Decision Support System (DSS) for Construction Project Risk Analysis and Evaluation via Evidential Reasoning (ER)

A Thesis submitted to the University of Manchester for the degree of Doctor of Philosophy in the Faculty of Humanities

2012

Abdulmaten Taroun
Manchester Business School
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ABSTRACT

This research explores the theory and practice of risk assessment and project evaluation and proposes novel alternatives. Reviewing literature revealed a continuous endeavour for better project risk modelling and analysis. A number of proposals for improving the prevailing Probability-Impact (P-I) risk model can be found in literature. Moreover, researchers have investigated the feasibility of different theories in analysing project risk. Furthermore, various decision support systems (DSSs) are available for aiding practitioners in risk assessment and decision making. Unfortunately, they are suffering from a low take-up. Instead, personal judgment and past experience are mainly used for analysing risk and making decisions.

In this research, a new risk model is proposed through extending the P-I risk model to include a third dimension: probability of impact materialisation. Such an extension reflects the characteristics of a risk, its surrounding environment and the ability of mitigating its impact. A new assessment methodology is devised. Dempster-Shafer Theory of Evidence (DST) is researched and presented as a novel alternative to Probability Theory (PT) and Fuzzy Sets Theory (FST) which dominate the literature of project risks analysis. A DST-based assessment methodology was developed for structuring the personal experience and professional judgment of risk analysts and utilising them for risk analysis. Benefiting from the unique features of the Evidential Reasoning (ER) approach, the proposed methodology enables analysts to express their evaluations in distributed forms, so that they can provide degrees of belief in a predefined set of assessment grades based on available information. This is a very effective way for tackling the problem of lack of information which is an inherent feature of most projects during the tendering stage. It is the first time that such an approach is ever used for handling construction risk assessment. Monetary equivalent is used as a common scale for measuring risk impact on various project success objectives, and the evidential reasoning (ER) algorithm is used as an assessment aggregation tool instead of the simple averaging procedure which might not be appropriate in all situations. A DST-based project evaluation framework was developed using project risks and benefits as evaluation attributes. Monetary equivalent was used also as a common scale for measuring project risks and benefits and the ER algorithm as an aggregation tool.

The viability of the proposed risk model, assessment methodology and project evaluation framework was investigated through conducting interviews with construction professionals and administering postal and online questionnaires. A decision support system (DSS) was devised to facilitate the proposed approaches and to perform the required calculations. The DSS was developed in light of the research findings regarding the reasons of low take-up of the existing tools. Four validation case studies were conducted. Senior managers in separate British construction companies tested the tool and found it useful, helpful and easy to use.

It is concluded that the proposed risk model, risk assessment methodology and project evaluation framework could be viable alternatives to the existing ones. Professional experience was modelled and utilised systematically for risk and benefit analysis. This may help closing the gap between theory and practice of risk analysis and decision making in construction. The research findings recommend further exploration of the potential applications of DST and ER in construction management domain.
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DEDICATION

To Laila
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<td>British Standards Institute</td>
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<td>C</td>
<td>Controllability coefficient</td>
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Chapter 1: Introduction

1.1 Introduction

“No project is risk free. Risk can be managed, minimised, shared, transferred, or accepted; it cannot be ignored” (Latham 1994). The construction industry is a very uncertain industry and construction work is one of the well known risky types of work (Larsson and Field 2002). The complexity of construction industry and its production methods generates enormous risks (Zou et al. 2007). Risk is associated with every project and each task and decision throughout the project life cycle (PLC) (BS-IEC-62198 2001). However, they are particularly evident in early stages of a project (Chapman and ward 1997). Project risks are believed to be the key barriers against meeting project success targets due to changes in a project they cause (Dey 2001).

Risk management (RM) is an essential component of construction project management. It is a continuous process of risk identification, risk analysis, risk treatment and risk review and monitoring. Among these four major components, risk analysis is the most difficult one (Baloi and Price 2003). However, it is frequently considered to be the most useful part of RM process (Smith et al. 2006). Construction risk analysis is a hot research topic; it has attracted so many researchers to contribute to it. The author of this thesis is interested in researching this domain; he believes that a genuine gap does exist in the literature of construction risk modelling and assessment.

Despite the criticism the Probability-Impact risk model has received over years, it is still prevailing. In literature, a number of improvement proposals are present. Nonetheless, these attempts have provided limited improvements to modelling construction risk; they are not comprehensive enough to consider the characteristics of construction risk and its surrounding environment. Risk analysis is mainly concerned with analysing risk impact on project cost or project duration independently. It appears that analysing risk impact on project quality is almost neglected. Moreover, literature is lacking an assessment methodology that captures risk impact on the three project objectives; cost, duration and quality, simultaneously. Lacking a common scale for assessing the different types of impact seems to be the reason (Williams 1995). In fact, risk cost was suggested as a viable solution to tackle this problem by many scholars. However, to the author’s knowledge, no comprehensive risk assessment methodology using risk cost systematically as a measurement scale has been developed yet.
An evident deviation between the theory and practice of construction risk analysis does exist. The construction industry, unfortunately, is accused of under-performing in risk analysis; literature points towards immature practice of risk analysis, limitations in the available tools and methodologies and continuous calls and attempts for improvement. Researchers have investigated various theories and techniques for assessing construction risks. They have generated a wide range of software and decision support systems (DSSs) to aid construction professionals in analysing construction risks. Unfortunately, these tools are suffering due to low take-up in practice. Instead, construction professionals depend mainly on past experience for risk analysis. It seems that the variety of tools could not bridge the gap between theory and practice or improve the practice of risk analysis. It is of great importance investigating this issue and trying to contribute to closing this gap by providing a usable DSS. Moreover, it is worth exploring the effect of the company’s size on the actual practice of risk analysis and researching the relationship between the size of the company and the maturity, sophistication and effectiveness of the different approaches or tools in use.

1.2 Research rationale

Having identified a genuine gap in literature, the researcher aims to provide an original contribution to filling it in. This research project investigates the limitations of the existing risk models and assessment methodologies in an attempt to provide viable alternatives. It also explores the actual practice of construction risk analysis and researches the reasons of low take-up of risk analysis tools and DSSs. From these premises, the research will propose an alternative risk model and suggest a new risk assessment methodology that enables assessing risk impact on different project objectives using monetary equivalent as a common scale. The proposed risk assessment methodology, simultaneously, assess the co-existing project benefits in order to generate a more realistic and comprehensive outcome. Such an outcome would enable decision makers to make more informative decisions such as contingency estimation, mark-up estimation, bid price, selecting optimum procurement route, evaluating different proposals or projects and composing project portfolio. A DSS will be developed to aid the decision making process when assessing project risk or evaluating different alternative projects. The DSS allows potential users to structure their cumulative experiences and use them as transparently and objectively as possible.
It is expected that the outcomes of this research would provide vital alternatives to the available ones in literature. This may attract more construction professionals to use objective and structured approaches or DSSs for risk analysis and decision making. The researcher is quite hopeful that this research will bring an original contribution to the literature of construction risk analysis and decision making. It is also hoped that it may help advance the practice of risk analysis and project evaluation.

1.3 Research overall aim

The overall aim of this research is researching construction risk modelling and assessment, project evaluation and selection and proposing a novel alternative that may solve the problem of low take-up of the available tools and DSSs. This requires comprehending the existing theories and tools used for these purposes and evaluating them for deploying more suitable theories and proposing novel analysis methodologies. This research aims to close the gap between theory and practice through structuring the professional experience systematically and producing a simple and easy to use tool based on a novel analysis methodology.

1.4 Research questions

Based on the aforementioned literature gap, the author’s practical experience as a construction project manager and his discussions with experts and construction professionals, this research project addresses the following research questions:

- How to better model construction risk in order to obtain a more realistic risk assessment?
- How are construction risks perceived and actually assessed by construction professionals?
- What are the major difficulties faced when assessing construction risk?
- How do construction practitioners take risk into consideration when evaluating different projects or alternative proposals?
- Why are DSSs and risk analysis tools not widely used in the construction industry?
How should personal experience and subjective judgment be structured and facilitated when assessing construction risk and evaluating projects?

These questions are the starting point of this academic endeavour. They were revised after accomplishing a critical and extensive literature review and after conducting a pilot study with a small construction company based in Greater Manchester. The final research questions are available at the end of chapter 3.

1.5 Research objectives

By addressing this research’s questions, it is aimed to achieve the following objectives:

- Comprehend construction risk modelling and propose an alternative model that better captures the nature and characteristics of risk. This objective demands a comprehensive review of previous contributions towards improving the Probability-Impact risk model and evaluating them in order to propose a viable alternative.

- Explore risk assessment tools, techniques and theories and appraise their usability in the construction industry. Achieving this requires investigating the actual practice of risk assessment and researching the limitations and drawbacks of the existing methodologies. This may enable examining the reasons that discourage people from using them. Moreover, this may identify the reasons for the heavy reliance on professional experience and personal judgment for risk assessment and decision making.

- Propose an alternative risk assessment approach which utilises the cumulative experience systematically and encourage professionals to standardise their practice. Such an approach may close the gap between theory and practice of risk analysis. Yet, it needs to be tested and evaluated theoretically and practically.

- Review the theory and practice of construction project evaluation and propose an alternative framework based on project risk and benefit levels. That requires proposing a benefit assessment methodology that integrates with the risk assessment methodology and uses common measurement scales.
• Investigate the effect of the size of the construction company on its practice of risk analysis and project evaluation. This covers the role of the cumulative experience in risk analysis and decision making and leads to propose a methodology of utilising the professional experience systematically.

• Build a decision support system (DSS) in order to utilise the proposed models and assessment methodologies and to assist professionals in analysing actual projects. This includes investigating the reasons why DSSs are not used in practice and discovering the features of usable and practical DSSs. This will also demand testing and evaluating the DSS in real cases in order to see the extent to which it meets the aspirations of the professionals.

1.6 Research scope

In the construction sector, clients and contractors have different attitudes and perspectives towards project risks, their management and, subsequently, allocation in the contract (Ahmed 1999). This research aims to propose a new risk model, assessment methodology and project evaluation framework, which can be used by both parties: construction clients and contractors. However, due to limitations in time and resources, the focus of this research will be on the contractor side only. Hence, data will be collected from contracting companies and validation case studies will be arranged with them. The proposed risk model, assessment methodology and project evaluation framework can be used to analyse any construction project regardless of its size or type. However, the importance of these proposals and the usefulness of them cannot be truly appreciated unless they are used in analysing complex and strategic projects. Moreover, the proposals can be used beyond the boundaries of the construction industry. Actually, they can be used in analysing any project in any project-based production systems. However, in this project the focus will be on construction industry.

1.7 Research methodology

Research methodology is the means by which a researcher can answer research questions. It includes the tools and techniques for data collection and analysis and justifies the rationale for choosing specific options to do so. The research was started by reviewing relevant literature in order to narrow down the research topic, draw
boundaries around an existing gap in construction risk assessment and modelling literature and decide on a set of research questions. The aforementioned questions clearly define the existing literature gap and largely govern the future research direction. The next step was developing an alternative risk model and risk assessment methodology in their initial forms. Having done that, I adopted the following research methodology to conduct this research project:

![Research methodology diagram]

**Figure 1-1: Research methodology**
A critical review of the published literature was conducted. The review covered the theories and techniques of risk management, risk analysis and decision making and project evaluation. Such a comprehensive and critical review helped me to comprehend and evaluate the existing models, tools and techniques used for analysing risk and evaluating construction projects. Furthermore, the review covered the actual practice and investigated the limitations and shortcomings of the existing techniques which might prevent people from using them extensively.

In order to enrich the findings of the literature review, a pilot study was conducted in a small construction company with an annual turnover of around £15 million. A focused group meeting was arranged with four managers in the company to discuss their practice of risk analysis and decision making and investigate the difficulties they are facing when doing such activities. The meeting was crucial to having valuable insights about the actual practice of risk assessment and project evaluation in the UK construction industry in general. It was a useful step to focus the research direction and to revisit the initial research questions. The outcomes of the previous activities are:

- a finalised version of a new risk model
- a new risk assessment methodology
- a new assessment methodology for assessing project benefits
- a new approach for construction project evaluation

A more sophisticated risk model and new risk and benefit assessment methodologies were proposed based on Dempster-Shafer theory of evidence (DST) and the Evidential reasoning approach (ER). They were used in a rather innovative way to suite the case of construction risk assessment. The above mentioned outcomes formed the theoretical basis upon which the field work is to be conducted. Besides researching for answers to the research questions, the field work aimed for checking the validity, suitability, feasibility and usability of the proposed models and methodologies in construction industry.

The research approach is a mixed-method approach and the field work included two questionnaires and seven semi-structured interviews. The field work started with three semi-structured interviews with construction professionals. The initial findings of these interviews were used to develop a questionnaire. A mail survey was administered and 420 questionnaires were sent to construction
professionals based in the UK, 96 valid responses and 37 invalid ones were received. In order to enrich the findings of the mail survey, an on-line survey was administered. The same questionnaire was distributed through professional communities interested in construction industry and project management. 164 responses from all over the world were received.

