Chapter 6
Quantitative Methods for Risk Analysis

Project appraisal or feasibility study is an important stage in the evolution of a project. It is necessary to consider alternatives, identify and assess risks, at a time when data is uncertain or unavailable. This chapter outlines the quantitative approach and describes in detail several risk assessment techniques.

6.1 Sanction

When the project is sanctioned, the investing organisation is committing itself to a major expenditure and is assuming the associated risks. This is the key decision in the life cycle of the project. In order to make a well-researched decision the client will require

Clear objectives The client's objectives in pursuing this investment must be clearly stated and agreed by senior management early in the appraisal phase for all that follows is directed at achievement of these objectives in the most effective manner. The primary objectives of quality, time and cost may well conflict and it is particularly important that the project team know whether minimum time for completion or minimum cost is the priority. These are rarely compatible and this requirement will greatly influence both appraisal and implementation of the project.

Market intelligence This relates to the commercial environment in which the project will be developed and later operated. It is necessary to study and predict trends in the market and the economy, anticipate technological developments and the actions of competitors.

Realistic estimates/predictions It is easy to be over-optimistic when promoting a new project. Estimates and predictions made during appraisal will extend over the whole life cycle of implementation and operation of the project. Consequently single figure estimates are likely to be misleading and due allowance for uncertainty and exclusions should be included.

Assessment of risk A thorough study of the uncertainties associated with the investment will help to establish confidence in the estimate and to allocate appropriate contingencies. More importantly at this early stage of project development, it will highlight areas where more information is needed and frequently generate imaginative responses to potential problems, thereby reducing risk.

Project execution plan This should give guidance on the most effective way to implement the project and to achieve the project objectives, taking account of all constraints and risks. Ideally, this plan will define the likely contract strategy and include a programme showing the timing of key decisions and award of contracts.

It is widely held that the success of the venture is greatly dependant on the effort expended during the appraisal phase preceding sanction. There is however, conflict between the desire to gain more information and thereby reduce uncertainty, the need to minimise the period of investment and the knowledge that expenditure on appraisal will have to be written off if the project is not sanctioned.

Expenditure on appraisal of major engineering projects rarely exceeds 10% of the capital cost of the project. The outcome of the appraisal as defined in the concept and the brief accepted at sanction will however freeze 80% of the cost. The opportunity to reduce cost during the subsequent implementation phase is relatively small, as shown in Figure 6.1.

6.2 Project appraisal and selection

Project appraisal is a process of investigation, review and evaluation undertaken as the project or alternative concepts of the project are defined. This study is designed to assist the client to reach informed and rational choices concerning the nature and scale of investment in the project and to provide the brief for subsequent implementation. The core of the process is an economic evaluation; based on a cash flow analysis of all costs and benefits that can be valued in monetary terms.

Appraisal is likely to be a cyclic process repeated as new ideas are developed, additional information received and uncertainty reduced, until the client is able to make the critical decision to sanction implementation of the project and commit the investment in anticipation of the predicted return.

It is important to realise that, if the results of the appraisal are unfavourable, this is the time to defer further work or abandon the project. The consequences of inadequate or unrealistic appraisal can be expensive, as in the case of the Montreal Olympics stadium, or disastrous.

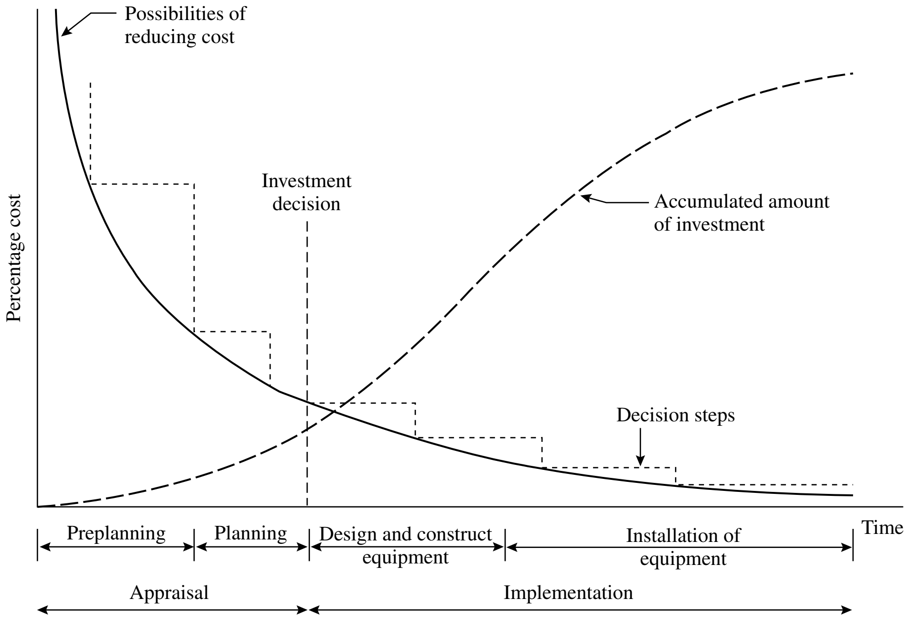

Figure 6.1 Graph of percentage cost against time showing how the important decisions for any project are made at the start of that project.

Ideally, all alternative concepts and ways of achieving the project objectives should be considered. The resulting proposal prepared for sanction must define the major parameters of the project – the location, the technology to be used, the size of the facility, the sources of finance and raw materials together with forecasts of the market and the predictions of the cost/benefit of the investment. There is usually an alternative way to utilise resources, especially money, and this is capable of being quantified, however roughly.

Investment decisions may be constrained by non-monetary factors such as:

- organisational policy, strategy and objectives;
- availability of resources such as manpower, management or technology.

Programme

It will be necessary to decide when is the best time to start the project based on previous considerations. Normally this means as soon as possible, because no profit can be made until the project is completed. Indeed, it may be that market conditions or other commitments impose a programme deadline, that is, a customer will not buy your product unless it can be supplied by mid-1998, when a processing factory will be ready. In inflationary times, it is particularly important to complete a project as soon as possible because of the adverse relationship between time and money. The cost of a project will double in 7.25 years at a rate of inflation of 10%.

