Chapter 2 Literature Survey

2.1 The Five Steps of Risk Management

All human activity involves risk. The success or failure of any venture depends on how one deals with it. *It* is this ***dealing with it*** that has developed into the process that is commonly known as risk management.

Buchan (1994), in his recent article, took three processes and implemented a fifteen step sequence, see Table 2.1, to account for risk management. The process is a simple step by step procedure, which if followed should reap beneficial results and a stable risk environment. The steps do vary from company to company because of their contrary risk attitudes and perceptions. Therefore, Table 2.1 is intended to be the foundation for which expansions or modifications should accrue to tailor the individual requirements of a given firm.

Three steps for risk management are identified by Buchan (1994). These three are increased to four in Bostwick's (1987) paper, and five by Mehr and Hedges (1963), Eloff *et al.* (1993), Nummedal *et al.* (1996), and the British Standards BS 8444 (1996). It is risk management, divided into five steps which is applied in this thesis. By using the terminology from **BS** 8444 (1996), the systematic five steps involved for a comprehensive risk management process are:

Risk identification
Risk estimation
Risk evaluation
Risk response
Risk monitoring

Risk Identification	Risk Analysis	Risk Response
Step: 1. Identify risks. 2. Categorise and place risks on priority list. 3. Risks judged as medium or low are deemed covered by project contingent reserves. 4. Establish a program for developing responses to major risks.	Step: 5. Establish causes of major risks. 6. Establish probability of risk impacting on scheme. 7. Establish the consequences if risk left untreated. 8. Develop possible alternative risk response strategies to control/mitigate major risks identified. 9. Analyse possible risk response strategies in terms of cost/ program/likelihood of success. 10. Consider and analyse any secondary risks that could arise from possible risk response strategies being considered.	Step: 11. Choose and develop risk response strategy. 12. Obtain commitment from parties involved to chosen risk response strategy. 13. Implement chosen risk response strategy. 14. Monitor success. 15. Risk is controlled OR Scope of risk changed, return to step 1.

Source: Buchan (1994)

Table 2.1 *Typical Risk Management Sequence*

These five stages fit together into a simple circular procedure, which if maintained obtains a controlled risk environment, see Figure 2.1. This sequence provided the framework for the questionnaire survey.

The stages of risk identification and estimation can also come under the broader title of risk analysis. Although the five steps that are required for risk management are depicted to follow each other sequentially, one will realise, from this chapter and 'the remainder of the thesis, that the steps are quite often inter-connected and very closely related. However, for clarity, the five steps are illustrated in series.

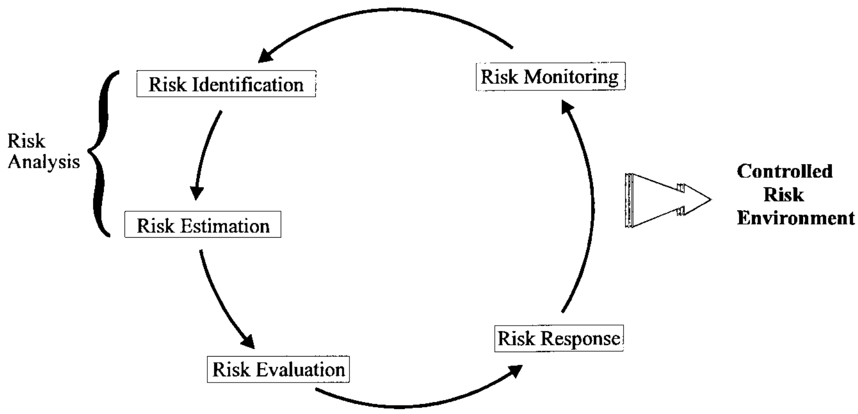

Figure 2.1 *Risk Management life-cycle*

Nummedal *et al.* (1996), on behalf of Phillips Petroleum Company, summarised the method used to update the non-conformances on the existing 26 platforms, that were operating on the Norwegian continental shelf, to conform with the 1992 Norwegian Petroleum Directorate Regulations. The cost of simply correcting all the non-conformances was deemed prohibitive, so the five step process of risk management was initiated incorporating a cost-benefit evaluation to identify risk reducing measures for implementation. It was found that the regulatory non-conformances were not the major risk contributors, but the results from the five step risk management process focused on the true risk contributors that facilitated significant safety improvements in a cost effective manner.

These five steps encompassing the risk management life-cycle can be divided further into a framework to represent the information, which is presented in this Literature Survey and further examined in the subsequent chapters of this thesis, see Figure 2.2. Notice from Figure 2.2, that the author has divided risk management into two stages, which is then sub-divided into the five steps mentioned above. The three stages of risk identification, estimation and evaluation come under the broader heading of risk assessment. Risk response and the monitoring of those risks are referred to under risk control. The terminology presented in Figure 2.2 is used throughout this thesis, but does not conform with every journal publication, book, leaflet etc. as risk and the management thereof is subjective in its understanding. It does, nevertheless, agree with the preponderance of literature written, and is totally compatible with the British Standards BS 8444 (1996) which is a guide to risk management.

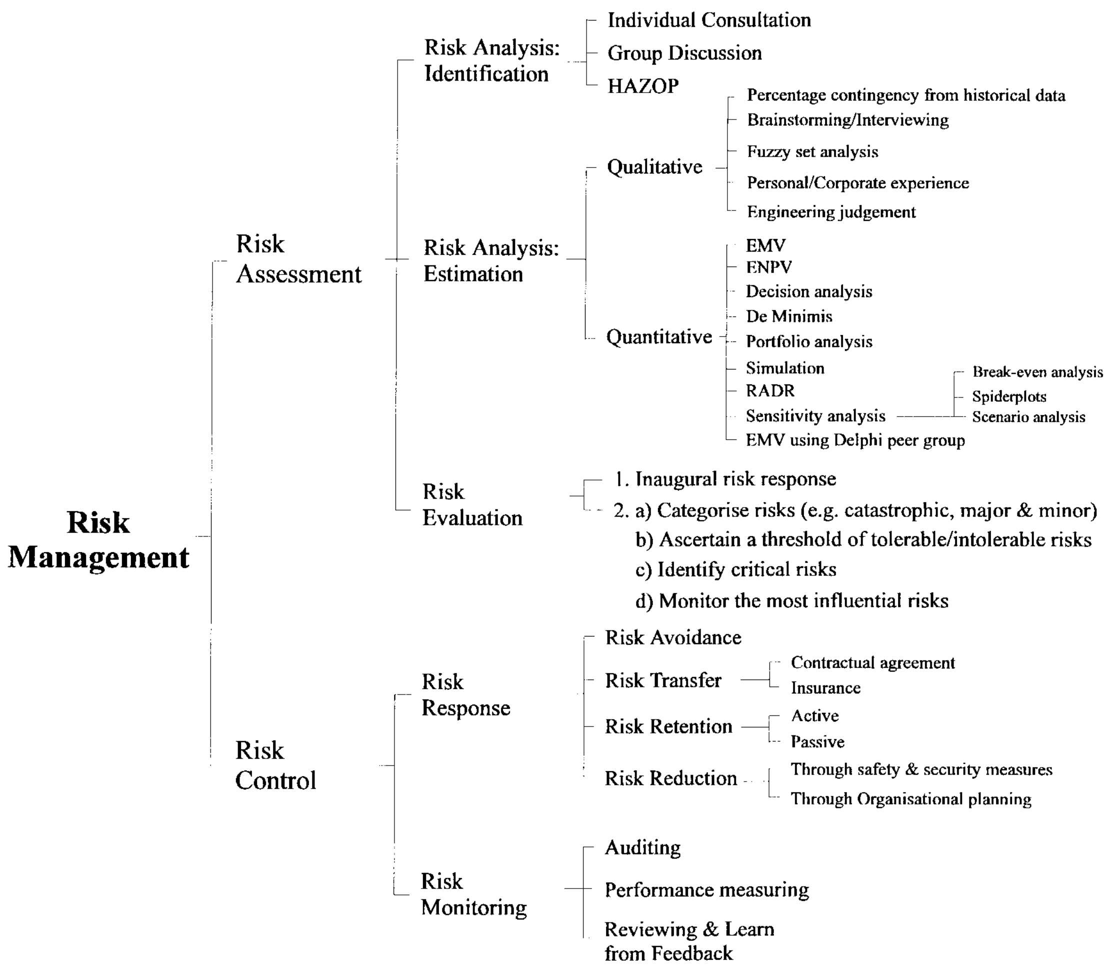

Figure 2.2 *Risk Management framework*

A list of risks that need to be responded to is given in Table 2.2. This list was attained from the responses to the questions in section 7 of the RMQ, see section 4.8.2, but is not exhaustive.

2.2 Risk Analysis: Identification

A definition of risk identification, according to Hertz and Thomas (1983a), is:

> "developing an understanding of the nature and impact of risk on the current and potential future activities of the organisation"
>
> Hertz and Thomas (1983a)

Table 2.2 *The possible risks that could be encountered during a large project*

Types of risk	List of examples of each type of risk
Financial	Investment; inflation; interest rates; rental levels; rate of return; taxation; rate of exchange; overheads; material and labour costs; project delays; shares; tender price; estimate errors; cash flows; contingency; getting paid the right amount in the final account at the right time; Loss making contacts; Client cease payment; Weather/ financial; financial stability of sub-contractor; Scope change unrecorded; late release of areas for design; cost overrun; client/customer/subcontractor insolvency; cost forecast reports; communicating reports; good staff; technical issues; accidents; environment; working practices; client bankruptcy; adequacy of rates and quantities; at tender stage all is an estimate; major omission in pricing; loading a BoQ rate in anticipation of a variation; building costs; good management limits risk; market conditions; economic policy; competitive tendering; financial control system; currency; fixed price; GNP; cost escalation; latent technical risk; lack of cash flow; project aborted; oil prices; exchange rate on manufacturing/procurement costs; 3rd party costs; client demand; uninsured losses; field development costs that do not turn out as expected; out-turn costs; rig rate fluctuations; market prices move up; prime cost estimate wrong; part of a project overspends budget; buying gains;
Technical	Excess wastage; reliability of quality; resale value; access to site; fitness for purpose; design liability; availability of materials and quality of labour; organisation and management of sub-contractors and project team; latent defects upon completion caused by poor workmanship or technology; safety of personnel; design solutions do not function as planned; building collapse; delayed failures; soil/ground conditions on any given site; marine; fire; explosion; helicopter crash; drilling dry holes; mechanical handling; dropped objects; ship collisions; new technology; oil reserves; contractor performance; design integrity; geology; risks associated with finding, developing and producing oil and gas reservoirs; plant failure; product failure; lack of specification; manufacture problems; market competition; new products; undefined operations; interface issues; systems failure; poor supervision; innovative design solutions; design risks; installation complexity; uniquely specified components; ill-maintained plant;
Operational (logistical)	Estimating the size of production; degree of novelty; transportation (loss or damage); change in project scope; Physical injury to construction operatives; improvements in understanding; gas release on offshore platform; human factor; poor operations leading to downtimes; shutdown work/modifications; loss of export systems e.g. pipeline damage/tanker weather problems; poor planning/control of maintenance; procedures; safety training; poor management; poor sub-contractors; poor staff; some group on the project fails to do its job; increased access constraints; spatial fit and space allocation; pipeline pigging; well workovers; hydrocarbon processing; maintenance access; high visibility; accident reporting; insurance claims; failure by groups not to adhere to procedures;

Table 2.2 cont.. *The possible risks that could be encountered during a large project*

Types of risk	List of examples of each type of risk
Time	Meeting design programme; meeting stipulated delivery schedule for the site or assembly/fabrication plant; meeting overall construction programme; minimising disruption due to overlap of work with other trades; delay by inclement weather; possibility of causing delay to other specialist contractors; project duration; late delivery of vital equipment by a supplier; schedule slippage, slippage=costs, delayed payments; time=money; resource limited; inadequate information; changes to work content; delay in selling; building costs over time; evaluation of work complexity; programme commitment; position on critical path; weather/supplier management; overrun of contract period; telescoped/verticality of programme; acceleration impacted cost; late decision of options; late information on design; poor assessment; offshore capital costs; drilling schedules; interface delays; timing of response to events/planning for contingencies; inadequate C.P.A.;
Environmental	*External:* Global warming; (greenhouse effect); destruction of the ozone layer;
	Internal: Weather conditions; ground conditions; Chemical/hydrocarbon pollution of air/water; explosion risk to life; offshore processing of oil and gas involving use of some externally applied chemicals; noise; dust; fumes; pollution: oil to sea, CO_4, SO_4, NO_4, CH_4, emissions; air pollution; use of asbestos and other contaminants; contaminants entering ecosystem; radioactive contamination; undefined products in equipment; overboard discharge; carbon tax; leak detection; HSE problems; clean-up costs; minimise pollution/legislation limits which affects operation; blow-outs; firs; COSHH regulations and their management; oil spills;
Political	Beaurocratic delays; changes in local regulations; changes in Government funding policy; European rules and regulations; physical danger to the public; change of Government; change of economic policy e.g. interest, public expenditure; changes in legislation during project; Government intervention; hidden agendas; protectionism; client and effect on workload; tax changes; nationalism; unstable Governments: manpower rationalisation; change of corporate tax position; location of manufacture; Government sponsor; client relations; employment/wage negotiations; EEC rulings; failure to win job due to unpopularity of British Government; rebel forces;
Reservoir (geology)	Hydrocarbon quantity/quality;

** This is not an exhaustive list **

Therefore, the risk identification stage is where all the potential risks that are foreseeable or predictable are recognised, as well as attempting to determine the unforeseen risks. This stage could be argued to be the most important of all the five stages. As Webb (1994) rightly pointed out, in the conclusion of his article:

> "formalised analysis can only deal with identifiable risks and in so doing demands perfect knowledge of the variables and how they will perform".
>
> Webb (1994)

If the risks have not been identified, then it is impossible to analyse them. He went to say:

> "some would argue that the greatest risks lie in the unknown and unforeseen, and these factors must lie outside the analysis".
>
> Webb (1994)

In their recent article, Schumacher *et al.* (1997) added to this, by forecasting that one of the future key constituents to successful risk management would be the improvement of risk identification, as measures to control the risk can only be assembled if the risks are identified in the first instant. Any unidentified risks can only be managed by pure chance.