- The questionnaire ended with a note aimed at those who might be interested in a further research collaboration. Four managers working in separate construction companies in the UK showed interest and sent their contact details. As a result, four on-phone interviews were conducted. Two of them were very interested in the research topic; they agreed to arrange for application sessions to test the aimed DSS in real projects.

- Building on the previous steps, a DSS was built to facilitate the theoretical contribution in software that can be used by construction companies. The DSS delivers three main services:
  - assessing construction project risks and intangible benefits
  - aggregating the individual assessments and generating project risk and benefit levels
  - combining the two levels together in order to aid project evaluation

  The software is a spreadsheet-based DSS with a simple and user-friendly interface. It is designed in alignment with the findings of the research regarding the features of a desirable DSS. It conducts all the required calculations and produces the results in numerical and graphical forms.

- Based on the theory and the published literature, the proposed methodologies, models and algorithms used for developing the DSS were validated theoretically. However, they required a practical validation which was more challenging. Practical validation was carried out using four validation cases in separate construction companies. With a set of validation criteria on board, the DSS was presented and participants were trained for using it after illustrating its theoretical basis. The feasibility of the tool and the usability of it in construction industry were examined and constructive feedback was received to improve it.

- Finally, research findings were analysed, theoretical and practical implications were researched, conclusions were drawn, research limitations were acknowledged and further research questions were raised. A detailed account
of the research methodology and tools and the rationale behind using them is provided in chapter 9.

1.8 Thesis structure

The structure of the thesis is presented in the following figure. In total, the thesis is composed of 13 chapters organised in five parts namely; introduction, literature review, theoretical contribution, field work and results and conclusions.

![Thesis structure diagram]

Figure 1-2: Thesis structure
• **The first part** contains two chapters: this introductory one and chapter two. **Chapter two** provides the theoretical foundations for the rest of the thesis; it defines risk and presents the process of risk management. It covers risk identification and analysis tools and techniques and emphasises the importance and usefulness of risk management. Chapter two ends with comparing the theory and the true practice of risk management in construction industry.

• **Part two** is composed of four chapters which review the related literatures to the research topic. **Chapter three** covers the literature of risk modelling and assessment. The review covers the models and assessment methodologies which have been devised and used over the last half a century. It ends with analysing the findings of the review and revising research questions. **Chapter four** is concerned with the limitations of the theories and tools used for aiding construction risk assessment. **Chapter five** presents the theory of project appraisal and the multi-criteria decision making theory. It also covers the tools used for evaluating projects and lays the foundations for developing a project evaluation framework. **Chapter six** presents Dempster-Shafer theory of evidence (DST) and the Evidential Reasoning (ER) approach. It envelops their advantages and disadvantages and shows their potential as viable alternatives to the existing theories used for risk assessment.

• **Part three** consists of two chapters detailing the theoretical contribution of this research project. **Chapter seven** presents a new risk model and a new risk assessment methodology in detail. It discusses the features of the new approach and highlights its merits and potential shortcomings. **Chapter eight**, however, demonstrates a proposed framework for evaluating different construction projects based on their risk and benefit levels. It contains modelling project intangible benefits and a new assessment methodology of assessing them. These two chapters form the theoretical basis upon which a DSS is to be devised.

• **Part four** is formed of three chapters illustrating the field work and the obtained results from it. **Chapter nine** discusses the research methodology, philosophical orientation, research approach and data collection methods. **Chapter ten** is designated to present the collected data and analyse them. The analysis covers the data collected from the questionnaires and the interviews. **Chapter eleven**, though, demonstrates the DSS and illustrates how to operate it in real cases. It
also presents the feedback of the participants in the validation cases and analyse them in an attempt to validate the tool.

- **Part five** is designated for discussing the obtained results and drawing conclusions. It is composed of two chapters. **Chapter twelve** discusses the research findings and investigates their validity and relationships to research questions and the literature. In addition, it critically evaluates the research process as a whole and examines the theoretical and practical implications of the research. Finally, **chapter thirteen** summarises the whole thesis, presents the key findings and conclusions, highlights the research contribution, discusses the research limitations and outlines future research questions.

1.9 **Summary**

This chapter is an introductory one that presents the research problem and outlines the research scope, objectives and questions. It also includes a brief presentation of the research methodology and demonstrates the structure of the thesis. Next chapter provides the reader with an introduction to risk and risk management, discusses the process of risk management, highlights its importance and discusses its practice.
Chapter 2: Risk and Risk Management

2.1 Introduction

This chapter provides an introduction and a theoretical basis for the next chapters. It starts with defining risk and differentiating it from uncertainty. Risk management (RM) process is then illustrated according to different standards and professional bodies. The chapter later compares between the theory and practice of RM by reviewing the actual practice of RM as it is documented in previous research studies. The chapter concludes the need to create risk analysis tools that reflect the actual practice in order to get acceptance and appreciation from construction professionals.

2.2 Risk/Uncertainty definition

2.2.1 Risk

The word risk is originated from the French word risqué. It began to appear in England, in its English version, around 1830 when it was used in insurance transactions (Smith et al. 2006). Literature has different risk definitions. According to Winch (2003) risk is the condition where information is still missing, but a probability distribution can be assigned to the occurrence of the event. A similar definition was made by Aven (2003) who argued that in risky situations, where performance measures have more than one possible outcome, the probability distribution of the values of the performance measures can be assigned objectively due to enough amount of information to do so. In a project context, the Association for Project Management (APM)\(^1\) has defined risk as “uncertain event or set of circumstances that should it occur, will have an effect on the achievement of the project objectives” (APM 2006, p.26). Similar definition was presented by the British Standards Institute. According to the British standard BS IEC-62198 (2001, p.7), risk is “a combination of the probability of an event occurring and its consequences for project objectives”. Hence, there is a direct link between risk and project success objectives. Since project success objectives used to be classified under three main categories, cost, duration and quality (Ford 2002), researchers used to view risk as a probability that any of these performance criteria goes wrong.

\(^{1}\) APM is a well established and globally recognised project management professional body based in UK.
combined with the consequences of such going wrong (Odeyinka et al. 2008). These definitions are very much representing the perception of risk from construction professionals' point of view. According to Akintoy and MacLeod (1997), construction contractors perceived risk as the likelihood of unforeseen events, which could affect the successful completion of the project in terms of cost, time and quality.

### 2.2.2 Uncertainty

Uncertainty is different from risk. Aven (2003) differentiated between risky situations and uncertain situations in which the available information is not enough to produce objective probabilities. Instead, probabilities are produced subjectively by expressing degrees of belief. In fact, differentiating between risk and uncertainty based on the availability of information and the ability to generate a probability distribution was originally introduced by the pioneering economist Frank Knight in 1921 in his book "Risk, Uncertainty and Profit" (Knight 1921). Helton (1997) perceived uncertainty in a rather different way. He argued that uncertainty can be “aleatory” due to the randomness of the events or “epistemic” due to lack of knowledge and enough information. Uncertainty can take different manifestations; it can be error, imprecision, variability, vagueness, ambiguity and ignorance\(^2\) (Baloi and Price 2003). According to Winch (2003), uncertainty stems from two sources:

1. Complexity: the information is in principle available, but it is too costly or time-consuming to collect and analyse.
2. Predictability: the past is not a reliable guide to the future.

Zimmermann (2000) argued that lack of information is the most probable and frequent cause of uncertainty. However, it can be caused by:

1. Complexity and inability to process large amount of data
2. Conflicting evidence and contradictory information
3. Ambiguity due to linguistic measures, which have different meanings, used to describe a situation
4. Imprecise measurements, and
5. The subjectivity and belief of the decision maker towards the phenomenon.

In a project context, Chapman and Ward (1997) perceived uncertainty as ‘variability’ in performance measures like cost, duration, or quality. They saw it representing

\(^2\) Ignorance usually represents lack of information. However, there is no universal definition of it as it has different context-related definitions. It is different from other types of uncertainty like vagueness or ambiguity. A full illustration of the different types of ignorance can be found in Kutsch and Hall (2010).
'ambiguity' and lack of clarity because of lack of information. Hence, uncertainty is mainly evident at the pre-execution stages of the PLC and it can appear as variability in estimates, uncertainty about design and logistics, uncertainty about project objectives and priorities and uncertainty about the relationships between project parties (Chapman and Ward 1997). In construction management literature, the term uncertainty used to describe the unknown events that may cause negative impact on the project objectives or have positive outcome by bringing new opportunities into the project. Perminova et al. (2008), for instance, defined uncertainty as an event which may have a negative impact on the project’s outcomes or beneficial impact on project performance. Therefore, as uncertain situations have less precise information than risky situations, the opportunity to have positive impact and the chance to change a threat into opportunity is greater in uncertain situations than in risky ones. It is believed that threat and opportunity are two sides of the same coin (Loosemore and Raftery 2006). However, the word risk gives a meaning of threat rather than opportunity (Ward and Chapman 2003). From this premise, scholars used to call for using the term uncertainty management instead of risk management (Chapman and Ward 2002; Ward and Chapman 2003).

2.3 Risk Management

Construction projects are becoming more complex which requires construction professionals to rethink their approach in dealing with project risks (Tah and Carr 2001). Project risks cannot be eliminated; they have to be managed. It is believed that successful projects are those projects where risks are effectively managed (Smith et al. 2006). Different institutes and professional bodies have provided slightly different definitions of project risk management. For instance, the British Standards Institute defines it as a “systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risk” (BS-IEC-62198 2001, p.7). The Project Management Institute (PMI)\(^3\) defines project risk management as “the art and science of identifying, assessing and responding to project risk throughout the life of a project and in the best interest of its objectives” (PMI 1992, p.II-3). The Association of Project Management (APM) describes it as a "structured process that allows individual risk events and overall project risk to be understood and managed proactively, and

\(^3\) Project Management Institute (PMI) is the largest professional organization dedicated for project management in the world. It is based in the USA with over 100,000 professional members from 125 different countries.
optimise project success by minimising threats and maximising opportunities” (APM 2006, p.26). It is clear how similar the above three definitions are. In general, RM is defined as a process of specific steps. Reviewing literature shows that almost the same definition was provided by all scholars and professional bodies. Essentially, all of them agreed that RM is a continuous process over the business or the project life cycle (PLC). The Office of Government Commerce (OGC) presented the RM as a sequence of steps for identifying, analysing and treating risks applied throughout the PLC (OGC 2007); it is a continuous and cyclic process that accompanies the project from its definition through its planning, execution and control phases up to its completion and closure (Chapman and Ward 1997). It is always useful to look at RM as a process and to consider its steps, their required inputs, function and outputs over the PLC. RM is not constrained to a project level; it is widely performed on an organisation level. Actually, Enterprise risk management (ERM) is perceived as the ultimate approach to risk management (COSO 2004). Literature is rich of standards and guidance to manage risk on an organisation level such as ISO 31000 and the risk management standard published by AIRMIC, ALARM and IRM in 2002.

2.3.1 Risk management process

Different professional bodies, standards and scholars have provided guidance for a risk management process. However, all of them agreed that the risk management process is a continuous endeavour over the PLC. APM (1997) recommended a RM process of five main steps namely; initiation, identification, assessment, response planning and response implementation. The initiation step defines the scope and the objectives of the process. The next step is identifying the key project risks that need to be assessed. Risks are assessed on two stages; qualitatively and quantitatively according to the amount of available information. Response actions are then planned to treat risks. The treatment strategies are later implemented and continuously reviewed and updated throughout the PLC.

British standards institute provided a similar RM process. According to BSI-6079-3 (2000), there are two broad phases within the risk management process. The first phase concentrates on defining the scope of risks to be managed. This can be looked at as a problem framing activity. The second deals with assessing and managing risk. It is equivalent to problem solving. Under these two main phases, the RM process consists of five key steps:
• Defining context: acknowledging the objectives of the business or the project and understanding the linkage between project objectives and the organisation’s strategy.
• Identifying risks affecting the pre-defined objectives and categorising them.
• Assessing risks’ likelihoods and impacts
• Combining the assessments of probability of occurrence and potential impact to prioritise the risks for further analysis.
• Treating risks by identifying different treatment options (reduction, elimination, insurance, acceptance or sharing) and then applying the suitable strategies.

Figure 2-1: Risk management process (BS 6079-3:2000)
As evident in figure (2-1), RM is an iterative process with continuous monitoring and update. Indeed, the feedback and communication loops are essential for an effective RM process.