It will therefore be necessary to determine the duration of the appraisal design and construction phases so that:

- the operation date can be determined;
- project costs can be determined; and
- the client's liabilities can be assessed and checked for viability. It may well be that the client's cash availability defines the speed at which the project can proceed.

The importance of time should be recognised throughout the appraisal. Many costs are time-related and would be extended by any delay. The programme must therefore be realistic and its significance taken fully into account when determining the project objectives.

Risk and uncertainty

The greatest degree of uncertainty about the future is encountered early in the life of a new project. Decisions taken during the appraisal stage have a very large impact on final cost, duration and benefits. The extent and effects of change are frequently underestimated during this phase although these are often considerable, particularly in developing countries and remote locations. The overriding conclusion drawn from recent research is that all parties involved in construction projects would benefit greatly from reductions in uncertainty prior to financial commitment.

At the appraisal stage, the engineering and project management input will normally concentrate on providing:

- realistic estimate of capital and running costs;
- realistic time scales and programmes for project implementation;
- appropriate specifications for performance standards.

At appraisal, the level of project definition is likely to be low and therefore risk response should be characterised by a broad-brush approach. It is recommended that effort should be concentrated on:

- seeking solutions that avoid/reduce risk, however care is needed to ensure that the consequences of avoiding risk, the secondary risks are not worse than the original risk;

- considering whether the extent or nature of the major risks is such that the normal transfer routes may be unavailable or particularly expensive;
- outlining any special treatment, which may need to be considered for risk transfer, for example, for insurance or unconventional contractual arrangement;
- setting realistic contingencies and estimating tolerances consistent with the objective of preparing the best estimate of anticipated total project cost; and
- identifying comparative differences in the riskiness of alternative project schemes.

Construction project managers will usually have less responsibility for identifying the revenues and benefits from the project: – this is usually the function of marketing or development planning departments. The involvement of project managers in the planning team is recommended, as the appraisal is essentially a multidisciplinary brainstorming exercise through which the client seeks to evaluate all alternative ways of achieving these objectives.

For many projects, this assessment is complex as not all the benefits or disbenefits may be quantifiable in monetary terms. For others it may be necessary to consider the development in the context of several different scenarios (or views of the future). In all cases, the predictions are concerned with the future needs of the customer or community. They must span the overall period of development and operations of the project that is likely to range from a minimum of eight or ten years for a plant manufacturing consumer products to 30 years for a power station and much longer for public works projects. Phasing of the development should always be considered.

Even at this early stage of project definition, maintenance policy and requirements should be stated, as these will affect both design and cost. Special emphasis should be given to future maintenance during the appraisal of projects in developing countries. The cost of dismantling or decommissioning may also be significant but is frequently conveniently ignored.

6.3 Project evaluation

The process of economic evaluation and the extent of uncertainty associated with project development are illustrated by the appraisal of the hypothetical new industrial plant in Chapter 7. The use of a range of financial criteria for quantification and ranking of the alternatives is strongly recommended. These will normally include discounting techniques but care must be taken when interpreting the results for projects of long duration.

Cost–benefit analysis

In most construction projects, factors other than money must be taken into account. If a dam is built it might drown a historical monument, reduce the likelihood of loss of life due to flooding, increase the growth of new industry because of the reduced dam flooding risk, and so on. Cost–benefit analysis provides a logical framework for evaluating alternative factors that may be highly conjectural in nature. If the analysis is confined to purely financial considerations, it fails to recognise the overall social objective, to produce the greatest possible benefit for a given cost.

At its heart lies the recognition that a factor should not be ignored because it is difficult or even impossible to quantify it in monetary terms. Methods are available to express, for instance, the value of recreational facilities, and although it may not be possible to put a figure on the value of human life, it is surely not something we can afford to ignore.

The essential cost–benefit analysis is to take into account all the factors, which influence either the benefits or the cost of a project. Imagination must be used to assign monetary values to what at first sight might appear to be intangibles. It should be mentioned that monetary values are highly subjective and must be evaluated with care. Even factors to which no monetary value can be assigned must be taken into consideration. The analysis should be applied to projects of roughly similar size and patterns of cash flow. Those with the higher cost–benefit ratios will be preferred. The maximum net benefit ratio is marginally greater than the next most favoured project. The scope of the secondary benefits to be taken into account frequently depends on the viewpoint of the analyst.

It is obvious that, in comparing alternatives, each project must be designed within itself at the minimum cost that will allow the fulfilment of objectives including the appropriate quality, level of performance and provision of safety.

Perhaps more important, the viewpoint from which each project is assessed plays a critical part in properly assessing both the benefits and cost that should be attributed to a project. For instance, if a private electricity board wishes to develop a hydroelectric power station, it will derive no benefit from the coincidental provision of additional public recreational facilities, which cannot therefore enter into its cost–benefit analysis. A public sector owner could quite properly include the recreational benefits in its cost–benefit analysis. Again, as far as the private developer is concerned, the cost of labour is equal to the market rate of remuneration, no matter what the unemployment level. For the public developer however, in times of high unemployment, the economic cost of labour may be nil, since the use of labour in this project does not preclude the use of other labour for other purposes.

6.4 Engineering risks

An essential aspect of project appraisal is the reduction of risk to a level that is acceptable to the investor. This process starts with a realistic assessment of the uncertainties associated with the data and predictions generated during appraisal. Many of the uncertainties will involve a possible range of outcome that could be better or worse than predicted.

The implications of several of the risks likely to be encountered in engineering projects are illustrated in Figures 6.2(a–e). It is relevant to note:

- that the single line investment curve shown in Figure 6.2 represents the *most likely* outcome of the investment. An idea of the spectrum of uncertainty arising from the estimates and predictions is shown in Figure 6.2(e);
- the maximum risk exposure occurs at the point of maximum investment – when the project is completed and either does not function or is no longer needed.

