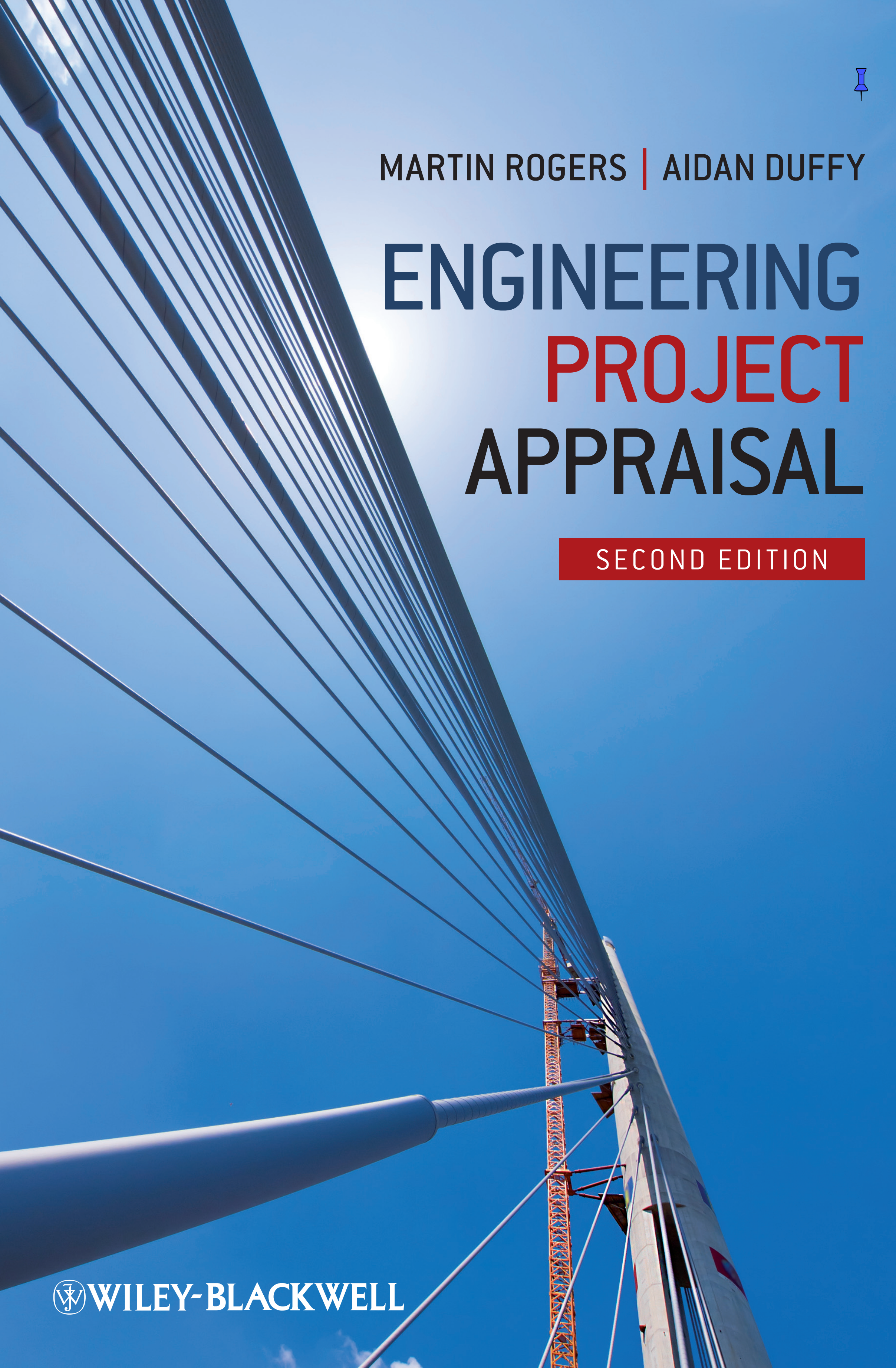
MARTIN ROGERS | AIDAN DUFFY

ENGINEERING PROJECT APPRAISAL

SECOND EDITION



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ENGINEERING PROJECT APPRAISAL

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The Evaluation of Alternative Development Schemes

Second Edition

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Preface

Practising engineers nowadays require a broad range of skills. They must be aware of and understand the economic, environmental and social contexts within which a development project takes place, and be able to resolve problems that arise in these areas. Accredited professional engineering courses now require students to develop an awareness of the economic, financial, social and environmental factors of significance to development projects, along with an understanding of risk analysis and quality systems. To achieve this level of understanding, engineering project appraisal must form a core subject area within any course wishing to fulfil this educational objective. The advent of programmes such as the public–private partnership schemes requires professional engineers to be aware of a much broader range of issues related to the proposed scheme than merely the technical aspects of its design and construction. The overall implications associated with each project option must also be considered at the planning stage as part of the engineer's input to the project.