The Project Management Institute also outlined a recommended project RM process. According to PMI (2004), project RM processes include the following elements:

- **RM planning:** comprehending the business case and the project objectives and deciding how to plan and execute RM activities.
• Risk identification: determining the key risks that might affect the project and documenting their characteristics. This information will be stored in risk register.
• Qualitative risk analysis: assessing the likelihood of occurrence and the impact of the identified risks in linguistic terms. These assessments should be combined together in order to prioritise risks for further and more detailed analysis.
• Quantitative risk analysis: a sophisticated and numerical analysis based on historical data to assess the effect of the identified risks on achieving project objectives.
• Risk response planning: developing strategies to deal with the downside of the risks and planning for turning them into opportunities.
• Risk monitoring and control: tracking the identified risks, monitoring any new risks, monitoring the execution of the response strategies and evaluating their effectiveness.

From figure (2-2), one can appreciate that each step needs inputs, has objectives, delivers outcomes and builds upon the previous one. The steps of RM were presented as separate steps. However, in reality they can hardly be detached from each other. In real practice, it is very usual that these steps may overlap or interact (PMI 2004).

As mentioned earlier, RM is not only performed on a project level. In 2002, a team of major RM organisations in the UK: the Institute of Risk Management (IRM), Association of Insurance and Risk Managers (AIRMIC) and the National Forum for Risk Management in the Public Sector (ALARM) published the Risk Management Standard (2002). The guidance did not provide a methodology for project risk management; it delivered a RM standard for businesses and organisations. It was one of the first internationally recognised guidance for RM; it was translated into 15 different languages. According to this standard, RM is concerned with both positive and negative aspects of risk and the main objective of RM is to add maximum sustainable value to every activity of the organisation (AIRMIC-ALARM-IRM 2002). The process of RM was presented in a very similar format to the aforementioned project RM processes. According to this standard RM process starts with considering the organisation’s strategic objectives and identifying the key risks that may affect these objectives, then moving towards assessing these risks before deciding on treatment strategies with continuous feedback and monitoring along the process. Recently, the same team of RM organisations published a new guidance; *A Structured approach to*
Enterprise Risk Management (ERM) and the Requirements of ISO 31000 (AIRMIC-ALARM-IRM 2010). In this guidance, the ISO 31000 was reviewed and ERM was presented as the ultimate approach for RM.

By reviewing the different approaches recommended by the main professional bodies and standard organisations, one can appreciate a clear consistency between them regarding the component of a formal RM process. Among the main components, risk assessment is probably the most difficult one to be conducted (Thomas et al. 2006). The focus of this research is on risk assessment in construction industry. However, before investigating construction risk assessment in detail, it is worth illustrating how to identify and classify the key risks which are to be assessed later.

2.3.1.1 Risk identification
Risk Identification determines which risks might affect the project and documents their characteristics (PMI 2004). It should be a continuous process throughout the PLC because risks constantly change. However, it is essentially important in the early stages of the PLC where strategic decisions are usually required to be made with limited amount of information. According to Kerzner (2003), opportunities and risks are relatively high in the early stages of the PLC because of the relatively limited amount of information. However, because of the relatively low amount of spending at this point, risk impact, the amount at stake, will be low. In contrast, in the late stages of the PLC, opportunity and risk significantly fall. However, at these stages risk impact is huge as any change in the project would have a devastating effect. The relationship between risk impact and the different PLC stages, which is displayed in figure (2-3), is one of the key drivers that made me focus on assessing project risks in the pre-tendering stage where limited information is available and strategic decisions are to be made.

![Figure 2-3: Life-Cycle risk analysis (Kerzner 2003)](image-url)
2.3.1.1 Risk identification tools
Different tools and techniques have been suggested by different guidance and standards. PMI (1992) recommended identifying risks after developing a project work break-down structure by activities (WBS) where risks associated with every activity can be identified. The British standard BS-IEC-62198 (2001) listed a number of methods for risk identification including:

- Expert opinion
- Structured interviews
- Questionnaires
- Historical data
- Previous experience
- Testing and modelling and
- Evaluation of other projects.

PMI (2004), on the other hand, provided a different set of tools and techniques for identifying risks. The set includes:

- Documentation Review
- Information gathering techniques (Brainstorming, Delphi Technique, Expert Interviews, SWOT analysis)
- Checklist analysis based on historical information and previous similar projects
- Assumptions analysis: analyses inaccuracy, inconsistency, or incompleteness of assumptions.
- Diagramming techniques: Cause-and-effect diagrams.

These are the most frequently recommended tools to identify project risks. The practice of risk identification, however, may be different from theory. According to Al-Tabtabai and Diekmann (1992), the main methods used by practitioners for risk identification were historical records, previous experience and intuition. Hence, there are different tools and techniques for identifying project risks. However, the strengths, weaknesses and suitability of them must always be reviewed before deciding which one to use (Kerzner 2003).

2.3.1.1.2 Risk register
The outputs of a risk identification process are usually contained in a document called a risk register (PMI 2004). This document contains a list of the identified risks,
information about their causes, list of potential treatment strategies and a record of treatment actions. A risk register should be updated continuously over the PLC. It is usually reviewed and updated during regular meetings of the management team. At the end of the project, risk register will envelope the details and the outcomes of the whole RM processes (PMI 2004). It is therefore, a very important document showing the journey of RM and documenting any lessons to be learnt for similar projects in the future. In fact, risk register is perceived by many construction professionals as the cornerstone of RM as will be illustrated when discussing the results of this research.

2.3.1.2 Risk categorisation
Risk categorisation or classification is an integrative part of risk analysis in an attempt to structure the diverse risks affecting a construction project (Flanagan and Norman 1993). Different institutes and professional bodies categorise construction project risks in different ways. PMI (1992) categorise risks into a three level hierarchal structure according to their sources. The top level of risk hierarchy contains the following categories:

- External–unpredictable and uncontrollable
- External–predictable but uncontrollable
- Internal nontechnical and uncontrollable
- Technical and general controllable, and
- Legal.

The British standard BSI-6079-3 (2000) categorises risks in a different manner. It provides prompt lists of risks under the following main categories:

- Human factors
- Political/societal
- Environmental
- Legal
- Economic/financial
- Commercial and
- Technical/operational.

Categorising risks as a prompt list was also advocated by APM (1997). The Construction Industry Research and Information Association (CIRIA), though,
categorised risk differently. Risks are looked at as causes to different failure patterns that may affect project objectives (CIRIA 1996). The failure patterns were identified as:

- Failure to keep the project within the estimated cost,
- failure to achieve the required completion date,
- failure to achieve the required quality,
- failure to meet the required operation needs,
- damage to the property as a result of fire or flood, and
- injury to a worker due to an inadequate system of working

CIRIA (1996) has also provided an extensive list of prompt lists of risk sources from which construction risk can be identified.

2.3.1.2.1 Hierarchical risk breakdown structure
Reviewing construction risk literature reveals a prevailing use of hierarchical structure for categorising construction risk. Researchers extensively used the hierarchical risk breakdown structure (HRBS) for categorising project risks. In literature, there are different risk hierarchical structures proposed to suite different research projects in different countries (Ahmed et al. 1999; Andi 2006; El-Sayegh 2008; Zou et al. 2007; Tah and Carr 2001). These hierarchies together with other lists recommended by different standards or guidance can be used as a starting point for identifying and classifying construction project risks. It must be known, however, that there is no universal risk list that suits every project. Inconsistency does exist among the recommended hierarchies and lists (Arikan 2005). Hence, every project must be analysed on its own and researchers can choose the list that best serves the purpose of the research (Zou et al. 2007).

RM is costly and time-consuming as it is a continuous process over the PLC (BS-IEC-62198 2001). From here, and bearing in mind the enormous number of risks that may affect construction projects, the focus of RM should be always on the key risks. Therefore, after identifying potential risks, these risks must be prioritised for further analysis.

2.3.1.3 Risk assessment
The purpose of risk assessment is to understand and quantify the likelihood of occurrence and the impact of a risk on project outcomes (OGC 2007). According to
PMI (1992), risk assessment aims to increase the understanding of the project, identify alternative delivery methods, consider all risks and uncertainties adequately in a systematic and structured way and ascertain the effects of risks on all project aspects. Flanagan and Norman (1993) argued that there is a gap between the existing RM techniques and their applications by construction contractors. Many reasons have been put forward to explain why this is the case. It seems that risk assessment is believed to be a major reason. However, risk assessment is frequently perceived as the most useful part of the RM process (Smith et al. 2006).

Risk assessment can be conducted qualitatively or quantitatively. The choice between quantitative or qualitative method depends upon the amount and type of information available for the analyst. Usually, risk assessment starts, as in the early stages of the PLC, with a qualitative approach because of lack of sufficient information to properly apply any quantitative methods (Smith et al. 2006). Quantitative analysis may be applied later when more data become available (BS-IEC-62198 2001).

2.3.1.3.1 Qualitative risk assessment
Qualitative assessment aims to describe and understand each risk in order to prioritise the identified risks (OGC 2007). Traditionally, assessing risk is achieved by assessing the probability of occurrence and the potential impact on project objectives. The impact can be represented in terms of additional cost, additional time, failure to meet project specifications and quality requirements or any other damage to project safety, sustainability or environment related targets. Different tools can be used for qualitative risk assessment. According to APM (1997), brainstorming, interviews, Delphi technique and probability-Impact tables can be used for qualitative risk assessment. Probability and impact can be assessed using linguistic terms or numerical scores. For instance, probability of occurrence can be measured using a scale from 'very unlikely' to 'almost certainty'. It can, alternatively, be assessed by percentages like 15%, 25%, 50%, etc. The same principle can be applied when assessing impact. However, the quality and credibility of a qualitative assessment demands a clear definition of the different levels of risks' probabilities and impacts (PMI 2004). In other words, any score assigned to risk probability or impact should be clear and understandable by anyone dealing with risk assessment. Obviously, such definitions can be customised to suite different projects under different situations.
Figure 2-4: Definition of risk impact levels on project objectives (PMI 2004)

Figure (2-4) presents a set of definitions of a risk impact scale. The figure shows the definitions of different levels of risk impact measured by linguistic terms and numerical scores.

The assessments of risk probability and impact are combined together in order to generate a risk assessment. Such an assessment is used as a basis for prioritising risks for a more detailed quantitative analysis (PMI 2004). The combination is usually done by multiplying the probability score by the impact score. It is often represented by a probability and impact (P-I) matrix or table which is one of the most famous tools for assessing risk qualitatively. It is an effective, easy to use and useful tool for prioritising risks. The matrix is usually divided into areas with different colours, where a risk falling in one of them can be defined as high, medium or low risk. Another method for representing the priority of a risk is the risk diagram (PMI 2004).

![Risk Diagram](image)

Figure 2-5: Risk diagram (BS-IEC-62198 2001)
Risk diagram is a graphical method used to define spaces representing different risk levels. It is similar to the P-I table as the spaces drawn on two axes represent risk probability and impact. Hence, after assessing risk probability and impact, a risk can be depicted on the diagram. According to the location of the depicted risk, it can be assigned a low, moderate, or high priority as it can be seen from the previous figure. Qualitative risk assessment is, therefore, mainly used for risk rating, not for risk quantification.

As mentioned earlier, it is very important to have a clear definition to each of the terms or scores used for rating risk probability or impact. Kerzner (2003) insisted this importance as everyone may understand the terms or the scores differently. The next figure shows the results of a survey conducted by Conrow (2000) to examine the meaning of different linguistic terms. People were asked to link a probability statement to a probability percentage.

![Figure 2-6: What probability statements mean to different people (Kerzner 2003)](image)

Figure (2-6) shows considerable difference in understanding specific probability statements. It is remarkable how big the differences were for some statements. The survey results suggest that a difference of around 30% exists in more than half of the considered statements. Such a result rings alarming bells about the reliability of using
linguistic terms as measures of risk probability and impact. This result should draw the attention of researchers to the importance of choosing well defined and reliable measures when assessing risk.

2.3.1.3.2 Quantitative risk assessment
After conducting a qualitative analysis, the prioritised risks are subject to numerical and more detailed analysis. Different tools can be used for assessing risk quantitatively. According to PMI (2004), the most commonly used techniques in quantitative risk assessment are:

- Sensitivity analysis: determines risks which have the biggest potential impact on project objectives. However, this tool has a limitation of being unable to deal with more than one risk simultaneously; it is difficult to consider the effect of multiple risks.
- Expected monetary value analysis (EMV): calculates the weighted average outcome when different scenarios are likely to happen with different probabilities.
- Decision tree analysis: evaluates different options based on their EMVs.
- Modelling and simulation, mainly Monte Carlo Simulation (MCS), techniques: widely used in construction management for cost and duration estimation. However, simulation methods can only analyse either duration or cost risks (Poh and Tah 2006).

APM (1997) listed the same tools for quantitative risk analysis. Moreover, it included influence diagram as a tool for assessing the effect of a risk on project objectives. The British standard BS-IEC-62198 (2001) stated that quantitative risk analysis can be conducted through techniques like fault tree analysis, failure modes and effects analysis, event tree analysis, sensitivity analysis, statistical techniques and network analysis.

As there is no best theory for uncertainty (Baloi and Price 2003), there is no perfect technique to deal with risk. All of the above techniques are well established with firm scientific basis. However, there is no tool without limitations which may cause a limited take-up of such tools by practitioners.