The techniques used to identify risks are simple, but require much organisation to attain the optimal results. The type of methods referred to are individual consultation, group discussions and HAZOP.

2.2.1 Individual Consultation

These one-on-one meetings are arranged as a preliminary exercise to initially identify the risks. This process involves key participants in the project in question. The purpose of this stage is to allow the interviewee to contemplate what *he/she* thinks are the main risks attached to either, the project as a whole, or as individual stages of the project or both. **As** the participants are from different disciplines, their viewpoints about the project are influenced by the specialised nature of their field. Such factors can only enhance this particular stage, because their different outlooks on the project enable the main risks to be identified more easily. Therefore, the more consultations that are conducted, and with a varied cross section of participants, (i.e. involve all members of the project, from the experts, designers, engineers etc. to the workforce), the greater chance that the full spectrum of risks are identified, which satisfies the aim of this method. Obviously, the main disadvantage of this technique is time. Interviewing all the necessary persons for this technique to be successful would consume much time. To assist this problem, Spetzler and Stael von Holstein (1975) have evolved a five phase procedure for conducting individual consultations, so the meetings do not exhaust more time than necessary. These phases are: Motivating; Structuring; Conditioning; Encoding and Verification. Chapman and Cooper (1987) point out the disadvantage with this technique, in general, in that a risk could be ignored because of the way in which the line of questioning was slanted, or if the interviewee did not have the relevant information at the time. This is less likely to happen if a panel or group of people were set up where wider ranges of views are available. This process forms the origination of the group discussions.

2.2.2 Group Discussion

Formal group discussion (Cooper and Chapman, 1987) is a process by which potential sources of risk are teased out. Raftery (1994) suggests this method should have a clear set of rules and a timetable. This technique should be carried out with the project team. One person should be the co-ordinator and *must* be able to:

1. chair meetings and
2. have a good sense of humour.

The discussive process should take the form of two distinct stages:

1. Creative session
2. Assessment stage

The creative stage permits any one member of the team, one at a time, to ‘throw’ in potential risks or sources of risk. Individual team members are not restricted to their own knowledge domain and outlandish ideas are encouraged. The rule at this point is that if any suggestion is made the co-ordinator writes it on the list and *no* criticisms of ideas or people are allowed from the floor. This accumulated list is on a flip chart, or the like, and the list is anonymous, so that there is no association of an idea with any one person. Therefore, this list is team based rather than individually.

Two points to mention about this technique and about risk assessment in general. Group discussions are a positive experience as long as the team members are committed to the project and motivated to achieve a successful outcome. This depends upon a number of factors like individuals’ personalities, project type, atmosphere within the meeting etc. The second point is, if a negative or cautious approach is being taken, then a realistic assessment of the problems associated with the project may not result. The whole affair, therefore, needs to be managed effectively and taken very seriously.

2.2.3 HAZOP

The oil industry also use a technique called Hazard and Operability Studies, or HAZOP (see reference ‘HAZOP Training Manual’). This technique can also be used to categorise risks and consider the potential consequences and could therefore be categorised under the qualitative risk analysis. However, its main objective is to identify risks, therefore, it is considered in this section on risk identification. The procedure adopted in a HAZOP study is based on the generation of questions that ensure comprehensive and systematic coverage of all the relevant areas in the design of a process. These questions are asked in an ordered and creative manner by design and operations personnel with technical experience and expert knowledge of the particular process design. The aim of the questions is to identify any design faults or process deviations that might exist which could lead to safety or operability problems.

A HAZOP study can be conducted at various times in the life of a plant, such as: a crude analysis of the initial flow-sheets; full study as soon as the initial design is available; a mini-study on any resulting design changes; a pre-commissioning study on the plant 'as-built'; a post start-up study once steady operation is achieved; or follow-up studies at regular intervals during the life of the plant.

The plant is considered section by section, line by line, and item by item, but never in complete isolation. The questions on the process are based around guide-words which investigate deviations from the intention of the design. The guide-words ensure that the questions explore every conceivable way in which the operation of the plant could deviate from the design intention.

HAZOP therefore searches the design, looking for every process deviation from normal. Once possible deviations have been identified, the study considers the possible causes and the possible consequences of deviations.

However, cases when causes are realistic and consequences are serious will be identified. These potential hazards are then noted for remedial action.

It must be recognised that HAZOPs are time-consuming and that there are few, if any, shortcuts.

The ideal HAZOP study team consists of six to eight members having expertise. in design, operations, and maintenance. The premise for the HAZOP technique is that experts with different backgrounds can identify problems more efficiently when working together than if working separately and combining their individual results.

Two key members of the team are the team leader who is experienced in the methodology of HAZOP, and the secretary who records the session. The team leader advises and assists the team and in particular stimulates team discussion to ensure comprehensive and systematic coverage of all the relevant areas.

Having identified all the possible risks, the next stage is to estimate them using two types of techniques.

2.3 Risk Analysis Techniques: Estimation Stage

There are various techniques that are at present available for risk analysis. They can be broadly grouped into two categories: Qualitative (section 2.3.1) and Quantitative (section 2.3.2). Qualitative techniques are used to distinguish the possibility of a risk occurring and the consequence of that risk in a linguistic manner; for example, a risk is described as low if that risk is unlikely to occur. It is an analysis in relative terms of the outcome and probability of a risk, e.g. a high risk compared to a medium or low risk. It is subjective and is dependent upon the experience of the analyst, allied to engineering judgement, and thus is inclined to be subjective. Therefore, these techniques are prone to inconsistencies, but are extremely valuable as an analytical process in the planning and control of a project. Qualitative techniques are usually employed at the beginning to identify and rank risks (The British Standards Institute, 1996). Those risks with a high or intermediate rank may be further analysed through quantitative techniques.

If little data is known on a risk, then a qualitative analysis is dominant (but subjective). If, however, additional information becomes available then the qualitative analysis forms the basis for more detailed quantitative methods.

Quantitative techniques are normally mathematically and/or computationally based (Thompson and Perry, 1992) and provide numerical probabilities, or frequencies, of the consequences and likelihood of identified risks. The values used in these techniques are obtained from historical databases, or are estimates, and still contain some extent of uncertainty (Smith, 1988), due to the possible use of subjectively attained values. The results of a quantitative technique are compared against company criteria, and decisions made as to whether the risks are acceptable or not. These techniques are then used to validate the qualitative techniques.

Restrepo (1995) identifies limitations to both forms of risk analysis. He says that in an ideal world, risk management decisions would be based on both qualitative and quantitative risk analyses. However, for the nuclear industry for which his paper was written, these decisions are more often qualitatively based, and frequently do not reflect the true weight of the risk. The limitations he identifies in qualitative risk analysis results are often quite vague, since they use generic terms to define risk or any component of it (i.e. consequences and likelihoods of occurrence). Conversely, quantitative risk analysis are often quite expensive to implement. This, given that enough finance is directed towards managing risk, supports the need for risk analysis to be a dual way process, involving a combination of the two types of analyses. Having identified the need for both forms of techniques, the analysis stage should always proceed with a qualitative analysis.

2.3.1 Qualitative analysis

The qualitative or "soft" core of risk analysis is mainly based on personal and corporate experience. This method is prone to questioning or errors as it relies on engineering judgement and is thus very subjective. However, this process may be all the information that is available, so is better than ignorance. The initial qualitative risk analysis usually determines the likelihood of the frequencies or consequences. This initial likelihood is non-numerical and involves applying subjective views.

These views obviously involve the concept of risk perception. This subject of how different people perceive the same risks is a vast area and one which has attracted a lot of research and will no doubt continue to do so. Jasonoff (1993) believes that perception of risk would vanish if people could comprehend probabilities in such a way so as to relate the risks they fear to those they encounter in their daily lives. The fear factor of risk is also distorted because the media tends to portray science inaccurately, with exaggerated accounts of uncertainty and conflict. Jackson and Carter (1984), writing specifically on the subject of risk perception, and Ansell and Wharton (1992) both suggest the one, if not *the*, greatest sources of risk in decision making is the lack of perception of the consequences of the decisions. More emphasis should be put on the identification of all risks and thus obtaining a more accurate perception of the risks to manage before applying an analysis. This is one of the main objectives of qualitative analysis.

One must introduce at this stage another concept, that of risk communication. One of Hadden's (1989) assumptions in her argument for better risk communication is to enable non-professionals to make better choices concerning risks they face. Fiorino (1989) writes "Experts profess to be puzzled by the apparent misinformation and irrationality behind non-experts attitudes, while non-experts question the arrogance and specialisation of technical and administrative elites". Slovic (1987) addresses this problem head on; his research aided risk management and policy-making by improving the communication of risk information between non-experts, technical experts and decision makers. His improvement relied upon a two-way process. Firstly, each side, non-experts and experts, have something valid to contribute; and secondly, each side must respect the insights and intelligence of the other. The whole idea of qualitative techniques is to identify every possible source of risk with the initial analysis utilising the thoughts and ideas of experienced employees and this includes non-experts and experts alike. DeGagne (1996) discovers the fundamentals of risk communication to the external element, the 'public'. He feels that making important decisions about risk requires both the external and internal views to be in agreement. This is not possible until the perspectives of the public are understood and it is critical to comprehend the perception and concerns of the community. Effective risk communication, through caring and empathy mainly, as well as commitment and dedication, honesty and openness, competence and expertise, will increase the likelihood of finding solutions to public concerns and will improve their understanding and ultimately, the quality of the solution. All of these factors result in trust and credibility for the company.

Qualitative approaches analyse risk based upon project characteristics (i.e. type of work, location etc.). Shafer (1991) says these project characteristics are related to contingency requirements in a qualitative way by using historical experience. This is usually done as a percentage of the base estimated cost, by relating similar project characteristics to previously completed projects supplied from a database or from a checklist, or by defining the worst, the best and the most likely cases, more commonly referred to as scenarios. Scenario analysis can be developed into a quantitative analysis by introducing cost figures and probabilities (see section 2.3.2.4.c (Flanagan and Norman, 1993). Here though, the concept can be applied in a method called fuzzy set analysis.

2.3.1.1 Fuzzy set analysis

The likelihood or frequency of a risk occurring or its consequence does not have to be a number, if it were it would be mistaken for a quantitative analysis. It could quite easily be a graded set of categories in natural language such as high-, medium-, or low-level risks (Buchan, 1994; Guarro, 1987). Kangari (1989) uses this response to levels of risk as fuzzy set terminology to construct a friendly user interface with the expert system. The use of fuzzy sets (Booker and Bryson, 1985; Ayyub and Haldar, 1984; Neitzel and Hoffman, 1980; Zadeh, 1965) allows an analyst to communicate degrees of risk of individual project elements to people in readily understood language terms. The concept of communication in risk is extremely important, so any successful method in this subject is vital. Bell (1989) talks about other phrases' in natural language such as, likely and unlikely. She goes on to point out a problem in the use of such terms and the previous system of linguistics as a measure of qualitative probability. The problem is:

> “that subjective interpretation of words such as ‘likely’ and ‘unlikely’ allows opportunity for errors in judgement about risk.”
>
> Bell (1989)

This is why an objective analysis is best, but due to the lack of information, this type of method may be the only option.

The methods that form the core of qualitative analysis are listed below. Although these processes are illustrated as separate techniques, it is feasible that they could be used together.

- Interviewing (see section 2.3.1.2)
- Brain-storming (see section 2.3.1.2)
- Personal and corporate experience (see section 2.3.1.3)
- Engineering judgement (see section 2.3.1.4)

2.3.1.2 Interviewing und Brain-storming

These two techniques, although labelled differently, are also used in the identification stage, see sections 2.2.1 and 2.2.2. The identification use of these techniques is designed to be reasonably informal. Obviously, all the risks need to be ascertained, but the atmosphere in which they are identified is more relaxed, as this leads to a more complete list. The analysis, and/or estimation, stage is more serious in nature. All the ideas are analysed individually and a final draft of the risks is assembled. The idea of the analysis stage is to categorise or rank the risks by using the one-on-one situation in interviewing, or the group discussions from brain-storming. Therefore, the end result from this stage is to prioritise the risks so as to know which of them are to be forwarded to the quantitative analysis. At this point, this threshold level or cut-off point must also be decided. The notion being the risks below this level, and thus those not to be analysed quantitatively, are covered by project contingent reserves. The ones above would not be, hence requiring further analysis.

2.3.1.3 Personal and Corporate experience

Experience is a hard quality to attain. Therefore, if there are employees with experience, then this property should be utilised. Experience enables the main risks in a project to be identified. Obviously, one looks at the more senior officers to excel in this department. However, there is always a chance that certain risks never encountered before are overlooked. **A** method often used in this situation is “rules of thumb” which is highly dependant upon the amount of experience the analyst has. This, according to Raftery (1994), is a rational response to dealing with a complicated world. The 80/20 rule is an example of a “rule of thumb” used when exploring two outline design alternatives. It implies 80% of the cost of the project may be accounted for by measuring the largest 20% of the units of finished work. This ratio changes from one company to the next and from one project to the next depending upon the policies of that company. For risk, such “rules of thumb” would include contingencies or factors of safety. **A** contingency, or risk premium (Flanagan and Norman, 1993; Raftery, 1994), is a percentage added onto the initial estimate in order to account for any unforeseen risks. This rather non-scientific method depends wholly upon the company’s or decision maker’s experience and his/her determination is based upon the trade off between risk and return. If one project resembles a previous project quite closely, then particular attention is given to the logistics of that project, and an amount specified by the experience of the decision maker results. If the project is not equivalent to a previous project, then the policies of the company, or engineering judgement (see section 2.3.1.4), decides on the contingency percentage. Factors of safety are used extensively in the construction industry. This “rule of thumb” method may be the only source in accounting for risk.

2.3.1.4 Engineeringjudgement

This is similar to personal and corporate experience, because engineering judgement is based on “a priori basis”. Engineering judgement plays an important role, as mentioned above, when one project does not resemble a previous one and no other information about the risks involved is available. Therefore, engineering judgement enables possible risks to be identified and their associated consequences to be estimated.