Figure 6.2(b) uses the dotted lines to illustrate the impact of both a greater and lower level of income generation on the project cash flow.

Figures 6.2(c) and (d) shows the significance and sensitivity of the cash flow to a delay in completion date and a delay in sanction data respectively.

Risks specific to a project are interactive, sometimes cumulative: they all affect cost and benefit.

Environmental risks frequently result in compromise following comparison of cost with benefit. They are likely to have a significant influence on the conceptual design and the response should therefore be agreed prior to sanction. Residual uncertainty may be incorporated in the analyses, usually as a contingency sum that may have to be expanded.

Risk to health and safety is normally considered as a hazard during design and embraces issues such as reliability and efficiency in addition to safety. In the case of facilities that process hazardous substances

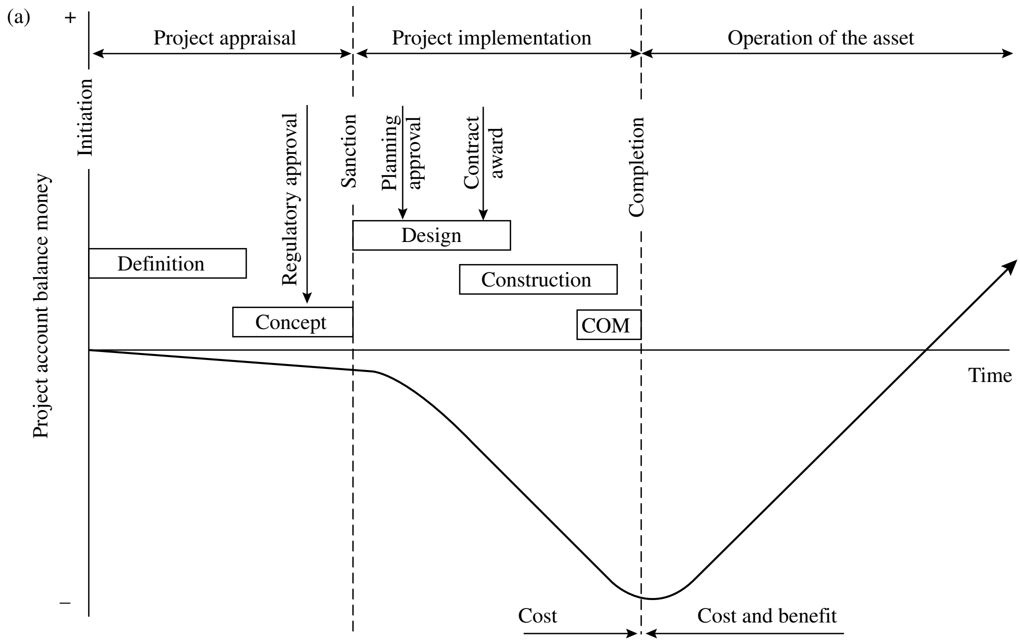

Figure 6.2 (a) Project cash flow – typical cash flow.

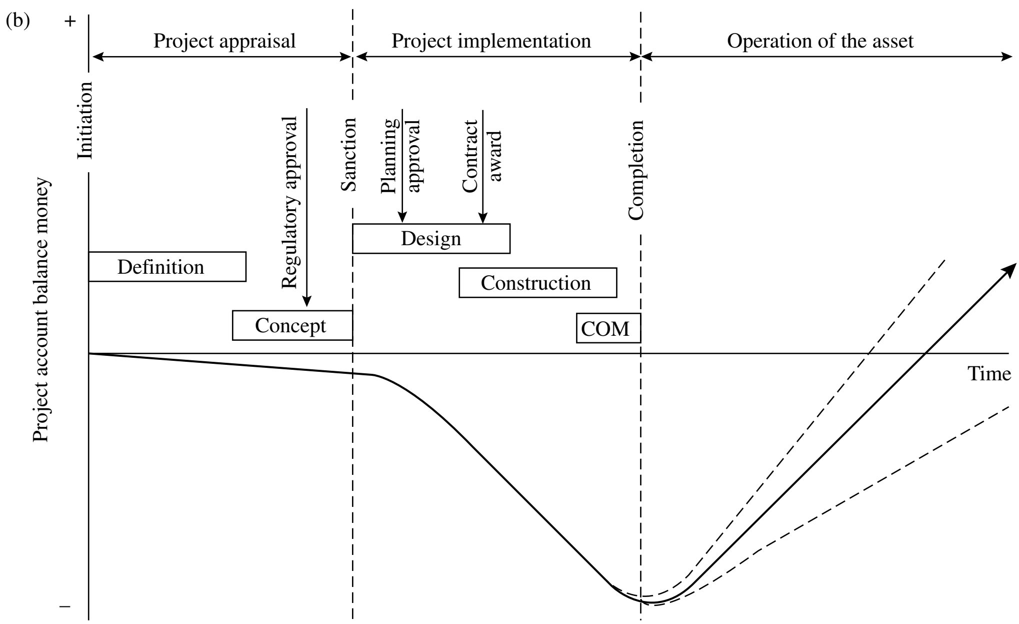

Figure 6.2 (b) Project cash flow – spectrum of operational performance.