The actual practice of risk analysis in construction industry is not that advanced. Practitioners used to depend on their practical experience and personal judgment for
analysing risk. Akintoye and Macleod (1997) argued that the most commonly used techniques were intuition and subjective judgment, sensitivity analysis, risk premium and risk adjusted discount rate. The heavy reliance on experience and personal judgment can be attributed to the special nature of construction industry and the limitations of the available tools. Indeed, it is worth investigating the reasons why experience is still the main tool for assessing construction risk. This research project aims to investigate this issue and provide a risk assessment methodology based on the practical experience and personal judgment of construction practitioners.

2.3.1.4 Risk treatment
So far, we have covered the first two phases of a risk management process. The third phase, as mentioned earlier, is risk treatment or risk response, planning and implementation. Risk treatment can be looked at as the task of identifying managerial strategies to deal with the negative impact of a risk and implementing these strategies should risks occur. These strategies could be reducing risk probability, reducing risk impact, transferring risks, insuring accepted risks, or creating a contingency plan (Turner 2005).

2.3.1.5 Risk communication, monitoring and control
The final component of a risk management process is risk communication, monitoring and control. It is a very important element that gives RM process its cyclic nature, monitors the application of risk treatment strategies, emphasises the importance of sharing RM results with all members of RM team, generates feedback and updates risk register.
Risk treatment and risk monitoring and control are beyond the scope of this research project. Hence, they were covered briefly. The key point is that an effective RM is essential for successful project management. Although all components are important to be investigated, this research focuses on risk assessment. Focusing on this component and developing a novel approach of risk assessment will be crucial for improving the effectiveness of RM and realising its benefits.

2.4 The importance of risk management
RM has become an essential and important element of project management (Chapman and Ward 1997), with direct effect on project success since risks are usually assessed
by their potential impact on project objectives (Zou et al. 2007). RM would essentially benefit project management in reducing uncertainty and improving decision making (Baloi and Price 2003). According to PMI (2004), RM maximises the probability and consequences of positive events, and minimises the probability and consequences of events adverse to project objectives. In construction, RM has traditionally been applied to deal with variations in project cost and duration. However, its application was expanded to include areas like bid/no-bid decision making, feasibility and marketability studies, health and safety, performance evaluation, and contingency management (Han et al. 2008). According to Cooper and Chapman (1987), risk analysis is crucial in five different situations:

- in the pre-feasibility appraisal stage where very minimal information is available and a decision has to be made whether to discard a project, postpone it, or proceed to more detailed feasibility studies
- when making a decision regarding whether or not to undertake a project with a net present value close to zero
- when a project or an investment involves unique and unusual risks or uncertainties
- when making strategic decisions such as choosing between alternative projects or investment proposals
- when making tactical decisions such as developing a detailed project plan or optimising its specifications

It is very clear how risk analysis is always attached to and fed into making decisions, either strategic or tactical. RM is not only important and beneficial on a project level; it is also very useful for the organisation itself. Increasingly, RM is becoming one of the essential functions of big organisations with designated department and staff to deal with it. RM is perceived as a competitive advantage that improves the organisation’s performance and preserves and creates value (E&Y 2009). Moreover, RM enhances management review and credit rating of the organisation. In 2007, KPMG surveyed 218 risk executives in top 200 organisations from different sectors. The survey documented the practices and benefits of RM in these organisations and the results were published by the Economist Intelligence Unit (EIU). According to the EIU (2007), risk executives found RM very useful to their businesses. The most frequently perceived benefits were: protecting and enhancing the reputation of the organisation, ensuring regulatory compliance, ensuring efficient resource allocation, avoiding losses, increasing shareholder value, and increasing the profitability of the business. The RM standard
(AIRMIC-ALARM-IRM, 2002) summarised the potential benefits of an effective RM to an organisation by:

- protecting the organisation's image and reputation
- aiding more informed decision-making process
- developing a knowledge base in the organisation by enhancing awareness of threats and opportunities
- contributing to an effective resource allocation and management
- increasing the operations' efficiency
- promoting risk culture among all staff to enhance their responsibility and improve corporate communication
- protecting the properties and the assets of the organisation

These benefits are definitely appealing for organisations to adopt risk management as a key function in their businesses. However, it is worth investigating the practice of RM in order to examine the effectiveness of RM function in realising these benefits. The next section investigates how RM is applied in construction industry and what are the key challenges against an effective implementation of it.

### 2.5 Risk management in practice

It seems that the real practice of RM in construction is still not advanced when compared with other risky sectors such as oil and petrochemical industries (Perry and Hayes 1985). In reality, the construction industry has a poor reputation in dealing with risk (Kangari and Riggs 1989) and there is a gap between theory and practice of RM (Thompson and Perry 1992). It is remarkable that practitioners have not fully appreciated the importance of RM for their businesses despite the huge body of knowledge available for them and the continuous developments of RM as an independent discipline (Baloi and Price 2003). It is of great importance investigating the actual practice of RM in construction. Such an investigation is crucial as it may disclose the reasons of the low take-up of the available tools and DSSs by practitioners. It is also useful for directing research towards better alternatives.

#### 2.5.1 Surveying the actual practice of risk management

While project management literature is rich of papers talking about RM, much fewer papers have address its actual application (Lyons and Skitmore 2004). Very few
papers have deal with practitioners’ perspectives and points of view regarding the existing tools and techniques for assessing and managing risk. Pike and Ho (1991) administered a survey in large UK capital investment firms concerning their risk analysis practice. They found that only around a quarter of the contacted firms used formal risk analysis; 57% of the respondents used subjective probability estimates based on their experience. According to them, a considerable gap between theory and practice of risk analysis did exist even if risk analysis is more likely to be limited to large and complex projects. They found that the major limitations in the risk analysis tools were (1) obtaining right input estimates, and (2) difficulties in understanding risk analysis approaches.

Tah et al. (1994) researched the actual practice of cost estimation and the usage of statistical analysis by construction contractors for assessing project cost risk. All contractors indicated that they did not perform any form of statistical analysis for risk analysis. Contractors explained such an attitude by indicating that statistical tools could not effectively represent the unique nature of construction risk. Akintoye and MacLeod (1997) investigated the actual practice of RM in the UK construction industry. They argued that experience and intuition were key tools for risk analysis. Moreover, they found that sophisticated and quantitative tools were not widely used for analysing risk. Almost similar results were obtained by Shen (1997) who administered a survey on RM practice in Hong Kong. The survey revealed that practitioners' experience and subjective judgement were the most effective and important tool for RM. The results also showed a very limited and rare usage of quantitative techniques due to limited understanding and lack of experience in such methods.

Based on these studies and other similar ones like Potts an Weston (1996) and Jackson et al. (1997), Wood and Ellis (2003) conducted a very important investigation of the actual practice of RM in the UK construction industry. The previous studies administered a questionnaire whereas Wood and Ellis (2003) conducted in-depth interviews in order to get better results. Their research findings, to a large extent, confirmed many of the findings of the previous questionnaire-based research which gave them confidence about the validity and reliability of their findings and conclusions. According to them:

- interest in RM comes largely from educated clients
- a continuous RM process over the PLC is mainly conducted by public sector
• a dominant reliance on judgment based on experience and intuition; the use of historical data is limited
• RM is conducted using simple tools like prompt lists, checklists and risk registers
• using complex techniques is limited due to scepticism about their usefulness
• MCS is widely used for obtaining confidence in project budgets.
• Cost is a common measure for assessing risk impact with overwhelming perception that RM would benefit in project budgeting and more realistic contingency estimation.

For comparison and confirmation reasons, Lyons and Skitmore (2004) conducted a survey among 200 construction contractors in Queensland in Australia. The results were, to a large extent, consistent with the results of the previous studies and the results of another three surveys in different times and countries (Baker et al. 1999a; Uher and Toakley 1999; Raz and Michael 2001) that were used as a basis for comparison. The results confirmed that intuition, judgment and experience are the most frequently used risk assessment techniques. Moreover, they showed that “qualitative methods for risk assessment were used most frequently, ahead of quantitative and semi-qualitative methods” (Lyons and Skitmore 2004). Similar results were obtained by Dikmen et al. (2004) who conducted a critical review of the existing RM support tools. They found that checklists, intuition and experience are the most frequently used tools for risk identification, personal judgment and experience were the key tools for assessing risk qualitatively, and sensitivity analysis and decision tree were the most known tools for quantitative assessment. In fact, Warszawski and Sacks (2004) argued that sensitivity analysis4 was the most commonly used tool for risk assessment in construction. However, they concluded that the more sophisticated methods were not widely used due to the fact that they required detailed input information which is unavailable to the average project owner or manager.

2.5.2 Between theory and practice

The limited application of risk analysis tools does not hamper their potential. Although

4 According to Warszawski and Sacks (2004), sensitivity analysis, despite its popularity, has three major drawbacks are:
   1- Assessing the impact of the identified risks separately,
   2- Considering risks to be mutually independent which contradicts reality, and
   3- Assuming linear change in every factor’s value over its range, which is different from reality.
they are not widely used and even past experience is the main tool for risk analysis. Research findings tell us that people who use advanced risk analysis methods appreciate their potential and feel positive about their benefits (Simister 1994). Laryea and Hughes (2008) concluded that the key to deal with the problem of limited application is devising risk analysis methodologies that appreciate the actual practice in construction industry and reflect what practitioners do in reality. Laryea and Hughes (2008) argued that dealing with risk and pricing it when tendering is not only based on analysing it; it is adjusted by decision makers in order to suite their strategic objectives. For instance, in order to win a contract, to beat competitors, to keep the workforce working or to establish a relationship with a specific client, it is very likely that directors in construction companies amend the contingency sum even if it is calculated based on a firm risk analysis. In fact, this behaviour was confirmed when interviewing construction managers during the field work of this research. Although Laryea and Hughes (2008) argued that introducing new models or methods may not necessarily be useful, I think that any proposed tool, as much as possible, should be simple and able to simulate the actual practice of the users. However, it should be in the same time reliable tool standing on a firm scientific theory. Moreover, risk analysis must be facilitated by a user friendly DSS that structures a risk analysis problem and allows decision makers to implement their strategies and tactics in a rather easy and transparent manner. Indeed, such a DSS is one of the aimed outcomes of this research project.

2.6 Summary and conclusions

In this chapter, risk, uncertainty and RM were defined. The RM process was presented according to different guidance and standards. The benefits of RM were highlighted and the actual practice of it was also discussed. There was an emphasis on the reasons why practitioners are not applying the available risk analysis tools. The key message that comes out of this chapter is the need to focus on actual practice of RM and to understand how people are dealing with risk in order to enhance the take-up of any proposed methodology or tool. The next chapter discusses in detail risk assessment. It presents an extensive and critical review of the risk assessment literature. It is a core element in this research as it draws the boundaries of an existing gap in literature and directs the research towards a contribution for filling it in.
Chapter 3: Construction Risk Modelling and Assessment

This chapter exhibits a comprehensive and critical review of the published literature of construction risk modelling and assessment. The review covered the peer-reviewed articles published in academic journals specialised in project and construction management, risk analysis and management, and management science. The focus was mainly on articles that aimed at providing methodologies for risk assessment or developments in risk modelling. This chapter provides a detailed account of the risk models and assessment techniques that have been developed or used over the last half a century. It defines the research gap which is analysed in next chapters.

3.1 Introduction

The construction industry has a poor reputation in risk analysis; risk is either ignored or subjectively dealt with through adding an approximate contingency sum (Kangari and Riggs, 1989). Risk analysis is a difficult task (Baloi and Price, 2003). Yet, it is frequently considered as the most useful part of a risk management (RM) process (Smith et al., 2006). Traditionally the focus has been on quantitative risk analysis using Probability Theory (PT) based tools (Tah and Carr, 2001). Gradually, there was a shift towards analysing risk based on subjective probabilities as objective probabilities are hardly available in construction. Risk analysis is inherently related to risk modelling. The Probability-Impact risk model is prevailing and risk is usually analysed through assessing its probability of occurrence and impact. However, the P-I risk model is criticised of being unable to guarantee a realistic risk assessment. Different theories, tools and techniques have been researched for aiding risk analysis and several papers have discussed potential improvements in the P-I risk model.