A qualitative analysis should always be performed before anything else, as the process outlined above enables a better understanding of the entire project because the main risks are identified, along with the potential consequences of those risks. As the project develops, the accuracy of the estimates improve, but some of the most influential decisions are made at this stage, so a qualitative analysis is vital. Therefore, one of the main advantages is that the project can then be planned, in both a cost and schedule basis, and as the procedure is explicitly defined, the project, if necessary, can be re-analysed and ultimately re-planned. This then forms the basis for a quantitative analysis. If enough information, by this stage, has been accumulated then numbers, probabilities, costs, outcomes etc. can be applied in the form of a quantitative analysis. Some of the processes pertaining to quantitative analysis are now considered.

2.3.2 Quantitative analysis

Quantitative analysis is used once the qualitative analysis has been completed. The risks that are deemed not covered by project contingent reserves are considered, estimated and a probability is attached to their consequence and likelihood of occurrence.

The quantitative or “hard” core risk analysis is based on likelihoods, probabilities, frequencies etc. from estimates, modelling, testing, historical data, mathematics etc. Therefore, these analyses still contain some degree of uncertainty, due to the possible use of subjectively attained values. The results from these analyses are numerical and give the analyst more information on the multitude of risks present in a major project. However, because some of the input data is subjectively obtained there is the possibility of bias, sometimes more technically referred to as heuristics (Kahneman and Tversky, 1973, 1974, 1979). From this method the likelihood or probability of an event happening can be identified, but as said before this probability can be from a subjective source. This is where the problems start to develop and aggregate. Heuristics does not just affect non-experts, the experts are also culprits of this phenomenon. Krimsky and Golding (1992) suggest four sets of human bias when estimating for risk:

1. *Overconfidence in the ability to foresee all possible failure modes*
2. *Insufficient sensitivity to problems of small "sample" sizes*
3. *Failure to **foresee** system interactions and interdependencies,* i.e. not taking into account unforeseen errors therefore designer error.
4. *"Calibration errors" and cognitive dissonance,* i.e. problems occur in the absence of reasonably definitive data, but the general tendency in risk analysis is for even reasonably definitive data to be in unreasonably short supply.

Covello (1983), in his paper, mentions the first factor of overconfidence, but in respect of risk estimates. Researches have shown that experts and non-experts alike are typically overconfident about their risk estimates. In one study, odds were asked of a number of candidates about the frequency of two lethal events (Slovic *et al.,* 1980). Most people claimed the odds of their estimate being incorrect were 100:1 or greater and in actual fact they were wrong once in every eight times. This kind of miscalculation can have serious judgmental errors. This all leads to a biased estimation of risk.

Greater sources of heuristics, and possibly more closely related to bias are human intellectual limitations. Covello (1983) feels the two most important ones are:

1. *Information availability,* (Tversky and Kahneman, 1973; Singleton and Hovden, 1994) i.e. if an event is fresh in the mind and thus easy to recall then people give it a higher probability of occurring again. Studies (Slovic *et al.,* 1980) show that risks of low-frequency are overestimated, and ones of high-frequency are underestimated.

2. *Representativeness,* i.e. the tendency of people to assume that roughly similar events (e.g. nuclear war and nuclear power) have the same characteristics and risks.

The comments following information availability, above, seem to be contradictory. Surely from the first sentence, the low frequency events should be underestimated and vice-versa. However, in Slovic's *et al.* (1980) studies the opposite occurred. The study was concerned with how people estimate the probability of dying from different causes, and the low risks that were overestimated were risks that were violent and dramatic, such as homicide, while the high risks that were underestimated were non-dramatic, such as dying from pneumonia. This, then, seems to agree more with the first sentence whereby vivid and more animated events are easier to recall and thus are given an inflated subjective probability.

Added to this list of heuristics, Slovic (1987) believes that on the one hand strong initial views are resistant to change. Once a distinct view has been determined, similar evidence seems reliable and defensive, whilst contrary evidence tends to be dismissed as erroneous. On the other hand, however, when people lack a strong belief, those peoples perspectives and actions are altered when presented with information about risks in different ways (e.g. mortality rates as opposed to survival rates) (Tversky and Kahneman, 1981).

As one can see from the literature above, attitudes towards risk are varied. Each person first, imagines different risks associated with a project stage or sub-stage and second, allocates a subjective probability to those risks. Those probabilities are influenced considerably by bias, or heuristics, in the mind of the analyst. This isall due to each separate individual having different perceptions on risk. Therefore, it is necessary to be able to communicate the thoughts and ideas of each individual on that certain situation. Companies vary in their management set-up and hierarchy, and communication, of not necessarily subjects just connected with risk, can sometimes be minimal or even non-existent. However, this can be overcome by introducing certain techniques as those pertaining to quantitative analysis, see Table 2.3, as well as those already described under qualitative analysis, in section 2.3.1.

Section	Quantitative analysis technique	Sub-division of analysis technique
2.3.2.1	*Expected monetary value (EMV)*	
2.3.2.2	*Expected net present value (ENPV)*	
2.3.2.3	*Decision analysis:*	
2.3.2.3 a)		Algorithms
2.3.2.3 b)		Decision matrix
2.3.2.3 c)		Decision trees
2.3.2.3 d)		Bayesian theory
2.3.2.3 e)		Stochastic decision tree
2.3.2.4	*Sensitivity analysis:*	
2.3.2.4 a)		Break-even analysis
2.3.2.4 b)		Spiderplots
2.3.2.4 c)		Scenario analysis
2.3.2.5	*EMV using a Delphi peer group*	
2.3.2.6	*Risk adjusted discount rate (RADR)*	
2.3.2.7	*De Minimis theory*	
2.3.2.8	*Simulation:*	
2.3.2.8 a)		Monte Carlo sampling
2.3.2.8 b)		Latin Hypercube sampling
2.3.2.9	*Portfolio theory*	

Table 2.3 *Quantitative Risk Analysis Techniques*

Firstly, the main objective of quantitative analysis is to obtain frequencies, usually per annum, of those risks that have been identified from the qualitative analysis to be worthy of quantification, and to discern which of those need measures to reduce those frequencies to a level that is deemed, by each individual company, to be acceptable. The term ‘risk’ associates with an event that may or may not occur. The fact that there is doubt as to whether an event will or will not happen means that the situation is risky. Consequently, this must be accounted for by allocating probabilities with the likelihood that this event will happen.

A probability is a number between zero and one (Stanley, 1992) which represents a judgement about the likelihood of an event. When a probability is equal to one, this represents a certain event. Conversely, when equal to zero, this represents event will never happen.

An analyst can express the probability associated with a risk in a number of ways:

- the absolute value, i.e. 0.2,
- the percentage value, i.e. 20%,
- a fractional value, i.e. one in five,
- odds, i.e. four to one against.

These four techniques are good for estimating probabilities concerning risks within the range of 0.1 to 0.9. Events with a probability of less than 0.1 are described as ***rare.*** It is much harder to accurately estimate the probability of events below this range. If one goes to greater extremes, e.g. 99% confidence, then the events are described as very rare and estimating these low percentiles is even more difficult (Alpert and Raiffa, 1982). Selvidge (1975) developed a technique for encoding rare events and she recommends a three step procedure:

1. Describe the uncertain event clearly and try to relate the event to one which the analyst is more accustomed.
2. Expression of uncertainty in relative terms. No numerical value should be assigned here, but the analyst should be able to rank the events in terms of the most probable event down to the least probable one. Then a semi-quantitative estimate between the events is required. e.g. to state how many times more likely event A is when compared to event B.
3. Numerical expression of probability. The analyst has a number of 'external calibration' techniques with which to help him/her relate to rare events:
    a) Use of reference events, such as plane crashes, tidal waves etc., which occur infrequently;
    b) use of reference processes;
    c) use of 'demonstrative' techniques. e.g. the analyst is given a piece of graph paper with one million squares on it: the chance of picking out one specific square at random has probability of 10^{-6}.

Offshore platforms are often evaluated using a probability analysis. McGuire's *et al.* (1991) describes how a probabilistic reliability analysis is used on offshore platforms and how the analysis considers environmental loads on the structure, inaccuracy in modelling loads and structural capacity as random quantities, and evaluates the likelihood of failure or other undesirable outcomes, such as excessive deformation. Probability analysis is incorporated into two other risk analyses for offshore platforms. Firstly, extreme load risk analysis concentrates on examples like this one for environmental conditions; the failure strength for the highest wave to strike the platform in its 50 year life cycle. Secondly, fatigue failure risk analysis focuses on the effect on welded connections from repeated changes in stress caused by wave action. Goyal's (1986) paper explains how probability analysis is utilised in four case studies, two of which are described in more detail and from the oil business. His results were presented in the form of F-N (frequency - no. of fatalities) curves, and the decisions about remedial measures in the one case, and the locality of pipelines in the other were possibly due to the probability risk analysis. Suggestions were that the probability risk analysis will continue to be used in the oil business. Therefore, a description of the techniques associated with this analysis follows.

2.3.2.1 Expected monetary value (EMV)

Cozzolino (1979) suggests that the expected value (EV) analysis, as he called it, "is not a risk analysis and can therefore be misleading". He feels in order to use this analysis to good effect one must draw up risk profiles which show clearly how risk averse a decision is. Basically, by itself it can become misleading as the decision becomes progressively more complex, because other factors are needed for a comprehensive decision to be made. McKim (1992) says this classical risk theory has several useful properties for project managers. The EMV of an event is an easy variable to calculate (see equation 2.1), but this can be combined with other analyses (like for example ENPV, Decision analysis, Scenario analysis and with using the Delphi peer group), to present a more deterministic analysis; therefore it is necessary to describe the EMV before any other quantitative analysis. The basic mathematical equation that determines the expected value (EV) is:

$$EV(x) = P(x) \times I(x) \qquad \textbf{Equation 2.1}$$

(where P(x) is the probability of event x happening and I(x) is the impact)

The expected monetary value can easily be found by measuring the term I(x), from equation 2.1, financially. The advantage of measuring this in monetary terms is that comparison of non-similar risks is possible (e.g. the risk of a schedule acceleration against the risk of liquidated damages if the project completion date is not met). Raftery (1994) gives an example of how a scenario analysis (see section 2.3.2.4.c) can be taken one step further to include equation 2.1. By estimating the necessary optimistic, most likely and pessimistic outcomes of a project with their respective probabilities, and by summing the products of these two variables for each outcome, the expected monetary value of that project can be obtained (and thus a decision on whether to proceed any further can be made).

Expected monetary values can be applied in a wide variety of situations. The added advantage of EMVs is that they explicitly allow for the probability of change in the input. However, the disadvantage is that EMVs may not give the best practical advice for a specific decision on a project. EMV should only be used as a decision criterion if it is used consistently over many similar sized projects. Nevertheless, the EMVs can form the basis of many analyses. One such analysis is useful in investment and development appraisal and is called Expected Net Present Value (ENPV) and is discussed next.

2.3.2.2 *Expected net present value (ENPV)*

The best way to describe this method is by illustrating it with an example. It has already been mentioned that the ENPV is useful in investment and development appraisal, therefore by taking the offshore industry as an example the following depicts a simple investment appraisal (Wilson, 1994). **A** company is to invest one million pounds in a new piece of equipment used to cut pipelines into specific lengths. The annual income is dependent upon the return obtained by the use of the machine, which is in turn relying upon the state of the offshore industry. This is due to the vagaries in the cost of a barrel of oil, e.g. $13.45 to $16.50/bbl in the first six months of 1994. Following the recession, the industry is on a minor upturn, but with the current economic and political climate, the upturn may be short lived. The incomes are net of all production costs. The model is based on a 10% discount rate in investment appraisal. This represents the long term inflation-adjusted cost of capital. Three states of the industry were considered to calculate the ENPVs with corresponding probabilities. Table 2.4 and Table 2.5 summarise this:

STATE OF THE INDUSTRY				
Year		Declines (£)	Remains Steady (£)	Growth accelerates (£)
Net income:	Year 1	340 000	360 000	400 000
	Year 2	300 000	400 000	500 000
	Year 3	300 000	400 000	500 000
	Year 4	300 000	400 000	500 000

Source: Wilson (1994)

Table 2.4 *Net income projections*

STATE	PROBABILITY	NPV (£)
Decline	0.2	279 000
Steady State	0.6	351 000
Growth	0.2	428 000

Source: Wilson (1994)

Table 2.5 *States, probabilities and NPV's*

Calculating the net present value (NPV) of each of the states is performed using equation 2.2:

$$NPV = [(\text{Sum of income years 1-4}) / 4] - \{[(\text{Sum of income years 1-4}) / 4] \times 10\%\}$$

Equation 2.2

On the basis of this information the industry calculates the *expected* NPV (ENPV) as follows:

		£
Decline	£279 000 × 0.2 =	55 800
Steady state	£351 000 × 0.6 =	210 600
Growth	£428 000 × 0.2 =	85 600
	ENPV =	352 000

Applying the same format as that for investment appraisals (shown above), development appraisals of new buildings or infrastructure projects could be obtained. Other areas within the construction industry that EMV and ENPV techniques can be used are for budget, tender prices or completion dates. The advantage of these techniques is that they can accommodate for changes in the input, but the disadvantage is that the probabilities are subjective, which can limit the accuracy level.

2.3.2.3 *Decision analysis*

The definition of decision analysis is:

> "Decision analysis is a technique for making decisions in an uncertain environment that formally treats both risk exposure and risk attitude. It provides a methodology to allow a decision-maker to include alternative outcomes, risk attitude and subjective impressions"
>
> Flanagan and Norman (1993)

The advantages of decision analysis are that they may deal with a foreseen difficulty or they may be used in a crisis decision. Also, the phenomenon of time is not an issue, as these decisions may be short-term, strategic, or long-term. Flanagan and Norman (1993) point out a number of steps that decision analysis should follow:

- recognising and structuring the problem;
- analysis of the values and uncertainties of the possible outcomes;
- determining the optimal choice;
- implementation of the decision.

The definition and procedure of decision analysis have been explained, therefore some techniques using this format are now discussed.