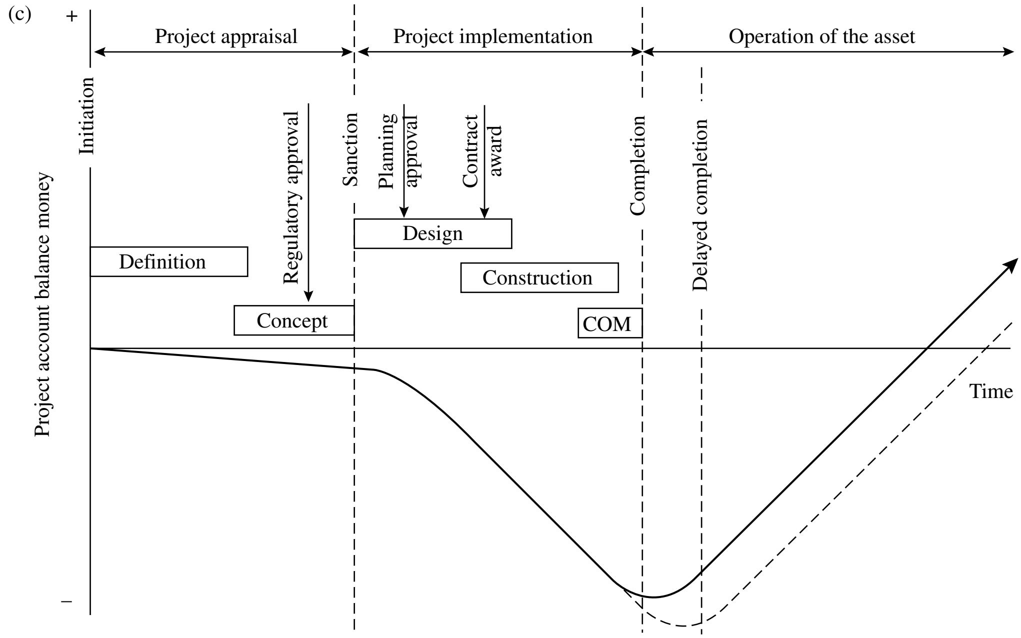

Figure 6.2 (c) Project cash flow – effect of delay in completions.

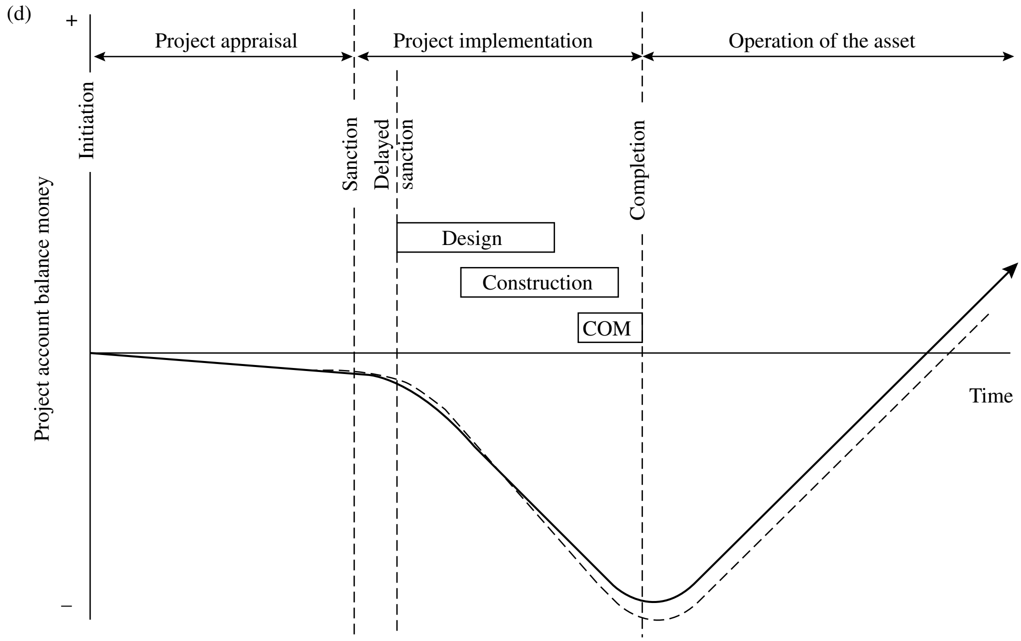

Figure 6.2 (d) Project cash flow – effect of delay in sanction.

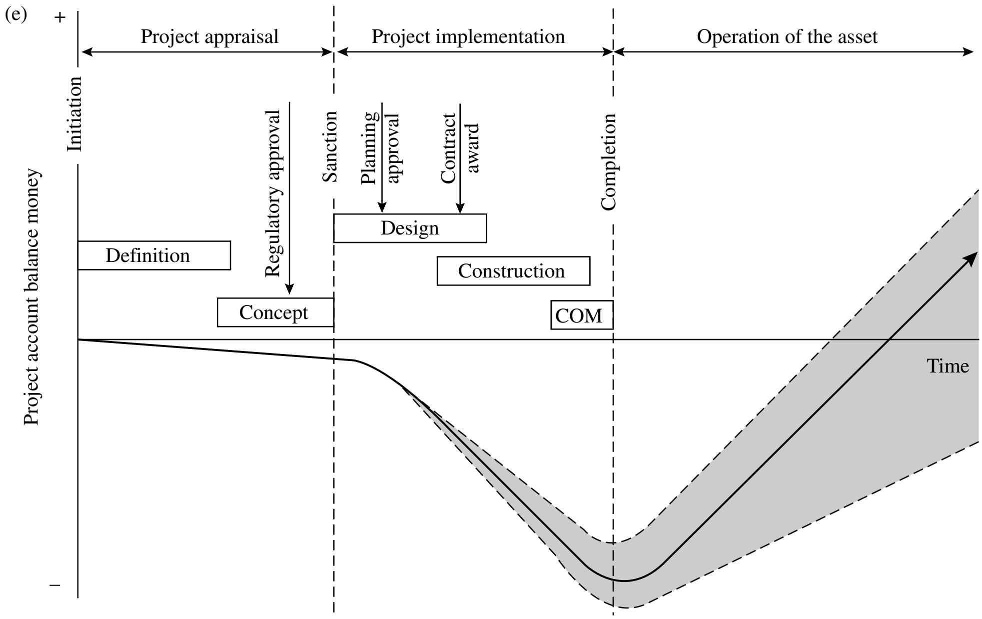

Figure 6.2 (e) Project cash flow – spectrum of change in implementation and operation.

a full-scale safety audit will be necessary or mandatory. This will have implications for both programme and cost.