It is of great importance reviewing the development of construction risk modelling and assessment in an attempt to open potential research venues. This paper presents the result of a systematic and critical literature review of the literature of construction risk modelling and assessment published over the last five decades. The research focused on peer-reviewed articles published in top quality academic journals specialised in project and construction management, risk analysis, and management science. The search utilised the key business and management journal databases available through the University of Manchester library like: Science Direct, ABI-Inform (Proquest),...
Business Source Premier (EBSCO), Emerald, and Sage Management & Organization Studies. The Google Scholar search engine was also deployed. Several key words were used to start the search like: project risk, construction risk, risk analysis, risk assessment, risk modelling and risk management. Initial search results used to lead to further search activities targeting specific papers. Due to lack of access to some journals, a number of articles were ordered through the University library. The review process lasted between October 2008 and August 2009. However, regular search activities were conducted after that to keep the review results updated. Around 400 articles were reviewed. Eventually, 66 ones were considered as directly related to the research aim. Each of these papers has either provided a methodology for assessing risk or presented a contribution towards improving risk modelling. Table (3-1) provides a breakdown of the 66 papers according to the publishing journal:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Journal</th>
<th>Number of Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC</td>
<td>Automation in Construction</td>
<td>3</td>
</tr>
<tr>
<td>BAE</td>
<td>Building and Environment</td>
<td>1</td>
</tr>
<tr>
<td>CJCE</td>
<td>Canadian Journal of Civil Engineering</td>
<td>2</td>
</tr>
<tr>
<td>CME</td>
<td>Construction Management and Economics</td>
<td>6</td>
</tr>
<tr>
<td>CSE</td>
<td>Computing Systems In Engineering</td>
<td>1</td>
</tr>
<tr>
<td>COR</td>
<td>Computers and Operations Research</td>
<td>1</td>
</tr>
<tr>
<td>ECAM</td>
<td>Engineering, Construction and Architectural Management</td>
<td>2</td>
</tr>
<tr>
<td>EJOR</td>
<td>European Journal of Operational Research</td>
<td>3</td>
</tr>
<tr>
<td>IEEETEM</td>
<td>IEEE Transaction on Engineering Management</td>
<td>3</td>
</tr>
<tr>
<td>UPM</td>
<td>International Journal of Project Management</td>
<td>24</td>
</tr>
<tr>
<td>JCEM</td>
<td>Journal of Construction Engineering and Management</td>
<td>9</td>
</tr>
<tr>
<td>JCCE</td>
<td>Journal of Computing in Civil Engineering</td>
<td>1</td>
</tr>
<tr>
<td>JME</td>
<td>Journal of Management in Engineering</td>
<td>2</td>
</tr>
<tr>
<td>JORS</td>
<td>Journal of the Operational Research Society</td>
<td>2</td>
</tr>
<tr>
<td>JSS</td>
<td>The Journal of Systems and Software</td>
<td>1</td>
</tr>
<tr>
<td>MD</td>
<td>Management Decision</td>
<td>1</td>
</tr>
<tr>
<td>OCLC</td>
<td>OCLC Systems &amp; Services</td>
<td>1</td>
</tr>
<tr>
<td>RESS</td>
<td>Reliability Engineering and System Safety</td>
<td>1</td>
</tr>
<tr>
<td>RM</td>
<td>Risk Management</td>
<td>1</td>
</tr>
<tr>
<td>SS</td>
<td>Safety Science</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3-1: The numbers of selected papers according to the publishing journal

It is very evident that the majority of the articles were published in three journals: International Journal of Project Management, Journal of Construction Engineering and Management and Construction Management and Economics which are among the most frequently referred to journals in the UK construction management courses. The International Journal of Project Management has clearly made a remarkable impact on the risk modelling and assessment literature. The above list can, to a large extent, resembles the ongoing development in construction risk modelling and assessment
over the last five decades. In the next section, a chronological discussion of these publications coupled with critical commentary of the contribution of each of them is provided. Later, an analysis and discussion of these publications is presented to enable eliciting the main themes and developmental trends. A detailed table recording these papers with their year of publication, author(s), used tools and techniques, key results, and critical comments is provided in Appendix (I).

3.2 Literature review

Risk analysis in construction industry is not new. It has its roots since the development of Program Evaluation and Review Technique (PERT) in 1950s for tackling uncertainty in project cost and duration. Conventionally, risk use to be perceived as an estimation variance. It is the 1980s when risk was perceived as a project attribute and RM became a well-established analytical function integrated in project management. During the 1990s researchers investigated different theories to account for the special nature of construction risk, and after the beginning of the new millennium risk analysis flourished as a hot research topic.

3.2.1 Before the 1980s

Although the origins of risk analysis can be traced back as far as 3200 BC (Baker et al. 1999b)\(^5\), risk had not appeared in construction literature until 1960s (Edwards and Bowen, 1998). Baker et al. (1999b) argued that the term “risk analysis" was used for the first time by Hertz (1964) who utilised the computer for generating probability distribution of the rate of return of investment projects. Reviewing literature shows that risk analysis publications started in the USA where risk was dealt with implicitly when researching other problems like bidding and cost and duration estimation. During those days risk was modelled as an estimation variance and RM was perceived as a way of reaching more accurate estimates during the tendering stage. According to Edwards and Bowen (1998), statistical methods were initially used before employing Monte-Carlo Simulation (MCS) during the 1970s. In fact, probabilistic estimates and MSC were the dominating approach of dealing with construction risk. However, it is very evident the dearth in risk analysis publication in that era; very few articles about risk analysis can be referred to like (Carr, 1977; Friedman, 1956; Gates, 1960, 1967, 1971; Gates and Scarpa, 1974; Morin and Clough, 1969; Spooner, 1974). Regarding risk

\(^5\) An interesting historical review of the origins of risk analysis can be found in Baker et al. (1999b).
management, it was the end of the 1970s when project RM started to became an essential component of project management theory (Merna and Al-Thani, 2008). Actually, reviewing the literature reveals that the beginning of the 1980s is the actual start of perceiving RM as an independent project management function and a research domain.

### 3.2.2 The 1980’s

Although the number of the published papers during this decade is relatively small, they symbolise the different approaches (schools) of dealing with construction risk at that time. Researchers continued using PT-based tools and MCS for risk analysis. However, Fuzzy Sets Theory (FST) was introduced at the end of this decade as a viable alternative for tackling subjectivity in construction risk analysis.

Chapman and Cooper (1983) presented one of the earliest attempts to address the need of structuring project risks and, systematically, identifying their sources. They present the “risk engineering” approach, which integrated different tools and techniques including PERT and decision tree, for combining risk events and producing joint probability distributions of activity durations, and subsequently, project duration. Risk was modelled as a distribution of variation in activity or project duration. Diekmann (1983) however, modelled risk as a variation of cost estimation. He reviewed different tools used for producing a probabilistic estimate of cost and used MCS for such a purpose. Contrary to the previous two publications, Barnes (1983) modelled risk as probability and impact (P-I) with risk impact defined as a variance in cost estimate. In a subsequent paper, Cooper et al. (1985) presented a method for analyzing project cost risk. A hierarchical risk breakdown structures was developed with project cost risk at the top of the hierarchy. Risk was modelled again as a variation of cost estimate. Beeston (1986) as well modelled risk as an estimation variance and used MCS to generate more accurate estimates. Clark and Chapman (1987) discussed the risk analysis methodology developed by Projects Department of BP’s Group Engineering and Technical Centre and used for project appraisal. According to this methodology, risk is modelled as a variance in cost or duration.

In one of the very few papers that highlighted the need of considering the impact of risk on specific project objectives, Franke (1987) advocated assessing risk impact in monetary terms. He proposed the use of “risk cost” as a common scale and adopted the P-I risk model. Although this paper proposed a pioneering approach for achieving a
comprehensive assessment of risk impact, overall project risk was treated in rather a simple way. It was obtained by summing the individual risk costs ignoring any interdependencies between these risks which might cause exaggeration in project risk assessment. In the late 1980s, Kangari and Riggs (1989) discussed the potential usage of FST as a risk assessment tool. It is the earliest paper in the published construction management literature that addressed FST potential in handling the subjectivity in construction risk assessment. It is a very important paper and one of most cited ones. Indeed, it presents an objective evaluation of the merits and shortcomings of FST for assessing construction risk.

3.2.3 The 1990’s

During the 1990’s construction risk modelling and assessment gained momentum and became a hot research topic. Researchers primarily used two theories: PT and FST, yet they were open for other tools and techniques like the Analytical Hierarchy Process (AHP).

Hull (1990) introduced different models, based on MSC and PERT, to assess proposal risks from cost and duration points of view, while Yeo (1990) presented a “contingency engineering” method, using both a range estimates method and the PERT technique, to assess project cost risk and estimate contingency. It is one of the earliest attempts to estimate risk contingency in a systematic way. Al Bahar and Crandall (1990) in turn, used influence diagramming and MCS to assess risk. They adopted the P-I risk model and provided a systematic approach for identifying, assessing and managing construction risks.

Pioneering its application in construction, Mustafa and Al-Bahar (1991) adopt the AHP to assess construction project risk. Becoming one of the most cited papers in the literature; it applied the concept of value and weight of AHP to assess risk probability and impact. The paper also evaluated the suitability of using AHP for assessing construction project risk, delineating its limitations for such applications. Influence diagramming was again adopted by Diekmann (1992) to represent risky situations and MCS and FST were deployed to do risk assessment calculations. Diekmann (1992) discussed, from a theoretical and practical perspective, the applicability and the shortcomings of PT-based risk analysis techniques. He concluded that the methods utilized at that time were either too simplistic or too complicated to be used by practitioners. Similarly, Huseby and Skogen (1992) used influence diagramming and
MCS to account for dependencies between risks and assess them. Influence diagramming and MCS were facilitated by software called DynRisk.

In one of the few attempts to price risk systematically, Paek et al. (1993) used FST to assist contractors in deciding on bid prices. Likewise, Tah et al. (1993) used FST to assist contractors in estimating risk contingency; the P-I risk model was adopted. AHP appeared again in Dey et al. (1994) in a risk assessment methodology which combined objective and subjective assessments; risk was again modelled as Probability-Impact. Riggs et al. (1994) proposed an approach for quantifying and integrating technical, cost, and schedule risks as utility functions. AHP was used to elicit utility functions and estimate probabilities that were used in a decision tree; the option with the maximum utility was chosen. Utility was used as a common scale for assessing the attractiveness of different scenarios with different levels of risk. The proposed model, however, could not assess risk; it could only assess the utilities of different risk scenarios. Williams (1995) conducted an extensive literature review of the available tools and methodologies of construction RM. He found that risk assessment used to focus on cost and duration related risks; quality related risks used to be neglected. He reported the lack of research towards assessing risk impact on different project objectives simultaneously and the lack of a common assessment scale. In fact, he recommended cost as a feasible solution. AHP was used again by Zhi (1995) to assess the risk levels of overseas construction projects; the P-I model was adopted and AHP was deployed with minor modification; the impact assessments fell in a [0-1] range instead of the AHP’s formal 1-9 ordinal scale.

Williams (1996) discussed the limitations of P-I risk model. He argued that multiplying probability and impact produces an expected value of risk which is misleading and cannot be simply followed to prioritise project risks. As a result, he called on considering both probability and impact for prioritising risks. He also concluded that a three dimensional risk model: Probability-Impact-Predictability, as recommended by Charette (1989), was a viable alternative to the P-I model. Wirba et al. (1996) presented a FST-based RM approach, which identifies risks, checks for dependencies among them and assesses risk likelihood of occurrence by using linguistic variables. While this paper is widely cited, there is a concern about the use of interdependence coefficients for dealing with risk interdependencies. Coefficients are computed by using the fuzzy weighted mean method, which is a point of weakness in FST as it only calculates the weighted average. In this paper, risk impact was considered as the cost of risk response strategy. A stochastic model was developed by Tavares et al. (1998)
to combine the randomness of the cost and duration of a project activity. Project risk was modelled as the probability of not meeting project objectives, i.e. duration and cost; however, no other objectives were considered. Similarly, Dawood (1998) used MCS to estimate an activity or project duration. Risk was modelled again as an estimation variance and RM was found useful for reaching an accurate estimate of project duration. Likewise, Mulholland and Christian (1999) used PERT to calculate a project duration. The variance of project duration distribution represented project schedule risk; the larger the variance, the greater the risk associated with project duration.

Yet again, the limitations of the P-I model were expounded by Ward (1999), who urged for improving risk assessment. Similar to Williams (1996), he insisted that the multiple impacts of risk on project objectives should be considered, in order, to calculate the overall risk impact. Additionally, he criticized the use of separate probability-impact grids and the summation of numerical scores for generating a single composite rating of a risk. As an alternative, he proposed using a weighted sum of alphabetical ratings. Although the alphabetical rating may be a better alternative to the numerical scoring, this approach may not applicable if the aim is to assess project risk. For instance, a risk rating could be expressed, based on its impacts on three project objectives, as: 3A+2C+5D. Such a rating can hardly be dealt with when aggregating risk assessments. In the case of aggregating a large number of risks with different scores of various project objectives, a very complicated and unmanageable score would be generated.

3.2.4 The new millennium

Since 2000, endeavours to model and assess construction risk have intensified and tools have become more sophisticated benefiting from the availability of high capacity PCs. As a result, risk assessment, very often, was facilitated by decision support systems (DSSs). Despite their limitations, AHP and FST became the principal approaches for handling ill-defined and complex problems with subjectivity involved. When compared with PT-based approaches, AHP and FST-based ones were considered in many cases as a better alternative for handling construction risk assessment. In fact, PT-based techniques continued to appear in literature, but with less frequency compared to the previous eras. The vast majority of the published papers dealt with risk as a project attribute rather than an estimation variance. This
marked a major shift in perception that resulted in integrating risk analysis in comprehensive decision making processes in many cases.