2.3.2.3.a Algorithms

Algorithms contain a set of instructions, which need to be followed and answered with answers such as 'yes' or 'no' in order for a decision to result. The responses given determine the path to be followed. A simple example is illustrated in Figure 2.3. The same concept is used for a means-end chain.

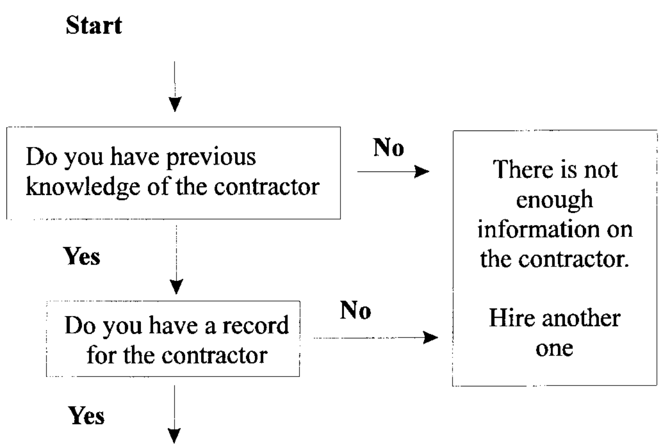

Figure 2.3 *A simple algorithm used for fault diagnosis*

This method identifies a series of decision points by clarifying a chain of objectives. If there is a goal B to be achieved, and assuming the end B may be too difficult to directly accomplish, so the decision-maker seeks a means B by which to achieve this end. This process may continue for several levels until a point is reached at which an impossible means is required. In practice, the development of such a chain results in a variety of combinations in which a given end may have several means. The advantage of these two techniques is that it encourages an orderly cataloguing of goals and their placement in a hierarchy.

2.3.2.3.b Decision matrix

A decision matrix is a representation of the options that are open to the decision-maker, the factors that are relevant, and the outcomes. Basically, this technique is a development of the ENPV method in that the matrix uses probabilities and the pay-offs against separate market conditions (e.g. 15% rise, stable, and 10% fall). The expected monetary values are again calculated by the product of the pay-offs with their respective probabilities. The difference being in this approach is that one strategy, or option, can be compared against others using standard deviations, and from that the coefficient of variation by:

$$\text{Coefficient of variation} = \frac{\text{Standard deviation (s.d.)}}{\text{Expected value (E.V.)}}$$ **Equation 2.3**

The coefficient of variation is a value between zero and one, with the value that which is closest to 1 being the most risky as the variation of possible outcomes is higher. Therefore, from this technique both the EMV and the ‘riskiness’ of each strategy can be ascertained and so the choice of strategy depends on the trade-off between return and risk. Note, that much of the primary information is based upon subjective estimates, and the outcome is, therefore, in part subjective but, by using the decision matrix, the final decision is based on objective criteria.

Daly (1993) uses a matrix in his ‘30 minute risk analysis’. His matrix is essentially a grid question and answer chart that lets users home in on what needs protecting. On the grid’s vertical axis, there are three columns that pertain to security objectives: data integrity, data sensitivity and data availability with the horizontal axis pinpointing what he is trying to protect the data against: accidental acts and deliberate acts. These squares within the matrix are then divided into categories of extremes e.g. for the squares in the integrity section for both acts, the extremes would be major or minor concern. Probabilities (subjective) can then be applied, but essentially this matrix is cheap, created by end-users and can be completed in minutes.

2.3.2.3.c Decision trees

The decision problems encountered in the construction industry usually have some definitive structure. A decision tree is a means of branching out problems by a series of either/or decisions. It illustrates a sequence of decisions and the expected outcomes under each possible set of circumstances. Therefore, for the construction industry this is a valuable decision tool. Both Cozzolino (1979) and Flanagan and Norman (1993) use decision trees in their literature. Cozzolino (1979) uses his when introducing a new product into the market, where the demand for the product is uncertain. From his analysis, the most profitable option would be to introduce it nationally and for the demand to be high. Alternatively, the demand could be large regionally and small nationally, or small nationally. The other option is to introduce the product regionally and if it proves successful, then proceed into a national market, but this is not as profitable as entering the national market from the start if, of course, the demand is large. This whole situation is represented by a decision tree. This method is easier to decide upon which strategy to opt for than to have the scenario explained in a report, or an equivalent document. Flanagan and Norman (1993) employ the use of a decision tree in order to tender for three separate projects. The contractor has the resources for only one project and must select the most profitable one, taking everything into consideration. By constructing a decision tree, like the one in Figure 2.4, the EMV can be calculated easily and from there a decision is possible on which is the most profitable option.

As a demonstration the EMV and the net EMV are calculated for the design and build option. A similar procedure would be performed for the remaining 2 projects.

EMV = £220 000 × 0.9 - £100 000 × 0.1 = £188 000

less the bidding costs of £20 000 giving a *net EMV* of *£168 000*

As one can notice, from the decision column, this is the most profitable decision of the three. The General contractor and Management contractor options attained net EMVs of £155 000 and £160 000 respectively.

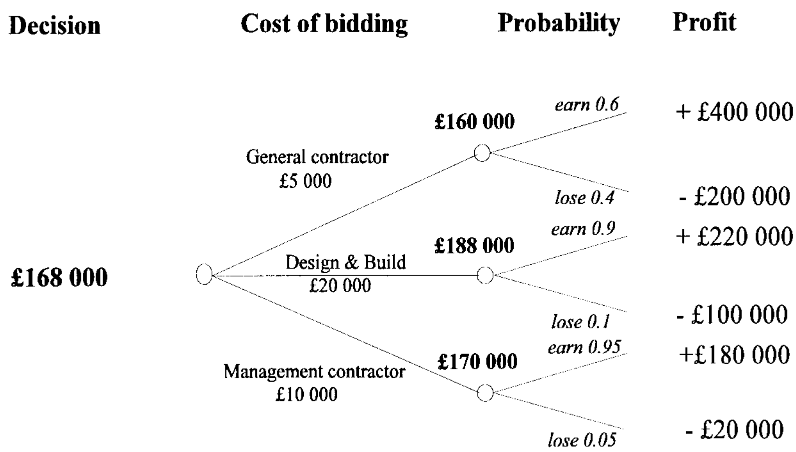

Figure 2.4 *An example of a decision tree*

In the same vein, decision trees can be altered slightly to be used as an event tree analysis (Crossland *et al.*, 1992). An event is postulated, and the options that could occur, like ignition or deluge operating, for example, are presented along the top with the yes or no choices contained in the tree. The numbers presented within event trees are probabilities and frequencies, which are ultimately multiplied together to reach an end probability. This is done for each branch of the tree and accumulated, to give a probability of that event occurring. Event trees are utilised frequently in the case study, see Chapter 6.

Rettedal *et al.* (1994) covers the main stages when applying a quantitative risk analysis (QRA) in offshore construction projects. When the stage of event outcome modelling is reached, the use of event tree analysis is most appropriate, as it investigates the way an event may develop to different outcomes, just like the decision tree. The example of the event tree in this paper is used to model the frequency of impacting a specific target from a dropped object.

Decision trees are a clear method of looking at the consequences of decisions. The advantages of such a technique are their logical structure with the possibility of revising probabilities if necessary. Magee (1964) in his paper wrote this about decision trees:

> "The unique feature of the decision tree is that it allows management to combine analytical techniques, such as discounted cash flow and present value methods, with a clear portrayal of the impact of future decision alternatives and events. Using the decision tree, management can consider various courses of action with greater ease and clarity. The interactions between present decision alternatives, uncertain events, and future choices and their results become more visible."
>
> Magee (1964)

Basically, he regarded this concept, in 1964, as having tremendous potential as a decision tool. He realised that decision trees were applicable in many areas of investment and were helpful in identifying choices, risks, gains and goals. Added to all of this, if further information becomes available, then this technique can be incorporated into the Bayesian analysis, which is reviewed next.

2.3.2.3.d Bayesian analysis

> "Thomas Bayes was born in 1702. He wrote 'An essay towards solving a problem in the Doctrine of Chances', which was not published until after his death in 1761. His fame was posthumous and is essentially a 20th Century phenomenon"
>
> Flanagan and Norman (1993)

Bayesian probability is a subjective probability and is thus a measure of the belief one has in the occurrence of an event. The Bayesian probability assigned to an event need not be a constant value, but can change with accumulated experience or when empirical evidence becomes available. These estimates of probability can be compiled into an interactive computer program, which continually queries the user on his or her estimates and then updates the estimates based on conditional probabilities using Bayes's theorem (Stewart, 1981). Bayes theorem is based on a number of equations, which are illustrated in equations 2.4 to 2.5 below. The probabilities are named prior and posterior probabilities: prior probabilities can be revised in the light of additional information to form posterior probabilities. **A** Bayesian approach can also be used in calibration problems (Lindley *et al.,* 1979), in combining expert judgements (Morris, 1977), in forecasting success (Walsh, 1979), in making use of uncertain or partial information (Potter and Anderson, 1980), in forming decision rules (Rastrigin *et al.,* 1979), and in using PERT (Programme evaluation and review technique) (Dyer and Sarin, 1979).

Flanagan and Norman (1993) simplify the equations used for Bayesian theory (Smith, 1988) in order to incorporate new information to amend the prior probabilities. Assume that there are *s* mutually exclusive events E_i ($i = 1......s$) with prior probabilities $P(E_i)$. Assume further that there are events F^k and that the probability of F^k given that E_i has occurred is $P(F^k/E_i)$. Then the probability that E_i occurs if one knows that F^k has occurred is given by:

$$P(E_j/F^k) = \frac{P(E_j) \times P(F^k / E_j)}{\sum \{P(E_i) \times P(F^k / E_i)}$$ **Equation 2.4**

If there are *i* mutually exclusive events E_i ($i = 1......s$), an event F can occur only if one of these *s* events happens and the probability of E_j happening when F is known to occur is:

$$P(E_j/F^k) = \frac{P(E_j) \times P(F / E_j)}{\sum \{P(E_i) \times P(F / E_i)\}}$$ **Equation 2.5**

where: $P(E_i)$ = Prior probability of event E_i

$P(F^k/E_i)$ = Conditional prob. of outcome F^k given E_i has occurred

$P(E_j/F^k)$ = Posterior probability of event E_j given F^k has occurred

This technique has the advantage of being able to perform an analysis with the information already known, and when, or if, more information comes to the fore. Developing this idea of decision analysis further, and combining the logic of the decision tree analysis just discussed, with the Monte Carlo simulation approach (see section 2.3.2.8.a), Stochastic decision tree analysis is created.

2.3.2.3.e Stochastic decision tree

This was originally developed by Hespos and Strassman in 1965 as another method for analysing decision problems over time. This method is particularly powerful for investment appraisal. It is important to recognise that most decision problems have a large number of inter-related investment decisions over the duration of a project. Therefore, Flanagan and Norman (1993) can identify a number of features specific to the stochastic decision tree approach:

- instead of using the EMV principle, all factors, including chance events, can be represented by continuous, empirical probability distributions;
- the information about the results of decisions made at sequential points in time can be obtained in probabilistic form;
- the probability distribution of possible results from any particular combination of decisions can be analysed using concepts of utility and risk.

The stochastic decision tree analysis follows similar stages to those outlined for the traditional decision tree approach. Once this structure is secure, probability distributions are used to evaluate all the possible combinations. This type of approach has the particular advantage of being flexible. It is used as a forward-analysis by evaluating each possible strategy branch in terms of a probability distribution. Once the output for each path is determined, the process is reversed and a backward-analysis follows. Then, observing all the branches of the tree and grading them in order of stochastic dominance, certain ones can be eliminated, reducing the decision set and permitting the analysis to focus on the most crucial decision paths.

The main advantage of all these decision tree analyses is the way one can illustrate a particularly complex problem in a simple, sequential, multi-stage logic to enable the client to understand the situation in a clear and intelligible way. This is done in the form of a decision tree with nodes, probabilities, choices, explanations of each branch, with an outcome of either the probability of a number of series of events occurring or the cost, or duration, of these series happening with their potential likelihoods, or consequences. When it comes to such matters as cost, quality or duration then there is much to gain, especially from the clients viewpoint, from structuring a decision tree like any of the above descriptions in section 2.3.2.3 c).

2.3.2.4 Sensitivity analysis

Hastie (1974) in his article claims that:

> "the sensitivity analysis is the key to improving the communication of uncertainty to decision makers".

With this in mind, a definition and a development of this analysis follows along with the means of presenting such information.

Firstly, a definition of this analysis is required. As the name suggests this is primarily an analysis which tests how sensitive an input variable is to slight changes on the project outcome. The more sensitive a variable, the greater the risk and vice-versa. One definition of the analysis is:

> "This aims to identify the uncertainty factors which have a significant impact on a project's return. This technique usually involves a series of 'what-if' questions by giving a percentage change to each key assumption one at a time. It is viewed as a first step to screen those factors to be specified in probabilities in more sophisticated methods."

Ho and Pike (1992)

Basically, the principle of sensitivity analysis consists of the examination of the impact of variations on the values of the input variables of a decision process on the final decision. It is an interactive process that informs one of the effects that changes in a cost or duration of an activity has on the life cycle cost or period. From this process, risky variables can be immediately identified, allowing the decision-maker to formulate the necessary precautions to reduce or manage the risks (Lorance, 1992) and consider responses should specific outcomes occur. Eschenbach (1992) talks primarily about feasibility studies and economic analyses and suggests the reasons for doing a sensitivity analysis may be because of measurement error, an uncertain future or unclear specifications. The goals he proposes of sensitivity analysis are relevant to both small and large projects and are:

- making better decisions,
- deciding which data estimates merit refinement, and
- focusing managerial attention during implementation.

> "Many people use sensitivity analysis as a backwards approach to answering the question about the accuracy of the cost and time estimates. Essentially, this form of analysis indicates the amount of change in an economic criterion that will result in a certain percentage change in each individual part of all component cash flows.
>
> Buck (1982)

Buck (1982) then delves into numerical examples, using sensitivity analysis, ascertaining the expected present worth values of individual projects and their associated variances, to find out exactly how uncertainties affect the project risk. In his paper, the expected present worth values are obtained, but these only reflect the environmental uncertainties as an average economic value, but that does not directly show the economic risk, whereas their respective variances do. Once these values are attained, his method allows prospective projects to be compared by ranking the projects by their riskiness. **A** maximum acceptable risk level can then be set and all the projects above that bracket are eliminated. Final project selection depends upon management's perception of present worth and risk. Byrne (I 992) suggests computer programs, section 2.3.2.8, can produce valuable information about the sensitivity of the possible outcomes to the variability of input factors as well as the likelihood of achieving various possible rates of return.