Innovation The consequential risk of inadequate performance may be reduced by thorough testing but appropriate time and cost provision must be included.

Risk to activity relates mainly to the implementation phase of the project. These risks arise mainly from uncertainty and is the responsibility of the project manager who should be allocated appropriate contingencies. The extent and nature of the contingencies depends on the magnitude and complexity of the risks and on the degree of flexibility required.

All uncertainties, particularly those that cause delay, will affect investment in the project. Many risks are associated with specific time constraints imposed on the project. The preparation of an outline programme is an essential early requirement of any approach to risk identification.

6.5 Risk management

The logical process of risk management has been defined earlier as:

- identification of risks/uncertainties;
- analysis of the implications (individual and collective);

- response to minimise risk;
- allocate appropriate contingencies.

If uncertainty is managed realistically, the process will:

- improve project planning by prompting what if questions;
- generate imaginative responses;
- give greater confidence in estimates;
- encourage provision of appropriate contingencies and consideration of how they should be managed.

Risk management should impose a discipline on those contributing to the project, both internally and on customers and contractors. By predicting the consequences of a delayed decision, failure to meet a deadline or a changed requirement, appropriate incentives/penalties can be devised. The use of range estimates will generate a flexible plan in which the allocation of resources and the use of contingencies are regulated.

Risk reduction

- Obtaining additional information.
- Performing additional tests/simulations.
- Allocating additional resources.
- Improving communication and managing organisational interfaces.

Market risk may frequently be reduced by staging the development of the project. All the above will incur additional cost in the early stages of project development.

Contingencies

The setting and management of contingencies is an essential part of project management. The three types of contingencies are: time (float), money (allowance in budget) and performance/quality (tolerances).

Their relative magnitude will be related to the project objectives. The responsibilities/authority to use contingencies should be allocated to a named person. It is essential to know what has been used and what remains at any point in time.

The role of people

All the above risks may be aggravated by the inadequate performance of individuals and organisations contributing to the project.

Control is exercised by and through people. As the project manager will need to delegate, he/she must have confidence in the members of the project or contract team and, ideally, should be involved in their selection.

Staff should be involved in risk management in order to utilise their ideas and to generate motivation and commitment. The roles, constraints and procedures must be clear, concise and understood by everyone with responsibility.

6.6 Probabilistic analysis

For real projects, ranges of values are preferable to single figure estimates because of the level of optimism that is inherent in a single figure estimate. Probabilistic risk analysis techniques are used to provide information such as estimates of the likelihood of achieving certain project targets and the likely range of outcomes of the project, in terms of its duration and economic parameters. There are a number of different probabilistic risk analysis techniques and each technique requires the specification of key project variables and their corresponding distributions. A probability distribution is used to describe the ways in which a value may be selected as representative of the estimated range of outcomes of a variable.

Probabilistic analysis techniques require a large number of calculations to be carried out, and this usually requires the speed and processing power of a computer. There are a number of computer programs available for use in the risk management process and most of these programs utilise one of the probabilistic analysis techniques described in this section.

Monte-Carlo technique

The Monte-Carlo technique was so called because of its imitation of the randomness of a roulette wheel. This technique was developed a number of years ago and has become one of the most popular probabilistic risk analysis techniques. Computer programs often make use of this technique in conjunction with model simulations. It has been well documented and the full mathematical calculations and equations required can be found in a number of texts.

The Monte-Carlo technique is a process for developing data using a random number generator. It should be used for problems involving random variables with known or assumed probability distributions. This technique requires the selection of different values from a probability distribution, the values corresponding to their probability of occurrence as defined by the probability distribution. In the analysis phase, the identified risks are quantified. The quantitative risk is usually included in the risk model by estimating a pessimistic, a normal and optimistic value, known as a triangular distribution, although others can be used (see below). It is very important that the risk analyst manage to transfer the information gathered in the identification phase into risk assessments reflecting the real risk affecting the parameters. Often the spread is far too conservative, that is, the risk is underestimated. It is also very important to discuss the assumptions behind the estimates to avoid the risk assessments that are anchored to the estimates.

It is very important to use a practical and approximate approach when quantifying risk and selecting probability distributions. Do not turn your project into a complete mathematical equation. Keep it simple!

Examples of typical risk distributions are given in Table 6.1. The risk quantifications as shown in the table were allowed for an industrial project and are based on subjective judgements (experience and knowledge) and *gut feeling* of members of the project team and is used as input to a risk model.

A simple explanation as to the way in which a Monte-Carlo technique operates is now given. A value is chosen from the probability distribution of each of the variables and run through the project model. Each pass through the project is called an iteration. It is normal to carry out one thousand, or more, iterations for an average project to ensure that the results are free from most statistical biases.

The Monte-Carlo technique requires a sequence of random numbers that have no predictable pattern and satisfy various statistical tests of randomness. Output histograms produced from a Monte-Carlo analysis can be tested in two ways to see if they are *robust*. The histograms should be sensitive to a change in the number of iterations used and insensitive to a change in the random number initiator.

Table 6.1 Examples of simple risk distributions.

Activity	Optimistic	Planned	Pessimistic	Distribution
Construction	16 m $	20 m $	30 m $	Lognormal
Equipment	8 m $	10 m $	12 m $	Triangular
Market size	35 m people	50 m people	65 m people	Triangular
Market share	6%	12%	36%	Triangular
Unit price	1 $	2 $	4 $	Triangular
Operational cost	1.6 m$	2 m $	2.4 m $	Triangular

Note: m = million.

However, the use of random numbers implies that all of the variables are independent of each other, and in many projects, this is not true. It is often the case that variables are interdependent, and a common example of this is when there is a delay in the design stage this often leads to a delay in the construction of a project. Sometimes interdependent project variables are specified as correlated in order to overcome this assumption.