Chapman and Ward (2000) criticized the use of Probability-Impact grid to size risk, arguing that it generated unnecessary uncertainty by over-simplifying the estimates of risk probability and impact. As an alternative, they propose the 'minimalist' approach that identifies risks and assesses their probabilities and impacts by specifying ranges instead of single scores. Hastak and Shaked (2000) deployed AHP for assessing international construction projects and adopted the P-I risk model. Although the developed method provided an assessment of project risk level, the assessment methodology was over-simplistic. Risks were subjectively assessed using a predetermined scale of 0–100, where 0 implies no risk and 100 implies maximum risk. Project risk level was obtained as the weighted sum of the individual assessments. Using FST, Tah and Carr (2000) assessed risk probability and impact and risk interdependencies. They tried to overcome the limitation of the fuzzy averaging rule by introducing a new aggregation formula based on the maximum risk estimate, $E_{max}$, using a modification factor ($\xi$) as follows: $E = \xi * E_{max}$. They agreed that their method needed further investigation. Actually, this aggregation rule might not be a successful choice for every case. For instance, what if there is more than one predominant risk factor? In this case one cannot specify the $E_{max}$ to apply the rule.

The methodology of Department of Contract and Management Services in Western Australia for ranking projects based on risk was adopted by Baccarini and Archer (2001) as a risk assessment methodology. The methodology utilizes the P-I risk model and calculates a risk score for project cost, time or quality. The methodology considers risk impact on specific project objectives. However, the aggregation of the separate assessments raises some concerns. The scores of likelihood of occurrence and risk impact on project cost, time and quality are averaged and then multiplied for generating a risk score. Eventually, project risk score is the highest of risk scores. It is clear that the way of generating individual risk scores and the overall project risk level is over-simplistic and may not yield realistic assessments. A DSS for managing risk in the early stages of a construction project is proposed by Dey (2001) based on AHP and decision trees. It aims to identify the best strategy, project scenario, for managing construction project risk through the expected monetary value (EMV) of every risk response strategy. The approach, hence, does not quantify the impact of any risk; it identifies the risk response scenario with the lowest expected cost. AHP was used to assess risk
probability of occurrence, and risk impact was represented by the extra cost and extra time that was reduced into monetary equivalent. Although the DSS provided risk impact on cost and duration, it did not consider impact on other project objectives and did not suggest a way of combining them together. Xu and Tong (2001) used stochastic programming as a tool for reaching accurate pricing. They dealt with risk as a variation in cost estimation. Tah and Carr (2001) deployed again the FST for assessing risk and providing project risk rating. They were able to provide separate ratings of risk impact on project duration, cost, quality and safety but they did not propose a methodology for combining these separate ratings. The limitations of the various ways by which construction risk had previously been dealt with were discussed by Hillson (2002). He urged for developing risk assessment through assessing both threat and opportunity simultaneously, using P-I models, qualitatively and quantitatively. Patterson and Neailey (2002) reviewed the use of risk register as a major RM tool and devised an interactive risk register data base as a DSS for risk assessment. The P-I model was adopted and both risk probability and impact were assessed using linguistic terms. Project risk level was obtained through averaging the individual risk assessments. Baloi and Price (2003) presented a very important review of the available tools and methodologies for risk analysis. They concluded that FST was a vital alternative to suite the case of the construction industry.

The nature of risk and its surrounding environment were matters of concern for many researchers. Nasir et al. (2003), for instance, used belief network and MCS for estimating activity duration. They looked at risk as variation in activity duration and considered the causal effects between different risks. It is worth mentioning that despite the prevalent usage of risk hierarchical structure for organising project risks, other approaches such as Bayesian Belief Networks (BBN), influence diagramming and fault trees were used to represent the interdependencies between different risks like: (Fan and Yu 2004; Oztas and Okmen 2004; Molenaar 2005; Poh and Tah 2006; and Thomas et al. 2006).

Ward and Chapman (2003) proposed using the term project uncertainty management instead of project risk management. They argued that the term risk was conveying a message of threat whereas the word uncertainty was more suitable to express that there is also opportunity. A different meaning of the term risk was used by Jannadi and Almishari (2003). They defined risk as the potential damage that may affect personnel or property. Hence, risk was specifically used to stand for health and safety problems. Jannadi and Almishari (2003) proposed a three dimensional risk model containing risk
probability of occurrence, severity of impact and ‘exposure’ to hazards. They also devised software (Risk Assessor Model RAM) to generate risk scores. Unfortunately, they did not propose a methodology for aggregating risk ratings and generating a project risk level. Choi et al. (2004) presented a Fuzzy-based uncertainty model that can deal with different types of uncertainty, objective probabilities and subjective judgments, according to the available amount of information. Fan and Yu (2004) used BBN to develop a model for assessing project risk. The P-I model was adopted and risk impact resembled the cost of damage incurred because of the occurrence of risk. MCS was again used by Oztas and Okmen (2004) to assess project cost and duration in risky environments. Although the tool considered the risks affecting both project cost and duration, it was not a risk assessment tool as the model output is an expected cost and duration.

3.2.5 Post 2005

There was a sharp increase in risk assessment and modelling papers published after 2005. Various proposals to improve risk modelling appeared after 2005 and different DSSs were devised to facilitate risk assessment.

Molenaar (2005) presented a methodology based on MCS, developed by the Washington State Department of Transportation (WSDOT), for estimating project cost by taking into account cost-related risks. The P-I risk model was adopted and risk impact stood for the extra cost incurred because of a risk happening. Shang et al. (2005) developed a DSS to facilitate construction risk assessment in the design and conceptual stages. The DSS allows different project members to access via the WWW and to express their assessments. These assessments are then weighted and synthesised. FST was utilised and linguistic variables were used to assess risk probability and impact. A new risk model was introduced by Cervone (2006) to consider the interdependencies between risks. It was argued that the P-I risk model has a limitation in dealing with risk as an independent variable, which is not necessarily the case in a project context. The proposed model included an additional dimension called “Risk Discrimination” using the definition of Kendrick (2003). According to Cervone (2006) risk discrimination “is designed to gauge the impact of a risk on the overall framework of the project, rather than looking at each risk as an independent variable within the project”. In the proposed model, risk can be assessed as follows: \( R = \frac{(P*I)}{D} \). The three dimensions were assessed qualitatively for the sake of prioritising risks. The paper suggests appreciating the interdependencies between risks by
reducing their independent scores. The reduction is performed through dividing the independent $P^I$ score of every risk by its discrimination factor $D$. In fact, the same model was adopted by Nieto-Morote and Ruz-Vila (2011) as will be illustrated later. The issue of risk interdependency was addressed as well by Poh and Tah (2006) who used influence networks to capture interdependencies among factors affecting the duration and cost of a construction activity. This methodology did not provide a tool for assessing cost and duration risk simultaneously; it could identify interdependencies among the parameters that determine an activity’s duration or cost. Thomas et al. (2006) used fault tree to model different risky scenarios and utilised linguistic variables to assess risk probability and impact. They attempted to improve risk assessments by considering the opinions of different experts; they called this method Fuzzy-Delphi. The model does not assess project risk; instead it provides a tool for assessing the risk levels of pre-assumed and specified risk scenarios. Dikmen and Birgonul (2006) used AHP within a multi-criteria decision making (MCDM) framework for risk and opportunity assessment in international construction projects. The P-I risk model was adopted and the overall risk level of a project was calculated by summing up the individual risk assessments. The simplistic approach of generating a project risk level is questionable. Moreover, the model cannot be used straightforward to quantify or assess project risk; it compares the risks of one project with their counterparts in other projects and provides relative risk scores. In fact, the relative nature of the results generated by AHP-based models is one of the key limitations of using AHP for risk assessment. AHP was used again, in combination with Utility Theory, by Hsueh et al. (2007) to develop a multi-criteria risk assessment model for construction Joint-Ventures. The model does not provide a project risk assessment; it calculates the expected utility of a project. Hence, the higher the expected utility value, the lower the project risk level.

Aven et al. (2007) discussed the nature of risk and argued that some risks are more manageable than others. This means that the chance of reducing the downside effect of one risk may be larger than other risks. Therefore, understanding the nature of risk would affect its assessment. To reflect this idea, the concept of risk “manageability” was introduced. According to Aven et al. (2007), an alternative with medium risk level and low manageability could eventually be riskier than an option with high risk and high manageability. Therefore, appreciating the issue of manageability would have a profound impact on risk assessment and decision making. Although manageability is a key issue to be considered when assessing risk, Aven et al. (2007) did not provide a clear methodology for assessing it. They called on researchers to consider it, but did not incorporate it clearly in a risk model.
Although manageability is a key issue to be considered when assessing risk, Aven et al. (2007) did not provide a clear methodology for assessing it. They called on researchers to appreciate it but did not incorporate it in a risk model. Similarly, Dikmen et al. (2007b) addressed the issue of risk manageability or “controllability”, but in a rather different way. They proposed a fuzzy risk assessment methodology for assessing the risk of cost overrun of international construction projects. They argued that the ability of a company to manage project risks should be considered when assessing risk. As a result, they consider the experience of a construction firm as an influencing factor that mitigates project risk level. Actually, Dikmen at al. (2007b) dealt with manageability as an attribute of a company in charge of managing project risk rather than a integrated attribute of risk itself; this is quite different from the argument of Aven et al. (2007).

In another proposal to improve modelling risk, Cagno et al. (2007) discussed risk “controllability” again but from a different perspective. They adopted the P-I risk model and quantified the ‘risk load’ allocated to every project element; risk impact is assessed in monetary terms but collectively as a single figure. The concept of risk ‘controllability’ was introduced as a ratio between the expected risk impact, before and after applying mitigation actions. In other words, risk controllability is dealt with as a tool for justifying mitigation actions economically. The proposed model is aimed to be used at a company level, and it cannot be used at project level. At a project level, however, risk is dealt with as a variation in project parameters.

The P-I risk model was subject to another improvement by Zeng et al. (2007) through adding a third dimension: “Factor Index” (FI). This dimension reflects the surrounding environment and the influences between the identified risks. Risk is modelled as: $R= $
**L*S*FI** where L stands for likelihood of occurrence and S stands for severity of risk impact. Zeng et al. (2007) used FST to handle subjectivity in construction risk assessment and deployed AHP to prioritise risks and derive relative weights for them. Similarly, Zhang and Zou (2007) combined the strengths of FST and AHP within, what they call, a “Fuzzy-AHP” approach. It is worth noting that both AHP and FST are well established in aiding decision making and handling uncertainty. However, both have limitations and utilising them together does not necessarily overcome their limitations. Like Zeng et al. (2007), Zhang (2007) insisted that assessing risk should not neglect its surrounding environment. He argued that project environment may have a mitigating effect on risk, which is largely neglected when assessing risk using statistical methods. He advocated considering the specific nature of a project when assessing risk and proposed the concept of “Project Vulnerability”. Project vulnerability has two distinct dimensions: the exposure of a project to a risk; and the capacity of a project system to cope with risk impacts. It is a very important paper trying to push research towards a more realistic risk assessment. However, it did not provide a method for assessing vulnerability or incorporating in risk assessment or risk model.

Case-based Reasoning was used by Dikmen et al. (2007a) to estimate construction project mark-up. Project risk was assessed through calculating a correct contingency sum. Dikmen et al. (2007c) used the Analytic Network Process (ANP) for project appraisal and selection. Risk was addressed as a major project attribute to be analysed within a Multi-Criteria Decision Making (MCDM) framework. Zou et al. (2007) tried to understand the key risks affecting construction industry in China. Risks were identified and prioritised according to their significance which is the impact on project objectives such as cost, time, quality, safety and environmental sustainability. In this study, the P-I risk model was adopted and project risk level was defined as the average of the assessed risks. A three dimensional risk model, **Significance-Probability-Impact**, was presented by Han et al. (2008). They defined “risk significance” as the degree to which a practical expert feels risk intuitively. This includes a general recognition of risk, the difficulty of gaining information and implementing management skills, the degree of indirect or potential loss and the relationship between project profitability and attitude toward risk. The output of assessing risk is a risk rating score related to a specific risk path, source-event, or project scenario. The paper, however, does not provide any mechanism for aggregating individual risk assessments and generating project risk level. Zayed (2008) proposed a risk model that calculates project risk level for prioritizing a set of projects. Project risk level was defined as the product of two risk indices: $R1$ that measures the risks on a macro level of the project and $R2$ that
measures the micro level ones; $R = R_1 \times R_2$. Each of the two indices is generated as a weighted sum of risk effects which are assessed by individual experts. AHP is deployed to generate importance weights of the risks. The P-I risk model was not adopted. Instead, a collective score, risk effect $E_i$, is used. Moreover, the method of generating project risk level neglects the interdependencies between risks. Similarly, risk was perceived as decision attribute by Zavadskas et al. (2010) who used different MCDA tools to compare between different construction projects and rank them according to their risk levels.