Singhvi's (1980) paper illustrates a risk analysis on a real-life investment proposal. Information was given to the management concerning the capital expenditure, additional working capital, net income, depreciation, residual value and net cash flow for the first twelve years of the project's life. The discounted cash flow return was calculated as well as the pay-back period. A sensitivity analysis was performed to determine the degree of change in terms of the project's discounted cash flow return if the key variables entering the financial justification are exposed to unfavourable variances. Then from these results one can observe, from spiderplots (see section 2.3.2.4.b), by altering a variable by a 10% change, the resultant effect on the discounted cash flow return. Then, the variables that are seen to be the most sensitive on the return of the project should receive more thorough investigation from the management to reduce such risks.

In Otway and von Winterfeldt's (1992) paper, one of the case studies' objective was to identify a site for the first civilian high-level radioactive waste repository in the United States by using expert judgement. Five sites were proposed and comparison was performed using a complete formal expert judgement process based upon multi-attribute utility analysis (Merkhofer and Keeney, 1987; Keeney and von Winterfeldt, 1988). Included within this analysis, many sensitivity analyses were conducted with the results from these showing the stable ranking of the five sites. Added to these analyses were informal judgements and through a combination of these, three of the sites were suitable for further investigation. Through further explanation, this process was scaled down to just one of 5 original sites.

Above, are papers which have at one stage used sensitivity analysis as an integral part of risk analysis. Now, it is important to identify the techniques which explain and illustrate such information. The techniques are threefold:

a) Break-even analysis,
b) Spiderplots, and
c) Scenario analysis

2.3.2.4.a Break-even analysis

The break-even analysis is used to determine the point at which two alternative options are of equivalent value. The analyst, therefore, must approach this form of analysis in a cost effective manner. Break-even analysis is valuable for helping making decisions, but it is less useful for deciding which data estimates need further development.

Basically, this method assists the decision-maker to decide which project or course of action to take. The technique calculates, taking into account different interest rates, the period in years before a project starts to begin to produce it's 'worth'. i.e. when it begins to become beneficial. Eschenbach (1992) formulates an example for using this technique. He considers a municipal project where interest rates, i, of 4%, 6%, or **8%** and horizons of 10, 20, or 50 years, N, are being discussed. These can be converted into favourable, average and unfavourable scenarios. The project looks more appealing when lower interest rates and longer time horizons are used, therefore, a favourable scenario would be 4% and 50 years, an average scenario would be 6% and 20 years and the unfavourable one **8%** and 10 years, as shown in Figure 2.5.

This example is with two variables and a break-even curve. The break-even curve is produced by initiating a zero value for the net present value; picking values for the horizon; and solving for the interest rate. The equation used to establish this curve is:

$$NPV = - B\&I - Equip + Rev \cdot (P/A,i,N) + SV \cdot (P/F,i,N)$$ **Equation 2.6**

$(P/A,i,N)$ and $(P/F,i,N)$ are respectively the uniform periodic and the single payment net present value factors, where i is the interest rate, N is the no. of periods, P occurs at time 0, A at the end of periods 1 through to N, and F at the end of period N. B&I is the building costs and Equip. is the equipment costs.

Break-even charts (Eschenbach 1992) represent economic loss and profit as a function of one or two problem variables. The number of possible one and two-variable break-even charts depends on how many variables there are in the beginning. In break-even charts, the project's value is plotted as a function of a variable. Spiderplots move one step further and combine these curves using an appropriate y-axis, the percentage change in the risk variable affecting the base case value.

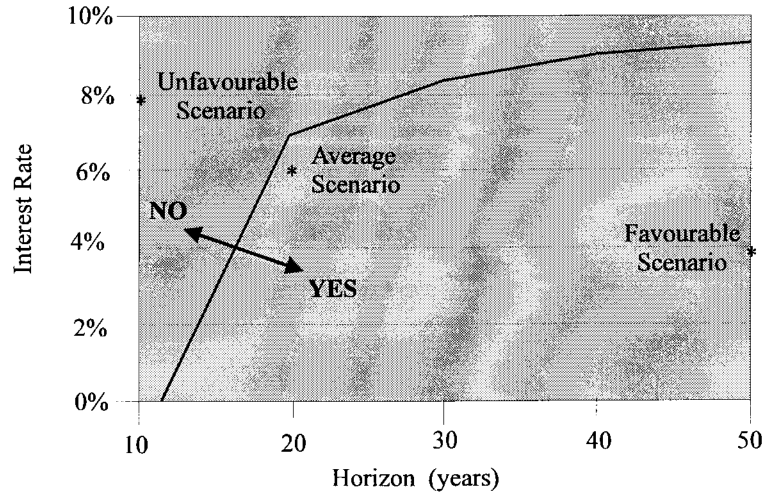

Figure 2.5 *Municipal Project Break-even - i vs. N*

2.3.2.4.b Spiderplots

The aim of spiderplots is to depict economic performance as functions of individual variables. On a spiderplot there are two directions to measure uncertainty. Usually, on the y-axis the potential uncertainty in the variable is measured and on the x-axis the impact of that uncertainty on the present worth, internal rate of return, or benefit/cost ratio. Throughout this example the internal rate of return (IRR) is representing the x-axis variable. At the centre of the 'spider' is the base case (an example of a spiderplot is shown in Figure 2.6). This is the expected estimate of the IRR if no sensitivity analyses were performed. Flanagan and Norman (1993) indicate the following steps that would be fully required in order to produce a comprehensive spiderplot:

1. Calculate the expected IRR (base case) by using expected values.
2. Identify the variables subject to risk using a decision tree approach.
3. Select one risky variable, which could be called 'parameter 1', and re-calculate the IRR using different percentage changes in the risk variable. The IRR chosen is re-calculated assuming the cost parameter changes by 1%, 2% and so on.
4. Plot the resulting IRR on the spiderplot, interpolating between the values. This generates the line 1-1 in Figure 2.6.
5. Repeat stages iii) to iv) for the other risky variables.

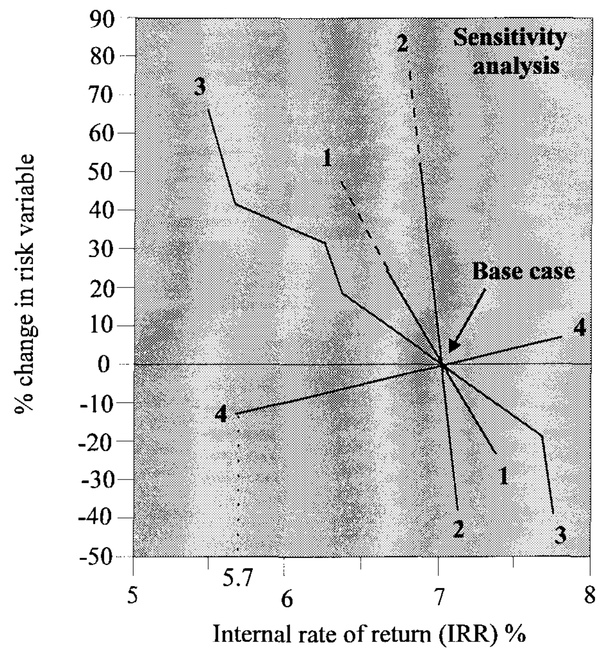

Figure 2.6 *An example of a spider diagram*

If there are too many variables all on the one spider then it is harder to interpret, Therefore, to avoid any confusion, draw up several separate diagrams.

The key to this technique is to observe the gradient of each individual parameter. The flatter the slope, the more sensitive the risk variable is to change and ultimately, the line with the flattest gradient is the riskiest variable. Therefore, from Figure 2.6 one can clearly see that parameter 4-4 is the flattest and is thus the riskiest. This variable requires the greatest attention from the management to reduce its impact. The only other thing to mention about these diagrams is, on parameters 1 and 2, dotted lines extend beyond the solid lines. The solid lines are the calculated variation in the IRR of each parameter when subjected to a percentage change, whereas the dotted lines are the projected or assumed variation obtained through extrapolation.

2.3.2.4.c Scenario analysis

Qualitative scenario analysis was mentioned earlier (in section 2.3.1.1). However, this method is more widely used as a quantitative technique. It can be applied to estimating the duration or the cost of a project. A number of papers have been written on the subject. The early definition of Kahn and Wiener (1967) is "an hypothetical sequence of events constructed for the purpose of focusing attention on causal processes and decision points". The more recent definitions includes that of MacNulty's (1977). He interprets a scenario as "a quantitative or qualitative picture of a given organisation or group, developed within the framework of a set of specified assumptions", and Brauers and Weber (1988) say, "a description of a possible future state of an organisation's environment considering possible developments of relevant interdependent factors in the environment". Currently, scenario analysis focuses the analysts' attention on a set of different descriptions of the future, which are explicitly designed to be feasible, but not necessarily the most likely. By studying such scenarios, the analyst understands the role of uncertainties and becomes prepared to take informed decisions that take a range of possible states, or developments, into account.

Buchan (1994) considers 3 major risks in a project, allocates a three point estimate of the costs of these three and then subjects them to a Monte Carlo (described in section 2.3.2.8.a)) simulation technique using @RISK software. The results gave 75% confidence limits. The risks are assumed to be independent. From the analysis of the simulation, one can visualise 'risk gaps' and can, therefore, identify the greatest risk, and action can be sought immediately.

Durway (1979) uses this concept of scenario analysis and incorporates it into a simulation using a computer program. In his model, one variable can be defined and the output from the Monte Carlo simulation gives values (in per cent) of the probability that the calculated rate of return is less than 10, 50 and 90 per cent of whichever variable has been specified. This method uses a computer language that the decision maker and computer can understand, and can combine theoretical knowledge of risk analysis with practical means on a computer, and on an interactive basis.

Eldin (1982) talks about the three point estimation for the duration of an offshore project in order to complete the fabrication of a jacket to coincide with a 'weather window' for hook-up, which is so important in the oil business. He gives 90% confidence intervals, with a 5% optimistic duration and a 95% pessimistic one. The objectives are to achieve an envelope, inside which duration, and thus cost, can be optimised. Aquino (1991) and Moder ***et** al.*, (1983) have also assumed 90% confidence intervals and have produced the following equations, 2.7 - 2.13, for cases:

1. *without* experience or subjective assignment:

$$E_e = [E_o + E_p + (4\ E_{mp})] / 6 \qquad \textbf{Equation 2.7}$$

$$V_p = [(E_p - E_o) / 3.2)]^2 \qquad \textbf{Equation 2.8}$$

2. *with* experience or historical database:

$$E_e = (E_1 + E_2 + ... + E_i + ... + E_n) / n \quad \text{where } n > 4 \qquad \textbf{Equation 2.9}$$

$$E_o = E_e - (k \times r), \text{ if } E_e > k \times r \qquad \textbf{Equation 2.10}$$

$$E_o = 0, \text{ if } E_e < k \times r \qquad \textbf{Equation 2.11}$$

$$E_p = E_e + (k \times r)$$ **Equation 2.12**

$$V_p = [(E_p - E_o) / 3.2]^2$$ **Equation 2.13**

where E_o = optimistic estimate i.e. probability is 5%, E_p = pessimistic estimate i.e. probability is 95%, E_{mp} = most probable value, E_e = expected value, V_p = variance, n = sample size and k and r are parameters that depend on the size and dispersion of the sample.

These equations are a simple and economical procedure that do not require sophisticated and complex computer systems. The better option, using the methodology suggested by Aquino (1992), would be to have adequate historical data, as this allows a real variance of the item, rather than using subjective values. Carroll (1983) has similar equations, 2.14 - 2.15, using three point estimation:

$$E_e = \frac{E_p + E_{mp} \times D + E_o}{D + 2}$$ **Equation 2.14**

$$S.d. = (E_o - E_p) / 6$$ **Equation 2.15**

Equations 2.14 and 2.15 are then applied to a computer program. This program varies the weight that is assigned to the mode until an expected value is attained that is realistic, and one which the analyst feels comfortable with to use it as a point estimate.

The scenario analysis can be taken a step further. Both Eschenbach (1992) and Schmidt (1991), instead of using three scenarios, have constructed a five scenario analysis, as can be seen in Figure 2.7. In theory, it is possible to have as many scenarios as the analyst would like or feel is necessary, although any more than five can be confusing rather than helpful.

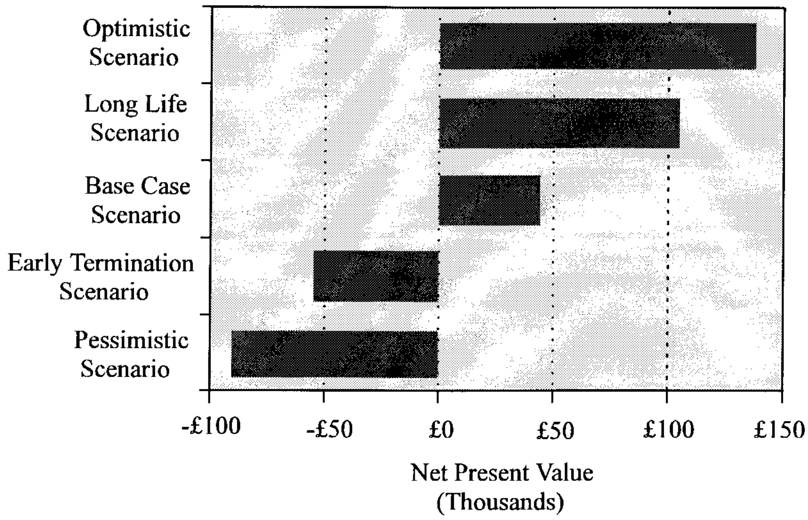

Figure 2.7 *A five scenario illustration*

The advantage of scenario analysis is that it emphasises the impact of combinations of risk on the total outcome. The disadvantage is that sufficient historical data is needed without the analysis becoming too subjective, and even then the situation under review may have subtle differences from past circumstances, which must be accounted for in the analysis.

