, annual worth and benefit/cost ratio – can be used within this methodology. It outlines the process of identifying and valuing the costs and benefits on which the options are to be compared. The importance of a sensitivity analysis for ensuring the robustness of the final result is emphasised. This chapter also includes case studies from the areas of highway engineering, water supply and sewer flooding alleviation, together with an introduction to some of the techniques that can be used to assign a monetary valuation to non-economic criteria. It concludes with brief descriptions of the application of CBA to different areas of engineering. Chapter 8 details the economic analysis of renewable energy supply and energy efficient projects. Chapter 9 introduces the concept of Value for Money in construction projects. Chapter 10 outlines three further methods of economic evaluation: Cost Effectiveness Analysis, Planned Balance Sheet and Goal Achievement Matrix. While all are derivatives of the Cost–Benefit Methodology, they do allow the inclusion within their framework of non-monetary valuations. As a result, the optimising principle, which lies at the heart of CBA, is somewhat diminished within these techniques; linkages between them and the compromise-based methods dealt with in subsequent chapters are highlighted. These three methods thus form a bridge between the first and second sections of the book.

Part II of the book, comprising Chapters 11 to 15, puts forward a number of multicriteria models, all of which have their basis in the 'compromise principle'. Within Chapter 11, a number of simple multicriteria techniques such as the Dominance, Satisficing, Sequential Elimination and Attitude-Oriented Methods are explained in some detail. Chapter 12 is of central importance within Part II. It details the most widely used multicriteria method, the Simple Additive Weighting (SAW) Model.

Techniques allowing uncertainty to be incorporated into criterion scores within the SAW Model, together with the various systems for assigning importance weights to the criteria, are outlined. Environmental Checklists are important applications of the SAW Model, and three types are explained in the text. The chapter concludes with a case study, outlining the application of the model to choosing a transport strategy for a major urban centre. Chapter 13 explains the Analytic Hierarchy Process (AHP) Method, a widely used decision model in the United States. Its use of hierarchies together with a seven-point scale to calculate the priorities assigned to the different options under consideration is detailed. In conclusion, Chapter 14 deals with Concordance Techniques, a set of multicriteria models used extensively throughout Europe to resolve decision problems in areas including engineering development. Worked examples of the different types of decision methods are given throughout the text.

Figure 1.2 Bridge on Arklow bypass, Ireland (Source: Arup. Photographer: Studioworks).

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