Cioffi and Khamooshi (2009) presented a statistical methodology for combining risk impacts and generating an overall impact, at a given confidence level, which leads to an appropriate contingency budget. The paper adopted the P-I risk model and defined risk impact as the incurred cost of risk occurrence. The statistical methodology had a weakness point of requiring the probabilities of occurrence to be averaged in order to perform the aggregation at certain confidence levels. In another paper, (Khamooshi and Cioffi, 2009), the researchers presented a methodology for estimating the number of risks that may occur at any given confidence level after averaging the probabilities of occurrence of the risks. Again, averaging the probabilities was inevitable in the proposed methodology which raises questions about the suitability of such an action for a realistic risk assessment. Luu et al. (2009) used Bayesian Belief Network (BBN) to model the relationships between risks that cause project delay and to quantify the probability of a construction project delay. The paper did not model risk as a project attribute, it modelled it as the probability of construction project delay. In fact, the proposed tool can only assess the probability of project delay.

Recently, Fung et al. (2010) have developed an Excel-based tool to assess project risk level from a safety perspective. Risk was modelled as a multiplication of an accident frequency and its severity. Severity, or risk impact, was defined as the sum of three risk impacts: extra time, extra cost and personal injury. The three types of impact were normalised into scores between 0-1. Hence, the maximum possible severity of a risk is 3. The researchers adopted the methodology of unifying different types of risk impact proposed by Larsson and Field (2002). Although the tool was able to rank the risks according to their scores, aggregating risk scores for generating project risk level was not considered. Mojtahedi et al. (2010), in turn, tried to extend the conventional project risk assessment by including health and safety and environmental aspect. They applied the multiple attribute group decision making (GTOPSIS) technique for collating different opinions of risk experts to prioritise risks. The researchers provided a breakdown of risk
impact into impact on cost, impact on time and impact on health, safety and environment. Hence, risk was modelled by means of likelihood of occurrence and these three types of impact.

Finally, Nieto-Morote and Ruz-Vila (2011) combined the strength of AHP and FST to deal with the complexity and subjectivity of construction risk assessment. They adopted the risk model of Cervone (2006) and used linguistic terms to assess risk likelihood, impact and discrimination. Fuzzy arithmetic average was used to aggregate the assessments of different experts, and fuzzy multiplication was used to aggregate risk scores to generating a project risk level at the top of the risk hierarchy. Similar to Zeng et al. (2007) and Zhang and Zou (2007), this paper combined the strengths of AHP and FST. However, both AHP and FST have limitations and utilising them together does not necessarily overcome their limitations.

The above literature review is summarised and organised in a table available in Appendix (I). The papers are ordered chronologically according to the publication date from the oldest to newest in order to show the historical development of risk modelling and assessment in construction and management domains. For every paper, the used tools and techniques and a summary of the key findings are demonstrated and critical comments are attached. It was a very useful way for analysing the literature and clearly defining an existing gap in it. Defining the gap was, in fact, the first step towards making a genuine contribution to the construction and project risk modelling and assessment literature.

3.3 Analysis and discussion of risk modelling and assessment literature

3.3.1 Risk modelling

Reviewing literature shows that construction risk was initially perceived as an estimation variance. Gradually, there was a shift in perception towards seeing it as a project attribute. As a project attribute, risk has been modelled as a multiplication of probability of occurrence and Impact. In fact, it is very evident that the P-I risk model is dominating the literature. However, a considerable number of improvement proposals can be appreciated. Researchers have addressed improving the P-I model from different perspectives as follows:
• **Predictability**: Charette (1989) proposed adding ‘predictability’ as a third dimension to the P-I risk model. This improvement was praised by Williams (1996).

• **Exposure**: Jannadi and Almishari (2003) added the extent of exposure to risk as a third dimension to the P-I model;

• **Discrimination**: Cervone (2006) called on considering the interdependencies between risks by reducing their independent scores that are generated by the P-I model;

• **Manageability**: Aven et al. (2007) argued that some risks are more manageable than others and urged to consider this fact when assessing risks. Incorporating risk manageability was also suggested by Dikmen et al. (2007b), but as an influencing factor that could mitigate the overall project risk level;

• **Controllability**: Cagno et al. (2007) considered ‘risk controllability’ as a ratio between the expected risk impacts before and after applying mitigation actions to justify them economically;

• **Factor Index**: Zeng et al. (2007) addressed the influence of the surrounding environment and the interdependencies between the identified risks by incorporating the factor index (I) as a third dimension in the P-I risk model;

• **Project Vulnerability**: Zhang (2007) advocated extending project risk analysis process by incorporating project vulnerability in order not to neglect the mediating effect of project environment on risk impact;

• **Significance**: Han et al. (2008) added ‘risk significance’ as a third dimension to the P-I model in order to reflect the unique nature of risk and the intuition of risk analyst when assessing a risk.

The above development proposals have, clearly, different approaches. Aven et al. (2007) and Zhang (2007) urged for considering risk manageability and project vulnerability when assessing risk without recommending a specific method to do that. Jannadi and Almishari (2003), Cervone (2006), Zeng et al. (2007), and Han et al. (2008), however, extended the P-I model and incorporated additional dimensions. Dikmen et al. (2007b), though, incorporated risk manageability as a influencing factor on project risk level and Cagno et al. (2007) considered risk controllability as a feasibility measure of the mitigation strategies. Apart from the format of improvement proposals, the aim of these proposals was to make the P-I model able to incorporate the unique nature of the risk in question, to reflect the surrounding environment and its influence on risk assessment and to consider the interdependencies between risks.
Among these approaches, the notion of extending the P-I risk model by incorporating additional explicit parameter(s) seems to be practical and convenient. Risk manageability of Cagno et al. (2007) does not reflect the nature of the risk. Hence, it cannot be considered as a genuine improvement in risk modelling. It considers risk mitigation strategy rather than the risk itself. Moreover, the proposed incorporation of “risk manageability” by Dikmen et al. (2007b) as an influencing factor on project risk level might not be very helpful. It would be difficult for a decision maker to provide an accurate figure that reflects his or her experience or the company’s experience in controlling all project risks; it may be much easier for the analyst to provide an accurate assessment of his or her experience in managing individual risks. Thus, when aggregating individual risk assessments, the controllability of project risk level will be automatically incorporated.

The author believes that construction risk can be better modelled through incorporating additional parameters in the P-I model. In fact, extending the P-I model comes in alignment with the common practice of structuring project risks in a hierarchical structure, analysing them individually and then aggregating their assessments. Such an extension allows risk analyst to produce a more realistic risk analysis at a micro level before aggregating the individual assessments and generating a project risk level. These additional parameters should clearly reflect:

- the unique nature of a risk and the experience of risk management team in controlling its impact and mitigating it,
- interdependencies between the identified risks and
- the effect of the surrounding project environment on risk impact.

The additional parameters should function as mitigation coefficients to reduce the maximum risk assessment generated by the P-I model when all these considerations are not applicable. It is believed that incorporating the adjustment parameters would enable risk analysts to produce a more realistic risk assessment and, eventually, project risk level.

3.3.2 Construction risk assessment

When examining the published literature of project risk assessment, two levels of analysis can be defined; risk assessment and project risk level estimation.
3.3.2.1 Risk assessment
Different approaches have been adopted to assess project risks. Researchers started by using statistical methods based on PT for dealing with duration risk or cost risk. This approach perceived risk as an estimation variance. In alignment with this perception, objective probability, frequency, has been always sought for. However, appropriate data for such an approach are hardly available in construction. Gradually, many researchers concluded that human factors, intuition, professional experience and personal judgment were essential to be considered. To reflect this, FST was introduced as an alternative for handling subjectivity in construction risk assessment. Actually, FST has not become popular for assessing construction risk until the 1990’s. Yet, by the beginning of the millennium it became one of the most investigated approaches. Besides the subjectivity issue, researchers were faced by the ever increasing complexity in risk analysis due to the growing complexity in construction projects. Over the last two decades, AHP has been perceived as an effective tool for handling the complexity in construction risk assessment. It has provided a systematic approach to structuring risk assessment problems by providing a logical approach for assessing risk impacts and importance weights. The wide adoption of AHP represented the change in risk perception from an estimation variance into a project attribute. AHP is originally a decision support tool. However, addressing project risk assessment as a decision making problem aims to gauge the amount of risk embedded in a project resulted in finding AHP very useful. Such a perception was in parallel with the extensive use of risk hierarchical breakdown structure for structuring project risks. It is worth noting that both FST and AHP have limitations which are admitted by the researchers who investigated their potential in risk assessment. Hence, the continuing research for utilising more suitable approaches for risk analysis is legitimate and required.

In terms of assessment domains, it was striking how neglected the analysis of project performance risk is in literature; the focus was mainly on cost risk or duration cost. In fact, there is a lack of enough research on assessing the risk of project quality or other strategic objectives, like sustainability for instance. Williams (1993) argued that the research movement towards a full three-fold success analysis has been slow. Subsequently, literature lacks an assessment methodology capable of comprehending risk impact on all project success objectives that allows generating a risk assessment of the overall performance of a construction project. The reason for such scarcity is attributed to the lack of a common scale which is able to measure risk impact on different project objectives (Williams, 1995). Yet, the most convenient common scale is thought to be the risk cost (Franke, 1987; Williams, 1995). Actually, risk cost has been
used as a risk impact measurement scale by different researchers (Cagno et al., 2007; Cioffi and Khamooshi, 2009; Fan and Yu, 2004; Franke, 1987; Molenaar, 2005). Nevertheless, none of them used risk cost for assessing risk impact on different project objectives. Hence, it is worth introducing an assessment methodology that enables assessing risk impact of specific project objectives using risk cost as a common scale. This will successfully lead to produce a comprehensive assessment that enables assessing the risk level of the overall project performance.

Finally, risk assessment was in most of the cases a rating score, numerical score or a linguistic variable, rather than risk quantification. When using monetary equivalents to measure risk impact, the assessment outcome used to be an expected contingency to cover the risk or an expected cost of mitigating its impact.

3.3.2.2 Project risk level
Different approaches were utilised to obtain a project risk level. Conventionally, researchers followed the objective probability approach and used PT-based techniques and MCS to combine probability distributions of the durations or costs of project activities. The main aim was to assess the risk of project cost overrun or project delay. As mentioned earlier, the perception of project risk has gradually changed from an estimation variance into a project attribute. At first, risk was dealt with as a project attribute that can be analysed at a project level. Such an approach is sufficient for analysing risks in small projects, not large and complex ones (Dey et al., 1994). Increasingly, systematic and more sophisticated approaches have been adopted to handle project risk analysis in large and complex projects. Project risks are systematically identified and categorised in hierarchical or network structures. Although other forms of risk categorisation like influence diagrams and fault trees can be noticed, the hierarchical risk breakdown structure is the most commonly used way of structuring project risks. Dealing with complex risk breakdown structures forced researchers to use suitable tools for comprehending the complexity of the case. It is evident from literature that many researchers have extensively employed AHP and FST for assessing project risk level.

Project risk level is obtained through aggregating individual risk assessments at the lowest level of a risk hierarchical structure. The aggregation mechanism was in most cases averaging the individual scores. Such an aggregation rule might not be the best option for obtaining a realistic risk assessment. While this limitation was recognised
and acknowledged by many researchers, it was often argued that it was the only available method. In other cases, project risk level was obtained as the weighted sum of the individual assessments. Such an approach has a limitation of assuming that the aggregated risks are independent. Utility theory was also employed for estimating project risk level indirectly. Hsueh et al. (2007), for instance, developed a multi-criteria risk assessment model for construction Joint-Ventures. The model does not provide a project risk level assessment. Instead, it calculates the expected utility of a project using the multiple attribute utility theory. Hence, for comparing between different projects, the higher the expected utility value, the lower the project risk level.

One could argue that the key for obtaining a realistic project risk level is starting with realistic risk assessments and then deploying a suitable aggregation rule. Therefore, researching an effective aggregation rule is crucial for a successful project risk level estimating.

### 3.4 Results from the literature review

The previous review of risk modelling and assessment literature has revealed important results. The key results are summarised as follows:

1. Despite the existing improvement proposals, the P-I risk model is still prevailing.
2. Unfortunately, the proposals of improving the P-I risk model are not detailed enough to comprehend the characteristics of risk and its surrounding environment.
3. There is an evident shift from perceiving risk as an estimation variance towards dealing with it as a project attribute.
4. Construction risk assessment is gaining more interests due to the increasing complexity in construction projects and their business environment.
5. Quantitative methods, based on probability theory, had been extensively deployed. Gradually, analytical assessment approaches have become the main stream, benefiting from the availability of different theories and tools like FST, AHP. Layrea and Hughes (2008) documented this paradigm shift from “classicalism”; using PT-based and simulation tools, towards “conceptualism”; using analytical tools. However, they argued that this shift did not result in more adoption of the analytical tools by professionals. Unfortunately, the take-up of the available risk analysis tools by practitioners is quite limited.
6. Progressively, sophisticated tools and DSSs are devised to take risk analysis beyond assessing project cost and duration variation. Researchers benefited from the widespread availability of PC in producing advanced and sophisticated DSSs. These tools enable risk analysts to conduct comprehensive analyses including risk identification, risk assessment, assessment aggregation and project risk level estimation.