Sensitivity analysis is a powerful technique in aiding a decision-maker when confronted with risky alternatives or projects. The analysis itself is enough to convince any decision-maker of a specific course of action without the outside influence of subjective involvement. Other advantages are that the analysis is quick and easy to use and it fully recognises uncertainty in the input variables. Also, it is possible to see how a single variable, or a combination of variables, can affect the outcome. The disadvantages are twofold. Firstly, sensitivity analyses do not take account of the likelihood of the range of input or output; therefore, they do not give a probabilistic picture of risk exposure. Secondly, risk attitudes are not allowed 'for explicitly.

The additional techniques, i.e. break-even analysis, spiderplots and scenario analysis, also contribute to a final decision being able to be made. These techniques vary in a subtle way from each other by the angle at which they approach the situation. It is necessary, therefore, to include as many of these illustrative techniques as possible, on top of the analysis itself, for the most complete sensitivity analysis.

*2.3.2.5 EMV using Delphi **peer** group*

This method is linked to the qualitative technique of brain-storming, section 2.3.1.2. In a way, this is the quantitative counterpart. It is also coupled with the earlier technique, the expected monetary value, section 2.3.2.1. A Delphi peer group is a pool of experts. A formal Delphi group is designed to extract the knowledge and technical expertise from these professionals, whilst removing the influences of seniority, hierarchies and personalities on the derived forecast. There are a number of specific individuals included within the Delphi group. Each individual, in turn and independently, is presented with the circumstances under review and the relevant information needed for that individual to analyse the situation and forecast a subjective probability estimate, i.e. in numerical terms. The reason why each individual is kept physically separate at this stage is to prevent any interaction among them, thus not permitting any stronger personalities to persuade, or dissuade, their colleagues to alter their predictions. Once everyone in the group has completed this exercise, the co-ordinator receives and summarises these estimates, and a summary is prepared as a feedback to the group. The group members are then asked to amend their forecasts in the light of the information on the summary. Again, the co-ordinator then prepares another summary and presents it to the ensemble. This process of prediction, amendment and feedback is continued until there is a consensus of opinion and the group do not wish to adjust their forecasts any longer. This final result is called a Delphi forecast. This method may seem to be difficult to implement but is possible, using electronic mail, to be conducted during 'an afternoon. The Delphi method is best used when analysing important projects at the budget and feasibility stages. This method exemplifies the importance and ever growing need to improve the communication between individuals, in influential situations such as risk, to iron out any heuristics that may encroach into an analysis.

2.3.2.6 ***Risk** adjusted discount rate (RADR)*

Raftery (1994) points out the advantages of RADR are that it is very simple to use and this method offers a way of dealing, simultaneously, with both risk exposure and risk attitudes. The method functions by separating the discount rate used in the cost model into component parts. To start with, one assumes a risk-free rate of interest. This rate of interest is then adjusted upwards by two factors:

1. The estimated *benefit* streams in the life of a project to account for the normal risk encountered in the type of investment in question.
2. The particular perceived risk of a specific project or investment.

The effect of these adjustments is to deem the project/investment less desirable by reducing the calculated present value of future income. Therefore, for the project to be accepted, a higher hurdle would need to be overcome. Obviously these adjustments are evaluated to reflect the degree of risk exposure for the type of project and the risk attitude of the decision-maker or his/her business. Apart from analysing what percentage values to add for these adjustments, a further complication arises when attempting to use RADR in life cycle costing. This introduces cost as well as the benefit streams in the life of the project (examples of cost streams would be maintenance, renewal, replacement, repair and operating costs). Slavish application to the project costs of the risk-adjusted rate for benefit streams would completely distort the analysis by rendering the project more desirable, which is not the objective of this technique, as mentioned earlier. Therefore, for the benefit streams the risk adjustments are an increasing function of risk and for cost streams the adjustments are a decreasing function (i.e. the discount rate on cost streams should be reduced to take account of increasing risk and uncertainty). Using RADR effectively in many building-cost models, ranges of discount rates would be necessary for one project/investment decision. Different risk-adjusted rates for different components of the problem may be thought to be useful. It would be appropriate, as there are, in this case, two rates (benefits and costs) to use two cost stream discount rates. Summarised as follows:

$$RADR_i = RFR + RA_1 + RA_2 \qquad \textbf{Equation 2.16}$$

There could be any number of RADRs for any given project/investment decision, therefore the need for the subscript '*i*'. RFR is the risk-free discount rate, RA_1 and RA, would be positive figures for benefit streams and negative for cost streams.

The advantages of RADR have already been remarked upon above. The limitations are threefold:

1. not suitably specific for construction budgeting,
2. no explicit way of calculating the risk adjustments, and are therefore difficult to justify, and
3. it is not feasible to distinguish between the adjustments of risk exposure and risk attitude.

2.3.2.7 De Minimis theory

In both Mumpower (I986) and Baram's (1988) papers, their definitions of this theory are that the *de minimis* risk management strategy sets a threshold, so that risks below the specified level are defined as trivial and exempted from further consideration. Any risks associated with a hazard, which exceed the specified *de minimis* threshold, would be subject to further analysis and perhaps, eventually, regulation. So, basically this method aids in deciding which risks are frivolous and helps to convert the main attention to the more dangerous ones. Mumpower (1986) analyses the *de minimis* strategy for risk management. The concept is grounded in rudimentary notions of cost-benefit analysis. Some risks are so low (therefore obviously under the *de minimis* threshold) that the costs of addressing them always outweigh the benefits. In this paper, he talks about applying the *de minimis* strategy to old and new risks alike.

Old risks being defined as those existing at present, and new risks are those that result from accepting or introducing new hazardous products, substances, procedures etc. Applying the *de minimis* strategy to old risks can also pertain to new risks. According to Mumpower though, there are differences, the strategy is likely to be innocuous with old risks, but could lead to unanticipated and undesirable consequences, when used in decisions about accepting a new risk.

Figure 2.8 is a typical example of a *de minimis* strategy with the level specified clearly on it. Any hazards falling within the shaded area is ignored whereas to the right of the *de minimis* level, greater attention is necessary (as safety should be the principal concern in all industries). Other factors, such as cost, size of the exposed population, risk levels, risk reduction per unit investment, etc., could be represented on a similar illustration, showing the level where more analysis is required. The problem with Figure 2.8 was pointed out by Whipple (1984). He remarked that an annual risk of 10^{-6} per exposed individual may be regarded quite differently depending on whether 10^{2} or 10^{6} individuals are exposed. The problem could be circumvented by defining the *de minimis* levels in terms of the total number of expected mortalities, instead of the probability of mortality for exposed individuals.

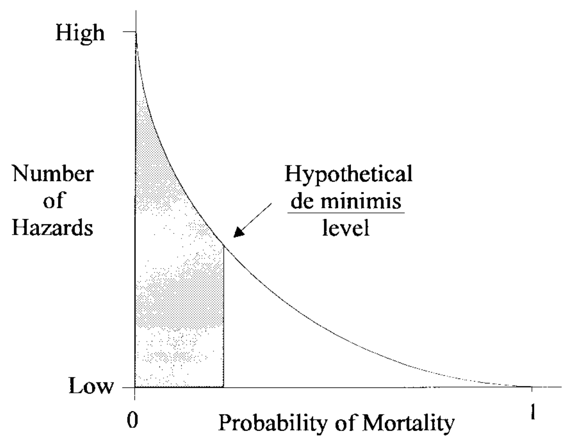

Figure 2.8 *A hypothetical de minimis level*

Previous analyses suggest that, especially when applied to old risks, the *de minimis* strategy is a reasonable one. The problem with the new risks is that multiple new risks falling under the *de minimis* level may collectively result in a total level of risk above that of the nominal *de minimis* level, although the actual decisions about accepting the new risks are based on the same cost-benefit calculus as that used for old risks. Further work is still required in this area of *de minimis* strategy as the analysis virtually ignores such factors as politics, societal, institutional etc., but nevertheless, it is still an important concept for risk management.

2.3.2.8 Simulation

Simulation is a technique of creating the typical life history based upon the past. The history of the cost, for example, of a building element can be represented by a frequency distribution. The main piece of equipment used in simulation is a computer. Computers are becoming more and more an integral part, and very much a crucial part, of the construction and oil and gas industries. Therefore, in designing these computer programs and software needed for simulation there must be requirements. Henrion and Granger Morgan (1985) suggest six requirements as illustrated in Table 2.6.

A computer aid for risk analysis should provide convenient means for:
• Representing uncertain quantities as probability distributions, either discrete or continuous, for propagating probabilistic values through a model, and for displaying the resulting distributions graphically;
• Performing various kinds of sensitivity and uncertainty analysis, both deterministic and stochastic;
• Representing models in a non-procedural language with conventional algebraic syntax;
• Interactively defining and editing input values and model structure, and supporting management and comparison of alternative model structures;
• Supporting progressive refinement and disaggregation of model structure, and allowing mathematical relationships to be specified independently of the dimensionality of the variables;
• Representing documentary and explanatory text in a form that is integrated with the mathematical structure of the variables.

Source: Henrion and Granger Morgan (1985)

Table 2.6 *Design Requirements for a computer aid for risk analysis*

These requirements will be proven to be fundamental, not only in simulation but in all the risk analyses using computers as an aid.

To introduce simulation a bit more, an analogy and an example will help, taken from Orczyk and Hancher (1987). Start firstly, with an event oriented arrow diagram. Each activity has a duration distribution, and these are described by taking 1,000 pieces of paper and writing possible durations on them for every activity. Once all the slips of paper have been completed then put the durations for each activity into separate jars. Then the next step is to pick one duration for each activity out of its jar. This would give a random sample of the activity duration distribution. The network could then be solved by using a deterministic value for each duration distribution. Finally, the pieces of paper would be replaced, the random sampling would be repeated and the network solved at least 400 times. These 400 solutions are used to produce a duration distribution of the project from which calculations can be made of the probability to meet specific deadlines. This process, if done by hand, would be time-consuming. The objective of simulation is to successfully compute this process in as small a time-scale as possible. **A** small example, adapted from Orczyk and Hancher (1987), is given in Table 2.7 and Figure 2.9. This example was run 400 times using simulation. As one can see from this information, having been quickly produced from simulation language software program, that it is now easy to calculate the expected day of completion (i.e. the mean) and the variation from that day, as well as the probabilities of completing the project on any specific day. This paper also identifies advantages and disadvantages of simulation. The advantage is that from simulation, it is possible to count how many times each activity lies on the critical path. From these variables the activity's Criticality Index (i.e. the probability an activity is on the critical path) can be calculated by dividing the number of times an activity is on the critical path by the total number of runs. The disadvantages, although not major, are that:

- the staff need to know a simulation language. This is possible, though, to learn enough for risk analysis in one week, and

- a computer simulation software package must be used, but this should cost no more the $1,000.

The method of risk simulation was first introduced by Hertz (1964) and has since been growing in popularity. He said that simulating the way that factors may combine as the future unfolds was the key to extracting the maximum information from the available forecasts. Carrying out this process on a computer, analysts using simulation must follow three steps:

1. Estimate the range of values for each of the factors and within that range the likelihood of occurrence of each value.
2. Select one particular value at random from the distribution of values for each factor. Combine the factors and compute the rate of return.
3. Do this process over and over again in order to define and evaluate the odds of the occurrence of each possible rate of return. The likelihood of various specific returns on the investment have to be tested as there are millions of combinations. The result will be a listing of the rates of return ranging from a loss to a maximum gain with their associated probabilities.

The average expectation is obtained as well as the variability of outcome values. Hertz (1964) also suggested similar advantages as Orczyk and Hancher (1987) i.e. simulation is not time-consuming and cheap to run, once the initial software has been purchased. He claimed that the reason conventional methods sometimes did not work, were because of the estimates from advanced calculations. They basically were just estimates. His solution was to collect realistic estimates for the key factors, thus finding out a great deal more about them. Therefore, the risk involved in each estimate can be evaluated ahead of time. This is where computers come into their own; computer programs can obtain clear portrayals of the risk surrounding investments. These programs are designed to ascertain such information as the sensitivity of possible outcomes, the variability of input factors and the likelihood of

	Duration probability Simulation		
Project duration Days	Observed Frequency	Relative Frequency	Cumulative Frequency
127	0	0	0
128	0	0	0
129	1	0.0025	0.0025
130	2	0.0050	0.0075
131	1	0.0025	0.0100
132	2	0.0050	0.0150
133	6	0.0150	0.0300
134	7	0.0175	0.0475
135	11	0.0275	0.0750
136	11	0.0275	0.1025
137	24	0.0600	0.1625
138	22	0.0550	0.2175
139	14	0.0350	0.2525
140	31	0.0775	0.3300
141	40	0.1000	0.4300
142	25	0.0625	0.4925
143	38	0.0950	0.5875
144	27	0.0675	0.6550
145	24	0.0600	0.7150
146	26	0.0650	0.7800
147	18	0.0450	0.8250
148	16	0.0400	0.8650
149	14	0.0350	0.9000
150	15	0.0375	0.9375
151	9	0.0225	0.9600
152	5	0.0125	0.9725
153	0	0.0000	0.9725
154	6	0.0150	0.9875
155	2	0.0050	0.9925
156	1	0.0025	0.9950
157	0	0.0000	0.9950
158	2	0.0050	1.0000
159	0	0.0000	1.0000
	400		
	Mean		**142.2**
	Standard deviation		**5.1**

Table 2.7 *A small example of a simulation*

achieving various possible rates of return. This simulation approach is extremely important as it lends some assurance to the decision-makers that the available information has been used with maximum efficiency, all done by merely extending the input estimates in terms of probabilities. This is why Hertz's (1964) rather apt comment on the cover of his article is:

"Application of probabilities will often yield entirely different and better results"

Hertz (1964)

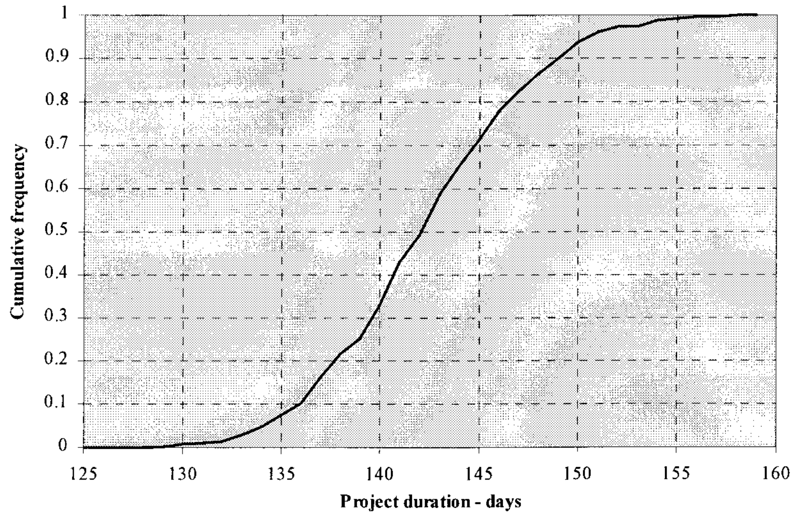

Figure 2.9 *Project duration probability*

Hertz and Thomas (1983b) wrote in their article that research and development were the riskiest areas that contained the most potential uncertainty. Simulation would aid this situation by assisting the senior executives to see the nature and consequences of possible choices more clearly, and to weigh the uncertainties they entail.