This textbook provides an introduction to the full breadth of evaluation techniques required for the assessment of competing engineering projects. The book is divided into two parts. An introduction to the topic of engineering project appraisal is given in Chapter 1. The remainder of Part I, spanning Chapters 2 to 10 of the book, initially covers the basic building blocks of economic appraisal, such as the time value of money, interest rates and time equivalence. It then proceeds to explain basic economic techniques, such as net present worth, internal rate of return and annual worth. The main application of these techniques to public project appraisal – Cost–Benefit Analysis (CBA) – is dealt with in detail, together with a number of related decision methods, such as Cost Effectiveness and Goal Achievement Matrix, all of which are derived from CBA but where the common aim is increased inclusiveness. Depreciation and taxation are also addressed. Value for money in construction projects and the economic analysis of renewable energy supply and energy efficient projects are also dealt with at the conclusion to the first part of the text.

The second part of the book, spanning Chapters 11 to 15, examines the appraisal techniques that are appropriate when factors other than purely economic ones require consideration. The text details three multicriteria models that are widely used in the planning and evaluation of engineering projects: the Simple Additive Weighting (SAW) Model, the Analytic Hierarchy Process (AHP) technique and Concordance Analysis. The procedures used by these models to deal with both risk and uncertainty are explained within the text. Previously, many textbooks in the area have made only brief reference to such models. In recent times, however, they have proved particularly useful in the evaluation of competing proposals in the transport, solid waste and water resources areas. The space given to them within this book reflects their growing importance as tools of engineering evaluation.

The economic and multicriteria methods should not be viewed as totally separate. Often, an initial economic evaluation undertaken for a set of competing project options can subsequently be assimilated into a wider evaluation where the economic scores constitute one criterion, viewed alongside other technical, environmental and social criteria within a multicriteria framework.

In an effort to make the book as useful as possible to both students and practising engineers, case studies and worked examples for the various economic and multicriteria techniques are given throughout the text. Within this second edition, additional worked examples are included within Chapters 2 and 3, with Chapter 7 containing two additional case studies, one from the water supply area and one from the sewer flooding alleviation area, to add to the existing case study from the highways area originally included within the first edition. Chapters 8 and 9, addressing value for money in the economic analysis of renewable energy supply, energy efficient projects and construction projects, respectively, are new chapters within the text, reflecting the growing importance of these topics within the planning, design and construction of engineering projects.

The book is seen as an essential text for both undergraduate and postgraduate students within professional engineering courses. It is also envisaged that students on planning and construction management courses will find the text useful.

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Introduction

Project appraisal

Project appraisal is a process of exploration, review and evaluation taken on by the decision maker as the alternative options for development are defined within the project planning process. It can also be expressed in terms of a number of mathematical techniques that simplify the comparison of project options on the basis of an agreed criterion or set of criteria. These techniques provide a rational and significant approach to evaluating diverse aspects of different alternatives and the ability of these alternatives to achieve a set objective. These aspects can be purely economic or can be more broadly set to encompass technical, environmental and social concerns as well. The primary objective is to aid in the process of making informed and rational choices regarding the most effective use of available scarce resources. In the context of the planning of engineering projects, it is concerned with establishing the priorities between competing project options by judging the real cost to society of resources. Its purpose is to judge the merits of each alternative based on a set of concerns that can be economic, technical, social or environmental (or any combination of these), depending on the nature of the evaluation.

Who are the decision makers? In the past, the decision whether to employ resources for one purpose rather than another lay with administrators, planners and financiers rather than engineers, who tended to concentrate their efforts on the design/construction aspects of the project in question. Nowadays, however, with engineers taking their place within project companies involved with the planning and financing of development projects, they are required to have a much broader range of skills. They are required both to be aware of and to understand the economic, environmental and social contexts within which a development project takes place, and to be able to resolve problems that arise in these areas.

Decisions within project appraisal have their basis in a number of fundamental concepts. They should be made among alternative courses of action, each of which is clearly and unambiguously defined. The decision itself should be based on the expected future outcomes arising from the various project options. It is desirable to have at least one if not several criteria of evaluation. These will allow judgements to be made between project options based on their relative intrinsic worth. Only criteria that demonstrate differences between the various options are of relevance to the decision maker. Any criterion where the options perform identically will not form the basis for making an informed choice.