The Monte-Carlo technique does not require the analyst to have a great amount of knowledge about computer modelling or statistical risk analysis techniques in order to use it effectively. However, it is not advisable to use it on projects where there are significant number of interdependent variables, unless the model specifies that, the variables are interdependent. Typically, the number of key variables would be less than 10% of the elements or activities of a project model.

When using a probabilistic analysis technique it is necessary to choose a probability distribution that is representative of the range and the way in which the values of a variable might vary. There are a number of different shapes of probability distribution that can be chosen to represent the probability of occurrence of a range of values that comprise a variable. The shape of the probability distribution chosen is often based on historical data, which would show the distribution of the outcomes for this variable on past projects. The use of historical data is an objective means of deciding the shape of the probability distribution for a variable. However, historical data from which to choose the shape of a probability distribution is not always available and in this event, it is left to the project modeller and those associated with the project to decide on the probability distribution shape. In addition, it can perpetuate old problems!

There are four commonly presented probability distributions, the normal, beta, rectangular and triangular distributions although the triangular (or triple) estimates are the most often used. This is because on most projects, definitive information regarding the likely distributions of key variables is not available but what information exists is likely to reflect a *most likely* outcome and an indication of the relative optimistic and pessimistic range of outcomes. In practice, not all distributions are symmetrical; it is often the case that probability distributions are skewed because it is more likely that there will be a delay in completing an activity than the activity being completed early.

It is important to choose a probability distribution that is appropriate for the variable being considered. If there is no historical data available, then careful consideration should be given to the variable and what is likely to be the result of that variable, before a decision is made about the shape of the distribution. Utilisation of the experience of members of the organisation, from previous similar projects, might assist in the decision as to which probability distribution is most appropriate for a particular variable.

6.7 Response to risks

Since all projects are unique and risks are dynamic through the life of the project, it is necessary to formulate responses to the risks that are appropriate. The information gained from the identification and analysis of the risks gives an understanding of their likely impact on the project if they are realised. This, in turn, enables an appropriate response to be chosen.

Typically, there are three main types of responses to risks, and these are – to avoid or reduce the risks, to transfer the risks and to retain the risks.

Risk avoidance or reduction is an obvious first stop. Once the risks, particularly the sources of risks, have been identified and analysed, it may be possible to formulate methods of avoiding certain risks while making only minor changes to the project. In extreme cases, projects may be abandoned due to an inability to avoid or reduce some of the risks. However, there will only be a few occasions when this response can be used, because the project can only be changed to a certain extent before it becomes either infeasible or unviable or becomes a different project!

By changing certain features of the project, it may be possible to reduce the amount of risk in the project, rather than trying to avoid the risks totally. It might be possible, for example, to change the method of construction to reduce the amount of risk involved in the construction phase of the project, while making little impact on the duration and cost of the project.

Risk transfer involves transferring risks from one party to another, without changing the total amount of risk in the project. Risk transfer can occur between the parties involved in the project or one party and an insurer. The decision to transfer or allocate risk to another party is implemented through an insurance policy or the conditions of contract. It is usually up to the client to initiate the transfer of risk, although there are several factors that need to be considered before any risk is transferred. First, consideration should be given as to whether or not the party that the risk is being transferred to, can do anything to manage or control the risk, and whether they could accept the consequences should the risk be realised. It is generally agreed that risks should be accepted by the party that is best able to manage or control them, or the party that is best able to accept the consequences should they be realised. There is little point in transferring a risk to a party that cannot manage the risk or cannot accept the consequences should it be realised. The second consideration is whether or not the risk premium that would have to be paid for the transfer of a risk is greater than the cost of the consequences should the risk be realised. Again, there is usually little point in paying more to transfer a risk than it would cost to accept the consequences should the risk be realised. Equally, there could be the problem that a low tenderer has not priced risk at all.

In some situations, the only option available is to retain a risk. The party that is holding a risk might be the only one that can manage the risk or accept the consequences should the risk be realised. The risks retained may be controllable or uncontrollable. If the risks are controllable, then control may be exerted to reduce the likelihood of occurrence or the impact of the risks. It is normal for the client to be left with some risks, and these are termed the residual risk. The client ultimately carries the risk in a project.

The timing of an action taken to mitigate the effects of a risk may dictate the action that is chosen. The first possible action is on advice that reduces the chance of the risk being realised. Then there are after-the-fact actions using readily available resources. This refers to an action taken once the risk has been realised, using the resources that are available at the time the action is taken, a purely after-the-fact action requiring essential prior actions. This action requires the use of contingency measures that are planned prior to the start of the project.

Despite the use of formalised procedures and techniques in the risk management process, the element of human judgement must not be overlooked. One of the most significant uses of judgement is in deciding which actions should be taken to manage the risks. There are no rules that can be applied in this situation, it is up to each party in the project to decide whether they are prepared to accept a risk or whether they wish to find some means of avoiding or transferring the risks but this depends upon the thoroughness and clarity of the risk identification and analysis. Judgement in this process will be influenced, to a certain extent, by the decision-makers perceptions of the risks and their attitude toward risk taking.

6.8 Successful risk management

Risk management is undertaken by both client and contractor organisations, but for different reasons. Clients will usually be concerned with the best use of their capital resources, the likely cost of procuring the facility and their return from their capital investment. Contractors will be concerned with the decision as to whether to tender for a given project in terms of the returns obtainable, the desired competitiveness of their tender and the most profitable means of constructing or increasingly designing and building the project.

The duration that clients typically take to propose, appraise and sanction projects can range from a number of months to many years. Contractors are often given a matter of weeks to tender for projects. It is apparent that the risk management exercise undertaken by the client should be more comprehensive than that undertaken by the contractor. In addition, clients often take the view that the sort of risk that might cause a contractor to default is exactly the type of risk that they do not wish to carry.

It is important to ensure that the requirements and nature of the project concerned determines the mechanisms employed, rather than selection based on expediency. There would be little point in employing risk management methods that require, for example, precise risk data if none was available but this is often the case.