As mentioned already, probability distributions are essential for a thorough simulation analysis. These are obviously applied to the variable under review of risk (e.g. duration, cost etc.). There are a number of probability distributions and Bjornsson (1977) has listed those that are most frequently used in simulation with some relevant additional information. The most common are:

- *Uniform distribution:* Used when little information is available, i.e. when all values for a variable in a certain interval are equally probable. Should not be used because of the sudden cut-off points. e.g. assume a uniform distribution between E100 and £500, any value of the variable has equal probability within the range but there is no condition for £99 or £501.

- *Triangular distribution:* Inclined to give the values near the extremes a lesser probability than the most probable value of the variable. Assumes linear variation from most probable to the extremes, so the distribution is completely described by three values.
- *Normal distribution;* Bell shaped curve. This distribution is totally defined by two parameters; the mean and standard deviation.
- *Beta distribution:* Range defined by the optimistic and pessimistic estimates, it can be skewed in any direction. Generally skewed towards the pessimistic as more disastrous unforeseen happenings are more likely to occur more frequently than relatively harmless events.
- *Lognormal distribution;* Symmetrical or asymmetrical shape. Very simple to use as only two determinants are required i.e. the 10^{th} and 90^{th} percentile.

Other proposed distributions are multivariate normal distributions, general curve distributions, stepwise distributions etc. These distributions could be used in a direct way to include dependencies between random variables. The fact that this analysis can cope with large amounts of input distribution is a huge advantage as this gives the flexibility to model precisely the perceptions of uncertainty surrounding all of the input variables. Bjornsson (1977) then goes on to perform a construction cost estimate by risk simulation. In his paper, a model of the cost estimate has been developed for risk simulation with variables representing quantities, prices, capabilities, etc. The ranges within which the variables might vary and the probabilities for these variations are then inputted into the model. **A** sampling technique, called Monte Carlo sampling, is then utilised to construct a probability distribution for the performance criterion, the total construction cost.

This procedure is possible using a software package called @RISK. Many papers have mentioned and used the package @RISK in conjunction with risk simulation.

There are many other packages available to the risk analyst, see section 4.7.3. **A** risk analysis possesses many sub-units, such as regions, divisions or operating units. Each smaller unit runs its own analysis. Once completed, they are all brought together into the larger "corporate" group to be analysed as the total consolidated unit. @RISK allows consolidation by letting multiple worksheets be included into a single simulation. This is one of the disadvantages in that each analysis needs to be structured carefully either to decompose into relatively independent sub-systems or to take into account the correlation between them. Correlation between components is possible, but requires a more sophisticated piece of software. @RISK also allows multiple changes of the uncertain variables in the input to achieve repeated simulations to test the sensitivity of the model.

Sampling is used in an @RISK simulation to generate possible values from probability distribution functions. Sampling is the basis for the thousands of 'what-if scenarios that @RISK calculates for ones worksheet. Each individual combination of input values is one sample. Sampling in a simulation is done repetitively **,** with one sample drawn every iteration from each input probability distribution. Eventually, after enough iterations, the sampled values for a probability distribution begin to be distributed to illustrate a known input probability distribution. The important factor to remember when certain sampling techniques are being evaluated is the amount of iterations required to accurately recreate an input distribution. The output distributions depend heavily on the precision of the complete sampling of input distributions. Therefore, the sampling technique that requires more iterative processes than a competing one, is less reliable. The two methods of sampling used in @RISK are Monte Carlo and Latin Hypercube.

2.3.2.8.a Monte Carlo sampling

The phrase 'Monte Carlo' was named thus during World War II as a code name for the simulation of problems associated with development of the atomic bomb. This is a traditional technique involving random numbers and behaviour. This means that any given sample can lie within the given range of the input distribution. In the Monte Carlo technique this is between 0 and 1. This method of sampling often requires a larger number of iterations to approximate an input distribution than the Latin Hypercube technique, especially if the input is highly skewed or has some outcomes of low probability. The problem with the Monte Carlo technique occurs when small numbers of iterations are performed and is enhanced when a distribution includes low probability outcomes. This problem is called 'clustering' and can have a major effect on the results. It is important to include these impacts and such outcomes must therefore be sampled. The problem arises that, if the probability is too low, not enough Monte Carlo iterations will sample these outcomes and thus not representing their probability accurately. This is why the Latin Hypercube method was developed (see section 2.3.2.8.b).

Cochrane (1992) uses Monte Carlo sampling within the @RISK estimating program to predict probable ranges of project cost. He selects risk ranges for the principal elements of the project. These values are applied to each of the principal elements to make it possible to arrive at the probable project cost. He found that if the project information is poorly defined, these risk ranges are wider. Conversely, if the information is rigorously generated, the range is narrower.

Mathur (1989) uses this method in capital cost estimating. He incorporates the Monte Carlo Analysis with Interactive Financial Planning System (IFPS). The IFPS can be used on any major mainframe computer, as well as by those familiar with the programming languages BASIC and FORTRAN. The input variables can be declared as statements in English and then the programs (Monte Carlo analysis), carry out the risk analysis. Mathur uses this method as a cost analysis of proposed schools, ,but suggests a fault is the lack of availability of historical cost data in this field as this information, if accessed, would enhance the accuracy of the estimates. In some countries, availability of such data may be a problem, not just to access it, but to update it due to fluctuations in inflation, changing technology, building regulations, etc. Such a disadvantage could be overcome, if cost indices are maintained to reflect these changes.

In a recent paper by Buchan (1994), the computer software that is referred to is Lotus 1-2-3 (version 2.4), but with “add-ins” @RISK and What’s Best **1.6.** Three major risks were identified and each were subjected to three point estimates (see section 2.3.1.1 and 2.3.2.4.c). These three point estimates were then subjected to the Monte Carlo simulation technique using the @RISK software. From the graphical results, one of the risks was more critical than the other two and so the project team addressed this one immediately.

Powell (1991) involves an extension program of the Monte Carlo simulation called Presto II. This simulates exploratory drilling (on prospects rather than plays). The idea of this program was to first find a reservoir in the Arctic and sample it to see whether it contained oil. Then, again by sampling, to find out *how much* oil. Finally, a separate study, produced on a spreadsheet, was performed to determine the profits of oil developments under a range of scenarios. Monte Carlo simulation was used to sample whether it was worth development, by incorporating random variables such as inflation, oil prices, transportation costs, development schedules, investment, production costs, etc. The findings from the simulation were that the results were sensitive to many factors, especially future oil prices and the location of the discovery.

The Monte Carlo simulation was used by Eldin and Boudry (1982) in an oil project to monitor the time spreads and the criticality levels (criticality level is the probability of an activity to be on the critical path during the network realisation), so as not to miss the all important necessary ‘weather window’ for hook-up. The simulation gave them a thousand samples for each designated milestone. Those spreads were then visualised on a network graphical output to achieve a clear picture to the project team. This criticality method was found to be a useful measure as it concentrated management on the activities of higher impact. They were defined as the higher the criticality the greater the impact.

The Monte Carlo technique can, therefore, be used for a multitude of situations, but a common limitation of the Monte Carlo sampling technique is that it is too time-consuming and requires too many iterations to achieve the input distributions and thus the output distributions. However, the reader will recognise, from the case study in Chapters 6 and 7, that this limitation does not exist. Nevertheless, it was for these reasons, along with the one earlier, which provided the incentive to design another sampling method, the Latin Hypercube technique.

2.3.2.8.b Latin Hypercube technique

This technique is a recent development and was designed to improve the Monte Carlo technique by achieving an accurate input distribution in fewer iterations. The key to this method is the stratification of the input probability distributions. Stratification divides the cumulative curve into equal parts on the cumulative probability axis (i.e. in Figure 2.9 five equal parts could have been illustrated, e.g. this could be 0.2, 0.4, 0.6 etc.). Then from each interval a sample or 'stratification' is randomly taken from the input distribution and forced to recreate the input probability distribution by representing values in each interval.

This sampling method of Latin Hypercube is sometimes referred to as "sampling without replacement". The number of stratifications of the cumulative distributions equates to the number of iterations performed. From each stratification, a sample is produced and not sampled from again because its value is already represented in the sampled set. The software package @RISK does this process automatically; it chooses a stratification and then randomly selects a value from within that interval.

The advantages of this technique over the Monte Carlo method are in terms of increased sampling efficiency and faster run-times. In addition to those, it also helps the analysis of scenarios with low probabilities, which was a limitation of the Monte Carlo technique, by forcing the sampling of the simulation to include these outlying events, therefore accurately represented in the simulation outputs.

Convergence is the key to knowing when sampling methods output distributions are stable; At the point of convergence, any additional iterations do not markedly change the shape or statistics of the sampled distribution. Typical measures of convergence are the sample mean versus the true mean, skewness, and percentile probabilities. @RISK provides a good environment to test how many iterations it takes for the two sampling methods to converge on an input distribution. As mentioned before, but here is empirical evidence, the Latin Hypercube sampling converges faster on the true distributions than its counterpart, the Monte Carlo technique.

2.3.2.9 Portfolio theory

The ultimate aim of portfolio analysis is to maintain the expected return and to minimise the risks of the portfolio. The overall risk of the portfolio cannot be measured in the same way as the total return, which is calculated by the weighted average of individual investments. To indicate the relationship between each individual investment risk a correlation coefficient, ranging from -1 to +1, is examined (+1 indicating that if the risk increases by one unit then the overall risk of the portfolio increase by one, zero means no overall correlation between individual investments in a portfolio and obviously -1 indicates the same as +1, but in reverse). If the correlation coefficient is less than +1, then the overall risk of a portfolio can be diversified. This theory is probably used a lot more in financial investments, but it does have some relevance in the construction industry. Assume two companies are involved with property development. Company **A** is only into housing construction; relatively traditional and can be small scale with few barriers to entry into the market, tender is more competitive and the return likely to be lower. Company B is not only involved with housing construction, but also office construction. Office construction has more risks, due to high technology materials used on more innovative design, but as there are fewer companies able to handle such risks, the competition is lower and the returns should be higher. The risk of the portfolio for company B is diversified and a better combination of return and risk is achieved than for the concentrated portfolio of company **A.** Company B diversifies risk only at the expense of expertise. If there is not the expertise to proceed with such diversification then the output of the construction team slows down and this, therefore, increases project costs and decreases competitiveness. Therefore, what is needed is:

> "**A** trade-off is necessary between gain that diversification gives through improving the return/risk mix, and the loss of economies of scale and learning economies reducing his exposure in any one project. The moral of the portfolio theory story is, 'Do not put all your eggs into one basket'!''
>
> Flanagan and Norman (1993)

In order to be able to choose between one project, or course of action, as opposed to another, comparison can be made easier by producing graphs representing single-point single criterion, once a probabilistic analysis has been evaluated. This method of analysis is called stochastic dominance.

2.3.3 Stochastic dominance

Stochastic dominance is not an analysis in the same vein as those mentioned in sections 2.3.2.1 - 2.3.2.9; it is more an informal method of analysing the results. Stochastic dominance is the analysis of probability distributions without specifying whether the mean or the variance are the parameters to be considered. Fundamentally, this technique graphically represents the probability density functions and the cumulative distribution functions of two or more projects/choices and this should emphasise the option that the decision-maker should select. The cost, duration or whatever variable of the project that has been analysed probabilistically can be subjected to this technique to ascertain which project is stochastically dominant. Certain visual examination of the stochastic graphs indicate quite clearly which option to continue with, others do not. If project cost is the variable under scrutiny then factors such as the cost, the variation of the cost from the mean (i.e. the variance), the likelihood that the cost meets the avowed target, etc. is analysed very closely. The final decision then depends wholly on the risk attitude the decision-maker has towards the nature of the project and the stochastic information presented in front of him/her.

2.3.4 Summary

This completes the explanations of the risk analysis techniques. There are, however, ten rules, listed below, on the 'do's' and don'ts' for risk analysis, from a general perspective, which were developed by the NTNF Risk Research Committee in 1983 (Vinnem, 1983). They are:

1. Any risk analysis and associated safety recommendation must be based on complete knowledge of the operating system.
2. A risk analysis in itself cannot define the acceptable level for society, nor is it possible to place responsibility for accidents by means of a risk analysis.
3. Risk analysis by itself cannot improve safety. It must be part of the safety management system of the project.
4. Successful application of risk analysis requires proper knowledge of the methods involved, and the ability to plan and carry out the analysis. The ability to interpret the results correctly is also required.
5. The risk analysis must match the needs of the decision maker and the associated criteria laid down for the particular system.
6. The information on which a risk analysis is based must be adequate to ensure that the analysis matches the real system.
7. It is essential to ensure that assumptions and limitations of a risk analysis are systematically checked and verified.
8. Collection, analysis and presentation of data must be based on insight and carried out with care.
9. The area of application of a risk analysis must be clearly stated in order to ensure that the results are used only where appropriate.