Ultimately, it is the people involved who make the decisions. The techniques outlined within this text are only tools to assist in the moving forward from this process. The outputs that result from these techniques are valid only for the individual or group of individuals who chose the model in question for the particular purpose of interest to them. A different group may have selected a different type of model or may indeed take the same results and interpret them in a different manner. The final decision must only be arrived at after appropriate consultations have taken place between all actors involved in making the decision, with the output from the project appraisal technique helping to make sense of the information at their disposal.

Students of engineering must develop an awareness of the relevant economic, financial, social and political factors of significance to engineering development projects, along with an understanding of risk analysis and quality systems. This knowledge is a vital building block in an engineering student's education, given that the ability to analyse and solve engineering problems must include a capacity to make choices on the basis of environmental/commercial as well as engineering/technical constraints. The ultimate objective of project appraisal is to secure the greatest benefit from the available scarce resources.

Planning and decision making as primary functions of management

Management can be defined in terms of its four primary functions. It is the process of planning and decision making, organising, leading and controlling an organisation's human, financial, physical and information resources to achieve organisational goals in an efficient and effective manner. During the planning phase of a development project, its form and design are finalised. The subsequent construction/implementation phase requires the organisation of human and other resources required to complete it. Appropriate leadership ensures that available resources are used to their utmost potential in delivering the finished product in the most efficient and effective manner. Finally, control mechanisms must be put in place throughout all phases of the project's development to monitor actual progress against that which was originally planned and expected. This process highlights those areas where corrective action needs to be taken in order that the project can be completed in a form as close as possible to that envisaged in the original plan. It helps ensure the effectiveness and efficiency needed for the successful completion of the project in the form originally planned.

Planning is the first and most important function of management. All other functions flow directly on from it. In the context of the management of engineering projects, planning involves the determination of the type of scheme that will best meet the goals and objectives of the organisation in question. Decision making, as a core element of the planning process, involves selecting a course of action from a set of alternative schemes. It is thus the point within the engineering management process at which engineering project appraisal takes place. Decision making and planning are codependent – a plan cannot exist until a decision is made to commit resources to it.

The process of engineering management is action-orientated, with decision making at its centre. Use of project appraisal techniques will guide the manager in the making of these decisions. To set the context within which project appraisal takes place, the identity of the decision maker, the most appropriate type of decision making for the process in question and the environment of certainty/uncertainty/risk within which the decision is made, must all be determined. These topics are dealt with in detail in Chapter 1.

In reality, however, the behaviour of engineering managers is not adequately described by the four 'functions' of management referred to above. With respect to engineering decision making in particular, it is, in fact, a diverse and project-specific process. To be effective, it must take place within the context of almost continuous communication with relevant interested parties both within and outside the organisation. Engineers must, therefore, be able to communicate effectively, convincing their fellow workers that the selected course of action is the most appropriate one, resolving any conflicts that might arise and, if necessary, using their intuition.

A brief history of project appraisal

Engineering project appraisal has emerged from two completely separate streams of work. The economics-based methods addressed in Part 1 of this book are closely aligned with conventional microeconomics, where the economic behaviour of very small segments of the economy, such as individual firms or public/private organisations, are scrutinised. Engineering economics focuses on economic decision making within such individual organisational units. Interest in economics among engineers arose both from the obvious applicability of the laws of economics to the production and use of scarce resources and the desire on their part to make informed financial analyses of the effects of the implementation of projects they had developed and designed. *The Economic Theory of the Location of Railways* by Wellington (1887) was one of the earliest books on engineering economy. Written in the United States at a time when railway construction was of overriding importance to the economy, it was born out of the belief that engineers, when deciding on prospective locations for railway lines, paid scant regard to the costs and revenues the line would generate over its life-span. Wellington deduced that capitalised costs should be considered as a basis for selecting preferred lengths of rail lines or their curvature. By bringing this problem to light, Wellington captured the basic thrust of engineering economics. He believed that good engineering management required that those making strategic or tactical decisions should be aware of the economic consequences of their choices.

A second significant author within classical engineering economics was Eugene L. Grant, who, in his text *Principles of Engineering Economy* (Grant, 1930), discussed the importance of using compound interest calculations as a basis for comparing long-term investments in capital goods alongside the need for evaluating short-term investments. Riggs *et al.* (1996) emphasised the importance of engineering economics in the phrase 'those that manage money manage all'.