The prerequisites for successful risk management would seem to be: full specification of the project and all identified associated construction risks, a clear perception of the construction risks being borne by each party, sufficient capability, competence and experience within the contracting parties to manage the identified construction risks and the motivation to manage risks, requiring a clear link between a party's ability to manage and actual management of risks and their receipt of reward.

The effectiveness of risk management is improved if all parties to a contract have the same appreciation of the identified risks. The contractor and the client should have similar views of the likelihood and potential effects of all risks. This can be achieved if pre-contract discussions between the client and the contractor ensure that a clear, mutual understanding of the relevant risks. A lack of understanding may lead to the contractor under-pricing their tender and pursuing claims for additional sums as the project proceeds. Alternatively, contractors may deliberately price low and expect to recover money through claims.

6.9 Principles of contingency fund estimation

Contractors employ contingencies in an attempt to guarantee their return when construction risks for which they are responsible occur. These contingencies represent the risk premium that the client pays for allocating construction risks to the contractor. The risk allocation strategy employed can have a major effect on the contractor's tender for a project, particularly when the project is perceived as high-risk by the contractor.

Current risk modelling techniques allow good correlation between the risks identified and quantitative risk analysis (QRA). Current risk management practise uses the risk register as a key management tool to identify risks and track management responses.

A danger inherent in combining the risk register and the QRA is that there is a belief that because discrete risks are identified, logged and modelled and then if a risk has not occurred, the value assigned to it can be subtracted from a budget figure that corresponds to a specified confidence level.

The errors in taking this view are outlined below:

- The input data for risk analyses are subjective and approximate. If precise data exists then by definition the issue in question cannot be a risk. It follows that the results of risk analyses are approximations. They are not accurate in the accounting sense.
- The model uses a sampling technique so the contribution of each risk to the total at any given confidence level is not known. If a risk has been avoided the reduction in the estimated cost should be calculated from running the model again with the risk deleted. The effect of deleting a risk must not be calculated by subtracting the value of the risk (itself a subjective evaluation) from a total budget at a given confidence level.
- Whilst it is correct to link certain risks to activities in the programme, it is an oversimplification to treat the programme as timelined that identifies dates by which risks should occur. First, the programme is at risk so any date should in fact be a range of dates. Second, although the programmed date that the risk should have occurred may have passed, the risk could have occurred without being reported. For example, a contractor may only notify the occurrence of a risk when he claims compensation for it some time after the event itself. Third, many risks are not discrete events that can be linked to a single point in the programme, so it is difficult to say they should have occurred by a given date.

The fundamental point is that the results of QRAs cannot be treated as entries in a set of accounts. Expressing in another way, the risk register does not constitute a budget with line items.

When the use of risk management as a separate discipline in project and construction management was being developed in the late 1970s and early 1980s it was recognised that many of the key risks that could be identified were the soft issues that are very difficult to quantify with precision. It was obvious that to ignore these risks because they were imprecise and difficult to quantify is absurd. It was equally obvious that the traditional approach to making allowances for these risks, plus anything else that could be thought of or happened to come along later, by adding a single figure contingency of say 10%, is inadequate. This approach does not define risks as discrete items. This means that they are frequently overlooked by management and not quantified.

To improve the situation and allow more realistic plans and estimates to be prepared, risks are identified and computer simulations are used to model complex scenarios. Put very crudely, whenever we prepare an estimate or plan, we usually consider more than one value: an optimistic outcome and a more pessimistic outcome, then we choose a value somewhere in between. When the single figure is selected, two values out of three are discarded. That is to say, more than two-thirds of our knowledge is discarded. In fact it is worse than this because the optimistic value may not be the best possible and the pessimistic is not the worst that could occur. In other words, neither the opportunities nor the major risks are included.

The main purpose is to demonstrate that there is a range of possible outcomes for a project rather than a single value and to show how risk and uncertainty influences that range. It was never the intention, nor is it possible, to treat the results of risk analyses as accurate forecasts of future outcomes. They are better approximations than single figure estimates with a nominal contingency sum added. They also lead to better understanding and management of risk.

Annexe: Alternative methods of risk analysis

Portfolio theory

Portfolio theory was originally developed within the context of a risk-averse individual investor who was concerned with how to combine shareholdings in several different companies in order to build up an investment portfolio that would maximise his expected returns for a given level of risk.

At any given time, most organisations are involved in a number of projects, each project containing different levels of risk. When the various levels of risk for each of the projects are combined the organisation can find itself exposed to very high levels of risk. An organisation that does not consider the amount of risk to which it is exposed may easily overstretch itself by taking on too many *risky* projects.

Appraisal techniques tend to consider individual risks or the risks related to a single project and this can have serious implications for an organisation. Some practitioners have applied this theory to the portfolio of projects built up by an organisation. This enables the organisation to perceive the amount of risk to which it is already exposed, and to decide whether it would be able to undertake another project, in terms of the additional risks that the organisation would be exposed to. Portfolio theory is a theory that assists the organisation in choosing what can be termed the *efficient set* of projects.

Delphi method

The Delphi method is an established technique for obtaining consensus estimates from several experts, and this technique can be applied to the assessment of risks. The general procedure for this technique is that an estimate of the variable(s), or risks, is obtained from each of the experts. This estimate can relate to the probability of occurrence or the likely impact of a variable. The experts are then informed of all the estimates and asked to give a revised estimate. This process continues until a consensus estimate is produced. This method can be viewed as a qualitative or quantitative technique, since the experts may or may not be asked to provide a quantitative estimate of a variable.

The Delphi method can be adapted for use in the assessment of risk in projects. This procedure starts with the formation of a team of experts that represent all aspects of the project. This is an interdisciplinary team of experts formed for the purpose of assessing the risks in a project. The experts meet and formulate an exact definition of the risk that is being considered. They then discuss the risk, paying particular attention to its causes and the interdependencies it has within the project. These experts then give their opinions as to the probability of occurrence of the risk and the impact of the risk on the project should it occur. The experts can also give a cost assessment of the risk based on the probability of occurrence and possible impact. This procedure is based on the consensus of opinions of the experts involved. The procedure proposed differs from the classical Delphi method in that the opinions of the experts are not gained from a survey but instead the experts are drawn together in meetings presided over by a moderator.