10. When presenting the results of a risk analysis, great care must be taken to ensure that they cannot be misinterpreted.

The risk analysis techniques, both qualitative and quantitative, have been described fully. The advantages and disadvantages are clearly stated for each method. These methods are theoretically described from the available literature, and as such are highly prone to alterations to suit the exact needs of the user. This could imply, for instance, slight differences in the techniques if the user is analysing financial risks or technical risks. Whichever way the techniques were performed, the risks, at the stages directly after the qualitative techniques and again once the quantitative techniques are completed, need to be evaluated, which is explained in the next section.

2.4 Risk Evaluation Stage

The steps of risk evaluation and risk monitoring are self-explanatory, but are briefly described in this section and section 2.6, respectively. Risk evaluation initially appraises the risk information once the risks have been qualitatively analysed. It is a subjective exercise, which collates all the knowledge and judgements of experienced personnel and assesses the extent of the consequences and frequencies of the estimated risks by categorising them into classifications. Risk matrices are usually applied to identify, or rank, the more critical risks, so more focus can ensue on those, by subjecting them to a quantitative analysis. Matrices can also be used once the numerical probabilities and frequencies have been attained from the quantitative analysis.

A typical example of a matrix used as the source of risk evaluation is from Trbojėvic *et al.* (1996), see Table 2.8. They are analysing the risks associated with dismantling and removal of an offshore platform. This matrix would suffice for both qualitative and quantitative analyses.

This form of risk ranking, using the risk matrix, was also used by Restrepo (1995) in the nuclear industry. Categories, similar to those in Table 2.8, were provided to categorise the frequency and consequence of hazards pertaining to radiology and toxicology under nuclear exposure. From the matrix, the more critical risks could be further analysed.

FREQUENCY		CONSEQUENCES				
Category	Frequency per year	1	2	3	4	5
		negligible	minor	moderate	major	total loss
8	continuous exposure					
7	> 1					
6	0.1					
5	0.01					
4	0.001					
3	0.0001					
2	0.00001	Tolerable	risks			
1	0.000001					

Table 2.8 *A typical example of a risk matrix*

A re-evaluation of the risks could be performed with the additional quantitative information. These risks are evaluated by comparing them to company acceptance criteria (Rettedal *et al.* 1994), to find out whether the frequency of occurrence of these risks are acceptable or not. Each individual company has their own justifiable boundaries and depending on which side of the boundary each individual risk lies, then determines the next step in accounting for each particular risk. No measures are required for the risks which are evaluated to be acceptable (sometimes referred to as 'tolerable'), assuming there are no obvious actions which could be taken to reduce the frequency of occurrence further. For the risks positioned on the wrong side of the boundary, decisions are made as to which strategy the company takes to respond to those risks.

2.5 Risk Response Strategy

The terminology involved within risk management can still be misleading and therefore misunderstood. It is, therefore, appropriate to briefly describe the methods available for responding to risk. There are four possible techniques (Raftery, 1994; Wong, 1977): namely risk avoidance (section 2.5.1), risk transfer (section 2.5.2), risk retention (section 2.5.3), and risk reduction (section 2.5.4).

Table 2.9 shows a typical breakdown, albeit simplistic, of likelihood against severity and the method for responding to risks on a project. This matrix method is similar to the one employed for the evaluation stage, except this identifies the response method to use, as opposed to which risk to be forwarded to quantitative analysis. Obviously, this is just an illustration, so the axes would change from company to company, as well as the specific methods within each box. The changes depend on many factors such as the size of the company, the attitude towards risk, the perceptions of risks etc.

	Likelihood				
Severity (£'s)	*Improb-able*	*Rare*	*Possible*	*Probable*	*Very likely*
Negligible (Up to 500)	Retain	Retain	Retain	Retain	Retain
Small (500-2,000)	Retain	Retain	Partial Insurance	Partial Insurance	Partial Insurance
Moderate (2,000-5,000)	Retain	Partial Insurance	Insure	Insure	Insure
Large (5,000-50,000)	Insure	Insure	Insure	Insure	Insure
Disastrous (over 50,000)	Insure	Insure	Cease activity	Cease activity	Cease activity

Table 2.9 *Deciding which method of handling risks depending upon likelihood and severity*

2.5.1 Risk avoidance

Sometimes referred to as risk elimination. Avoiding risk can be as simple as a contractor not placing a bid or even the owner not proceeding with project funding. There are a number of ways a contractor can eliminate risks and a few examples are given below:

- tendering at a very high bid,
- placing conditions on the bid, a method employed during pre-contract negotiations as to which party takes full responsibility for certain risks, and
- not bidding on the high-risk portion of the contract.

2.5.2 Risk transfer

Risk transfer can take two basic forms:

1. The property or activity responsible for the risk may be transferred, e.g. hire a sub-contractor to work on a hazardous process, and
2. The property or activity may be retained, but the financial risk transferred, e.g. insurance or client takes the costs of risk by contract

The first of these two is quite similar to the second, in that the financial risk of the property or activity is transferred to another party i.e. the sub-contractor as opposed to the client.

Insurance policies can be up to a certain amount and although insurance may not totally eliminate financial uncertainty, it does enable the risk analyst to reduce substantially the degree of uncertainty that he/she has to bear. The main advantage of insurance is that it converts such uncertainty into a known cost, the premium, which is payable on a certain date. The limitations, however, according to Carter and Doherty (1974) to the benefits of insurance are:

- Not all risks are insurable
- Insurance rarely, if ever, provides full and perfect compensation for losses, and
- Not all premiums are as certain as to the timing and amount as implied above.

There are other ways of using insurance as a means of transferring the financial devastations of a risk occurring, namely risk sharing and captive insurance companies. Risk sharing can be done with an insurer by two ways. Firstly, the potential exposure is open-ended (e.g. liability risks), and secondly, the actions of the insured can significantly influence loss experience (e.g. credit or libel insurance) or partial insurance in the form of an excess (or deductible)(Rode, 1995). There are 3 forms of risk sharing:

1. *Co-insurance:* insurers are liable for a specified percentage of each claim. Under this method insurance companies can lay off risks to other insurance companies. This is sometimes referred to as re-insurance.
2. *Excess **or** deductible:* Applies to each loss (simple deductible, i.e. lump sum deducted from each claim) or to the accumulated losses (aggregate deductible, i.e. lump sum deducted from accumulated claim) within a period of insurance.
3. ***First** loss cover:* opposite of deductibles; in a deductible, the insured pay the first £*x* of any loss and the insurer pays the balance, with first loss cover, the position is reversed.

A captive insurance company (Carter and Doherty, 1974) is a privately owned insurance company directly related to risk management. A 'captive' is created and owned by an organisation. All the risks that are encountered by that organisation are insured through this captive. **A** captive differs from normal insurance companies in four ways:

1. it need only consider the experience of one insured and calculate the risk rate accordingly,
2. it has no acquisition costs
3. it need have no branch or other sophisticated organisation or premises of its own
4. it need not aim to make a profit.

The advantages of captives are that they reduce insurance costs, the payments of premiums may be agreed upon by the company, as well as deciding the amount of cover it requires, at a reasonable price. The disadvantages are that risks can arise from inflation (increases the cost of claims and administration), investment earnings (funds have to be held to cover liabilities) and international currency instability. The last of these disadvantages is only applicable when captives are set up abroad. The reason for being established in foreign tax havens is to reap the benefits of privileged tax treatment.

One further advantage of some insurance companies, captive or otherwise, is that they can provide other services, adapted from Carter and Doherty (1974), such as:

- Loss handling services, i.e. class of insurance e.g. property losses
- Loss prevention advice,
- Recovery of uninsured losses, e.g. a policyholder has partial insurance, the insurer may be prepared to deal with the policyholders share of any claim against 3rd party responsible for the loss,
- Other advice on other insurance problems, e.g. exemption or insurance clauses in contracts.

Another way of transferring risk is through contract agreements. Indemnity clauses in contracts are the financial consequences of injury, loss or damage, which may be transferred from one party to another. It is only possible to have a contract legally binding by having the attention of both parties, or more, during negotiations. The problem with this type of transference is that the contracts, in the main, tend to be negotiated by sales-persons rather than legally or risk management oriented persons. Therefore, the true effect of risk may not be fully understood by the sales-persons and thus negotiations are under-, or over-, estimated. This then results in the risk manager not knowing which risks are transferred or retained under contract so he/she will arrange too much or, more seriously, too little protection.

Retained risks were mentioned in the last paragraph as a way of handling risks. Discussion of this method follows.

2.5.3 Risk retention

This is the method of responding to risks by the body who controls them. The risks, foreseen or unforeseen, are controlled and financed by the company or contractor that is fulfilling the terms of contract. There are two retention methods, active and passive. Active retention, sometimes referred to as self-insurance, is a deliberate management strategy after a conscious evaluation of the possible losses and costs of alternative ways of handling risks. Passive retention, on the other hand, (sometimes called non-insurance) occurs through neglect, ignorance or absence of decision, e.g. a risk has not been identified and responding to the consequences of that risk must be borne by the contractor performing the work. There are three basic reasons for actively retaining a risk (Carter and Doherty, 1974):

1. The required insurance premium is judged to be too high,
2. The cost of administering the insurance arrangements may be too high, and
3. The loss prevention requirements of the insurer are considered excessive.

As one can see from Table 2.9 the risks suitable for retention are the ones which occur frequently but have small losses, and the very rare events with catastrophic consequences. These risks are usually very expensive to insure, the premiums are usually too high. The risks in-between should be decided by the management whether to insure, retain or share (e.g. partial insurance). The decision depends on the size of the company and the nature of the risks.

Retained risks are financed by a number of different ways:

- Accepting a diminution of assets: simplest method,
- Absorbing losses as part of current operating costs,
  Diversion of internal funds: divert funds from alternative use within the firm,
- Ad-hoc loans: external loans, problems are high interest rates and bad repayment terms,

- Contingency loans: facilities made for the provision of credit in the event of future loss, and
- Funding: self-insurance, a sum is set aside every year and used when a loss occurs.

It may argued that reducing risks is a part of risk retention, because the risk has to be retained before pursuing actions to reduce the effects of a foreseen risk. Alternatively risk reduction may be an action within the overall risk assessment and it is because of the possible wider use of risk reduction, it has been categorised separately.

2.5.4 Risk reduction

Loss prevention is one of the ways of risk reduction. Loss prevention can be classified into four basic categories:

1. Preconditions for a loss, i.e. faults in the premises, e.g. badly insulated wire,
2. Prevention of loss; devices designed to prevent preconditions for loss, e.g. cut-off switches
3. Early discovery of loss producing events, e.g. sprinkler system, and
4. Limitation of loss, e.g. fire doors, compartmentalisation.

The actual reduction of risks within these four categories are confined to the improvements of the physical, procedural, and educational and training devices. The physical devices can be improved by continually maintaining and updating the devices, which help prevent loss. The effect of improving procedural devices can be outstanding. Simple, low cost measures like housekeeping, maintenance, first aid procedures and security can lead to better morale, improved labour relations and increased productivity as well as their more obvious benefits. Education and training within every department of a business is important, none more so than reducing the harmful effects of risks within the working environment. Loss prevention consumes a lot of capital resources. With better education and training devices, this effect might be not so damaging, resulting in the capital being available for more productive investments. One point worth noting and, to be careful of, especially indicative in the costs and benefits of loss prevention, is that over-protection can be just as costly to the firm as under-protection.

2.5.5 Other methods of handling risks: (Carter and Doherty (1974))

2.5.5.1 Risk spreading or diversification

This is an extension of the process risk sharing. The insurers set up a fund to which a large number of individuals contribute, should a claim occur. Risk spreading is possible, internally or externally, through a company. Internally through loss prevention measures or organisational arrangements. Externally through diversifying sources of supply and sales, reciprocal production agreements or mutual insurance arrangements. **A** few of these processes of diversifying risk are self-explanatory but some are not. Reciprocal production arrangements apply mainly to suppliers and affects them most in times of high productivity. This is an agreement between suppliers that if, for instance, a fire occurs at one of their plants then the others, who entered into the reciprocal agreement, undertake some minimum level of output on their behalf. Mutual insurance arrangements basically define a captive or self-insurance company; but if the companies are small enough not to have their own, then a large number of similar firms, i.e. involved in the same industry, can form a mutual insurance.

2.5.5.2 Reducing risk liability by use of the employment contract

If the employer, assuming a claim has accrued, can prove that the necessary precautions regarding safety; (of the plant, appliances, system of work, instructions of the job), statutory requirements, the finding of competent employees and the instructions to those employees, have met the required level in strict conformity with the statute, then the employer is not liable. Therefore, the employer can escape liability by showing a constant vigilance in anticipating risk areas, monitoring existing hazards, and eliminating all potentially unsafe situations. The procedure therefore is, a) an accident happens, b) an investigation should be immediate by qualified people, c) the persons under investigation should be suspended, if necessary, pending the outcome of the enquiry, d) sanctions could be reprimand, warning, suspension without pay as a punitive sanction, or dismissal. The employee(s) in question, though, should be given the opportunity to state their own case.

This concludes the explanations for risk response and once the selected strategy is in place, these risks then are required to be continually monitored.

2.6 Risk Monitoring Stage

Risk monitoring is the continuing process of reviewing the state of the risk once it has been identified, estimated, evaluated and responded to. This stage is the last of the five, but can initiate the entire five step process of risk management off again, if the risk under observation requires re-managing. This could be for any number of reasons, such as a change of the nearby working area or a change of procedure or operation etc. These factors may re-define the risk, thus necessitating differing techniques to take account of the mitigating circumstances.

Leonard (1995) describes the five step process of risk management, albeit using different terminology. However, his last stage is monitoring the risks. He believes that monitoring must be continual, with the risks that are un-mitigating and designated as major requiring annual review. Otherwise, departments should designate a review period of either annual or biennial for all other risks. Auxiliary rewards from the monitoring process includes improved communications amongst departments and employees, increased disaster recovery planning, management skill development and more efficient budget planning.

It is now necessary to try to identify the current trends that pertain to the five steps of risk management. This was done using an extensive questionnaire sent to both the construction and the oil and gas industries.