The second strand of thought from which engineering project appraisal has emerged, and one which is dealt with in Part 2 of the book, involves the examination of multicriteria-based methods of project analysis that go beyond the evaluation solely of the proposal's economic consequences. This class of decision methods was devised in order to allow the appraisal of projects in situations where other non-economic consequences needed to be introduced into the analysis. These have proved particularly appropriate in the civil engineering field, where complex development projects involving attributes that are diverse in nature and are often difficult to measure quantitatively let alone in monetary units are required to be evaluated. Work on these methods has proceeded on both sides of the Atlantic. In the United States, Keeney & Raiffa's *Decisions with Multiple Objectives* (Keeney & Raiffa, 1976) and Saaty's *The Analytic Hierarchy Process* (Saaty, 1980) introduced the theoretical basis for two multicriteria techniques that have been widely applied to engineering option choice problems. In Europe, Roy's ELECTRE Model (Roy, 1968) has been used over the past 30 years to solve decision problems in the transport, environmental and water engineering fields. In general, multicriteria decision methods offer a level of flexibility and inclusiveness that purely economics-based models tend to lack. On the downside, with some of the more complex multicriteria models, however, the numerical computation involved can be quite complex, unwieldy and inaccessible.

Summary

A practitioner within the field of engineering project appraisal will draw upon his or her combined knowledge of both engineering and decision modelling and will pick the appraisal tool, be it a purely economics-based or a multicriteria model, which he or she feels will be best suited to the problem under scrutiny and will most easily identify the correct course of action. There is still some debate among practitioners in the field regarding the theoretical basis for some of the methods referred to in this text. However, all the major evaluation methods outlined have shown themselves to be readily applicable to problems of option choice for engineering development projects. Such is the variety of methods open to the practitioner that the problem often lies in identifying from the wide variety of available methods that method which is most appropriate to the problem in hand. It is hoped that this text will go some way to guiding potential users of the models towards choosing the particular appraisal methodology which best suits their needs in terms of the quality and type of data available to be input into the model, the level of detail required in the final results output from it, and the time and resources at the decision maker's disposal for completing the decision process.

This book concerns itself with project appraisal in the broadest context. The assessments detailed here concentrate on the effect an engineering development has on society as a whole rather than on the project promoters themselves. Major engineering development projects, even if partially or wholly funded by private sector capital, must be assessed in terms of their effect on all those who come within its influence.

The aim of this book is to give civil engineers a basic technical knowledge of project appraisal, providing them with a platform which will allow them to participate as informed professionals within the planning process for any major infrastructure project. While the book concentrates on providing technical information on the appraisal techniques, it must be realised that the use of these in isolation will never achieve the results desired. All students of project appraisal must realise the importance of the political dimension inherent in such a selection process. Politics intrudes at every step in the decision process and at every level in the decision hierarchy. The politics of engineering project planning must be recognised and managed effectively. A more detailed discussion of the political decision-making process is given in Chapter 1.

This is not a comprehensive or advanced text on engineering project appraisal. The book cannot, through limitations on space, deal with all the complexities of the individual appraisal techniques detailed within the book. It is, nonetheless, hoped that it gives the reader a sufficiently broad knowledge of the range of assessment methods available to practitioners in the area, and will enable them to delve deeper if necessary into the technical complexities of any of the models outlined in the text and to participate fully, with professionals from other disciplines if necessary, in the planning and selection process for major infrastructure projects.

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PART 1

ECONOMICS-BASED PROJECT APPRAISAL TECHNIQUES

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,

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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).

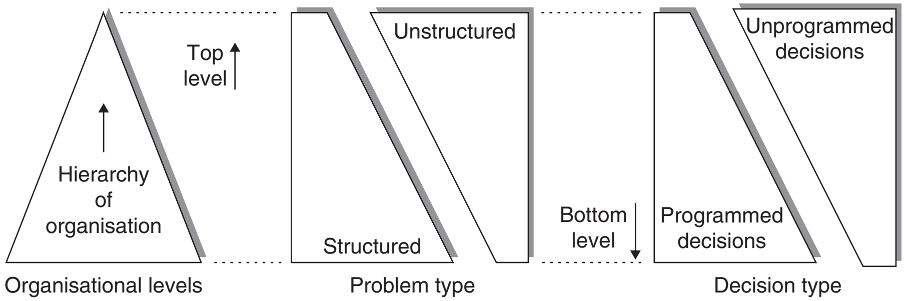

Figure 1.1 Types of problems and decisions at different levels of the organisation.

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