This risk analysis technique is expensive, in terms of the resources used, the cost of the resources and the time taken. The technique relies heavily on the opinions of people deemed to be experts. If the group of experts chosen does not represent a sufficiently interdisciplinary team then the results produced may be biased and of little use. In order to produce results of any value the team must hear the opinions of experts from all fields related to the project. However, it would be difficult to find a time when all the experts could meet to discuss the risks in a project. If the classical Delphi method is used then it is not necessary to get all the experts together at once, thus allowing a wider range of experts to be used, but the time taken to get a consensus view would be significantly increased.

The Delphi method is a very subjective technique and the results gained from this should be viewed with caution. This technique would be best used on projects where there is little information available or where the organisation concerned has little previous experience of carrying out similar projects. Due to the expense incurred from using this technique those constrained by a tight budget should not use this technique.

Influence diagrams

Although this is a relatively new technique, it appears to be based on the much older network planning technique. The influence diagramming technique involves mapping out the project, identifying the sources of risk and possible responses to these risks. This information is then represented diagrammatically.

Although influence diagrams are essentially a qualitative method of analysing the risks in a project, costs and times can be included in the diagram if desired. To use this technique it is necessary to have some understanding of risk sources and their importance. However, the main advantage of influence diagrams is that the relationships between the risk sources and activities in the project can be easily seen. By being able to see these relationships it makes it much easier to identify effective responses to the risks, and in some cases, it is possible to identify one response to a number of risks.

This technique is very useful and relatively cheap, in terms of the time that it takes to perform the analysis and the resources that are required. The influence diagramming technique requires consideration of the entire project and then displays this information in a simple and understandable way. This technique assists in identifying risk responses that apply to several risks. However, it is a subjective technique and if used on projects that can be divided into a number of small sections the diagram becomes unclear. This technique is best applied to projects that are divided into a few major activities, where alternative strategies are being considered and where quantitative assessment of the risks is not required.

Decision trees

Decision trees, also known as decision networks, are diagrams that depict a sequence of decisions and chance events, as they are understood by the decision-maker. The decision tree is made up of two types of nodes, decision nodes and chance event nodes. A decision node represents a decision that has to be made and a chance event node represents an event that has a chance of occurring, possibly a risk. A decision tree starts at a decision point node on the left hand side and the information is conveyed going across the page from left to right. At the time represented by a specific node all prior decisions, or decisions to the left of the node, have been made and uncertainties related to prior chance event nodes have been removed. Each decision node should have at least one branch, or arrow, coming from it and these branches represent the decision alternatives.

The branches of a decision tree indicate the alternative courses of action that can be taken, and in this form, the decision tree can be considered a qualitative risk analysis technique. However, if probabilities are assigned to the branches of the decision tree indicating the likelihood of each course of action occurring or being taken, then the decision tree is used as a quantitative risk analysis technique. A decision tree does not necessarily have to have probabilities of occurrence assigned to the branches when it is being used as a quantitative technique; there are several other measures that could be used. Examples of other measures are the cost of taking a particular route or the gain expected from taking a route, and it is up to the decision-maker to determine which measure is most appropriate for the project.

The procedure for constructing a decision tree begins with the identification of decision points in the project and the possible alternative courses of action available at each of the decision points. Once this has been completed, it is necessary to identify the chance-event points, or uncertainties in the project and establish the possible alternative outcomes of each chance-event. When used as a quantitative technique, the quantitative information, such as the cost of the possible alternative courses of action, must be estimated. Finally, the decision tree should be evaluated to obtain the expected values for following each alternative course of action.

The main advantage of using a decision tree is that, whether it used as a qualitative or quantitative technique, it requires the entire project to be set out in a logical sequence. This ensures that the decision-maker has considered all the options available in the project at an early stage. An advantage of using decision trees is that they clarify and communicate the sequence of events to be considered in making a choice. Since decision trees are a diagrammatical representation of project information, they are easily understood. They give everyone involved a common understanding of the way in which the decision-maker perceived the project. This technique does not identify the best alternative or course of action to be taken; it merely sets out all the possible alternatives. If it is used quantitatively then it can give some measure of the likelihood of alternatives or courses of action occurring, or of the possible gain from taking a particular course of action.

Decision trees are a very useful technique for getting information across to those involved in the project. They are cheap and easy to produce, since they only require the use of one person who has a good understanding of the project, the chance events and the alternatives available. However, if the project has a large number of decision nodes or chance event nodes then the decision tree can become complicated. If it is used for a quantitative analysis on that type of project then the calculations involved become time consuming and tedious, and to some extent, subjective. The measure that is used in a quantitative analysis gives the outcomes derived from taking different routes, however, this measure is subjective and not always very meaningful. In projects that contain a number of chance event nodes the measure produced for each route can show the probability of that route actually being taken, but the probability of each route being taken is likely to be small due to the large number of opportunities to take different routes. This technique is best used to evaluate different approaches to a project. It is a good technique for communicating information.

Latin Hyper-Cube sampling

Latin Hyper-Cube sampling is a technique that statisticians recommend for use when there are a large number of parameters to be varied. For problems containing several variable parameters there will be a very large number of possible choices, and, in these cases, the sample size is usually smaller than the number of possible choices. In a case such as this, a Latin Hyper-Cube can be constructed and the sample is then chosen from this in a deterministic, statistical way. The values, once chosen, are then input into the model in same way as for the Monte-Carlo technique, producing a range of possible outcomes for the model. This is only a simple explanation of the technique, but information that is more detailed can be found in other texts.

The difference between this technique and the Monte-Carlo technique lies in the choice of the sample, therefore, many of the advantages and limitations are the same. Latin Hyper-Cube sampling is a relatively new technique, particularly in the field of project and risk modelling, giving a limited scope for its current use.