7. It seems that the risk of cost or duration overrun have been hot research topics (Akinci, 1998; Akinci and Fischer, 1998; Assaf and Al-Hejji, 2006; Baloi and Price, 2003; Dawood, 1998; Jahren and Ashe, 1990; Kaming et al., 1997; Lowe et al., 2006, 2007), whereas analysing risk impact on project quality have been almost neglected.

8. Literature is lacking a comprehensive framework that considers the different types of impact of a risk on different project objectives simultaneously and aggregates them together.

9. Although many authors recommend the use of ‘risk cost’ as a common assessment scale of risk impact on specific project objectives (Chan and Au, 2008; Dey, 2001; Franke, 1987; Paek et al., 1993; Sanchez, 2005; Williams, 1993; Williams, 1995), risk cost has never been used systematically for such a purpose. It is interesting to investigate why such a methodology is lacking while estimating contingency allowances is a hot research topic and a well-established practice in construction industry.

10. The conventional way of aggregating individual risk assessments is averaging them or obtaining a weighted sum of them. These methods are not always the suitable way for obtaining an aggregated risk assessment. A successful assessment of project risk level requires deploying an effective aggregation rule.

11. The conventional way of aggregating risk assessments is averaging, but it may not be always a suitable way of getting an overall risk assessment.

12. Although researchers have represented interdependencies between risks using influence diagrams, hierarchical structures or networks, the hierarchical structure is the most frequently used way of categorising risks and establishing their relationships.

13. The interdependencies between risks on different levels in the hierarchy, vertical dependency, are used to be assessed by means of linguistic terms or
probability distributions. However, the interdependencies between risks on the same level of the hierarchy, horizontal dependency, have never been addressed in an explicit and clear manner.\(^6\)

These results define a clear gap in the existing literature of risk modelling and analysis. This research, essentially, addresses this gap and attempt to fill it in.

### 3.5 A literature gap

The previous results are used as guidance in the research for a vital alternative that might fill in this literature gap. This research aims to propose a new risk model that can better capture the nature of construction risk. Moreover, it aims to devise a new assessment approach capable of considering the impact of a risk on the various project objectives in an attempt to yield a more realistic and useful results. In order to achieve that, monetary equivalent “risk cost” is proposed to be used as a common scale of risk impact on different objectives. Risk cost is to be utilized within a transparent approach that structures and facilitates the experience and personal judgments of construction professionals. Risk cost is believed to be a measurement scale understood by all parties. Such a scale might encourage construction professionals to use risk analysis tools. This might also contribute to providing a usable and practical alternative for assessing risk bearing in mind the lack of an accepted method for risk assessment in the construction industry (Mulholland and Christian 1999). Therefore, the ultimate aim of this research is participating in bridging the existing gap between theory and practice by providing a rigorous but usable and simple assessment methodology and tool.

### 3.6 Research questions revisited

The initial research questions were revised after conducting an extensive literature review and carrying out a pilot study with a small construction company based in greater Manchester. The pilot study was very helpful in providing deep insights about the usual practice of risk assessment and project evaluation. The participants in the

\(^6\) Two different terms are being used to differentiate two types of interdependencies across the risk hierarchical structure:

1- Vertical dependency: represents the case when a risk is influenced by a number of risks situated on a lower level of the risk hierarchical structure.

2- Horizontal dependency: stands for the case when a risk is influenced by a number of risks on the same level of the hierarchy.
pilot study discussed the difficulties they faced when assessing risk and expressed the reasons for not using special tools or DSSs. The pilot study findings and the literature review results were crucial to narrow the research focus and to revise the initial research questions. The final questions of this research project are:

- What other parameters can be included in the P-I risk model in order to better model risk and generate a more realistic risk assessment?
- To what extent risk cost is a feasible alternative for measuring risk impact on different project objectives?
- Is it suitable to use a monetary equivalent as a common scale for assessing project risks and intangible benefits when evaluating different construction projects?
- Can past experience and personal judgment be structured and used objectively when assessing risk and evaluating construction projects?
- Do construction professionals complement their reliance on experience and personal judgment with special tools for aiding risk assessment and project evaluation?
- What are the main reasons of the low take-up of DSSs for aiding risk assessment and decision making in construction industry?
- What are the key features of a DSS that attract construction professionals to use it?

These questions will direct the research project and heavily shape it. They are the basis upon which the data collection techniques, questionnaires and interviews, will be developed.

### 3.7 Summary and conclusions

This chapter presented an extensive review of the project and construction risk modelling and assessment literature. After reviewing around 400 academic papers, 66
papers published in peer-reviewed journals were identified as directly related to the research problem. These papers were considered because they have presented a contribution towards risk modelling or assessment. A chronological development of risk modelling and risk assessment was presented. A detailed table showing the methods used in these papers and the key results together with reviewing comments is available in Appendix (I). The results of the literature review define a gap in the project risk modelling and assessment literature. These results, together with the findings of a pilot study, helped in revising the initial research questions.

It is concluded that there is a real need for devising a model which can better describe construction risk and capture its characteristics within its surrounding environment. Moreover, using a common scale that measures the impact of a risk on the different project objectives is essential for obtaining a comprehensive and detailed risk assessment. Furthermore, the usability of a DSS might be enhanced by facilitating the practical experience and personal judgement of the practitioners and structuring them in a rather objective and transparent manner.

Next chapter discusses the limitations of the existing theories and tools that have been used to handle risk assessment. It shows the limitations that may contribute to the low take-up of the tools. This will be crucial for researching an innovative alternative upon which a DSS can be built to aid construction risk assessment.
Chapter 4: Limitations in the Theories and Tools Used for Construction Risk Assessment

This chapter reviews the most frequently used theories and tools for modelling and assessing construction risk. The focus will be particularly on Probability Theory (PT), Fuzzy Sets Theory (FST) and Analytical Hierarchy Process (AHP). Although each of them is well-established and very useful, they might not be the best option to deal with construction risk. Hence, this chapter reviews the limitation of them for modelling and assessing construction risk. The limitations of risk analysis tools and DSSs are also reviewed. Such reviews are crucial for understanding the potential difficulties of conducting risk assessment, the shortcomings of the used techniques and approaches and the reasons of heavy reliance on practical experience for assessing risk. This will also highlight the required features of a vital alternative. The chapter ends with a conclusion that Dempster-Shafer Theory of Evidence (DST) could be a viable framework for analysing construction risk.

4.1 Introduction

Risk is associated with every project and each process and decision throughout the project life cycle (BS-IEC-62198 2001). Different tools and techniques have been used to assess construction risk. The choice of an appropriate technique, though, depends mainly upon the difficulty at knowledge acquisition, data collection, development difficulty and the suitability to a specific application domain (Baloi and Price 2003). Literature review revealed that PT was the conventional way of modelling and assessing construction risk. Under this theory risk is modelled as an estimation variance. Over the last two decades, FST has been notably used as an alternative to PT because of its ability to capture the subjectivity of construction risk. It provided researcher with a means of using natural words, linguistic variables, to describe risk likelihood or impact. It also enabled them to aggregate individual risk assessments through the fuzzy averaging rule. AHP, which is a decision making tool, provided researcher with a very effective way of structuring complex situations and assessing risk likelihood, impact or importance weight. The previously reported literature review indicates very clearly that PT, FST and AHP are the most frequently used frameworks for handling construction risk assessment and decision making. Although they have
enjoyed a prevailing presence in construction risk literature, each of them has its limitations when dealing with risk analysis. There is no best theory of uncertainty (Baloi and Price 2003), however DST could provide a viable alternative to construction risk assessment. Such a claim is a major objective of this research. It requires further research and validation, but before that the limitations of PT, FST and AHP need to be fully appreciated.

4.2 The limitations of PT

PT has been used extensively to model uncertainty; it is particularly suitable to repetitive experiments or events. According to Liu et al. (2002), two major schools of thought exist under the PT umbrella; the Frequentists and the Bayesians. The frequentists, objectivists, believe that probabilities must relate to long frequencies of occurrence (Flanagan and Norman 1993). Therefore, the objective probability of an event can only be determined after repeated observations. The probability can be estimated as the ratio between the frequency of an event occurrence and the total number of observation. However, in subjective probability theory, the Bayesian, the probability of an event is the degree of belief or confidence placed in its occurrence by the decision maker on the basis of the available evidence (Liu et al. 2002). It seems that objective probability theory has been used very often for assessing construction risk. Risk was considered implicitly when assessing uncertain duration or cost of a project activity. However, the dependence of this approach on repetitive observation, which is not usually attainable in construction projects due to the unique nature of each of them, is a major obstacle against employing PT. Construction risk is subjective by definition, so objective probability could hardly represent it. As a result, probabilistic approach cannot be utilised to assess risk (Dikmen et al. 2007b) and PT might not be the perfect choice for handling it.

PT has traditionally been used to deal with all types of uncertainty. PT is definitely suitable for dealing with the aleatory type of uncertainty. However, it is unable to model the epistemic uncertainty, even through Bayesian probabilities, (Sentz and Ferson 2002). The only way PT deals with the epistemic uncertainty, lack of enough information, is adopting the “Principle of Insufficient Reason”\(^7\) and assuming that all events are equally likely to happen, i.e. using a uniform probability distribution. This

\(^7\) In a random selection of one card out of four cards with different colours, the principle of insufficient reason suggests that all the cards are equally likely to appear. Hence, the probability that next card is going to be red for, instance, is \(\frac{1}{4}\). As a result, the probability depends on the total number of cards.
limitation represents the inability of PT of representing ignorance and differentiate it from randomness. Dempster (1969) highlighted this limitation and mentioned another shortcoming in PT which is the requirement of the subjective belief in an event and its negation to sum to unity. This implies that the belief in one hypothesis should decrease the belief in other hypotheses which is not necessarily true. These two limitations are very crucial in our case. Construction risk assessment has its major role when it is conducted at the very early stages of the PLC. Unfortunately, at this stage the amount of available information to make informative decisions or to analyse project risks is very limited. Subsequently, using PT will force decision makers to make assumptions that might not be suitable for a realistic risk assessment.

The assumption of events independence is a major limitation in the PT-based approaches for analysing risk such as MCS. Such an assumption is not appropriate in the case of construction risks which are very much interrelated and dependent on each other. In reality, MCS has been under criticism by many researchers. Almost all of the criticism was pointing towards its limitation in representing interdependencies between different risks and the assumptions that they are independent (Beeston 1986; Diekmann 1992; Raz and Michael 2001; Burroughs and Juntima 2004). These limitations can, to some extent, explain why practitioners are relying on their experience and personal judgment when analysing construction risk. Byrne (2005), however, gave another reason for the heavy reliance on practical experience. He argued that decision makers estimate probability intuitively while making common decisions and reject any procedure that imposes a structure on an intuitive process. He insisted the subjective nature of construction risk as probabilities are assessed differently by various people due to different perceptions of possible outcomes.

To conclude, the subjective nature of construction risk and the interdependencies between risks together with the special nature of construction projects are major barriers against using PT-based quantitative tools. Dissatisfaction with the inability of such tools to capture the subjectivity in risk assessments has led to researchers seeking more suitable approaches like the FST (Tah and Carr 2001). The subjectivity issue of construction risk became a major concern to the researchers in this area. Indeed, Dikmen et al. (2007b) called on “structuring and facilitating” individual knowledge, past experience and professional judgment in an objective and structured framework when assessing construction risk.
4.3 The limitations of FST

Literature review showed that FST was introduced as a genuine tool for assessing construction risk in the late 1980s. Since then, it has flourished and become an essential approach for decision making and risk assessment in construction. However, it has limitations which have been acknowledged by the researchers who investigated its potential.

The concept of fuzzy sets theory was developed by Lotfi Zadeh (Zadeh 1965) in order to deal with uncertainty using natural words because of the lack of precise crisp numbers that can represent uncertainty. The main concern of this approach was the meaning of information rather than its measurement (Zadeh 1978). The fuzzy logic provides a great approach for dealing with ill-defined problems which suffer from imprecision due to the lack of precisely defined criteria or mathematical models (Dikmen and Akbiyikli 2009). Hence, it provides a “systematic way to interpret linguistic variables in a natural decision-making procedure…and resembles human reasoning in its use of imprecise information to generate decisions” (Liu et al. 2002).

In order to model uncertainty, FST uses linguistic variables and membership functions. A linguistic variable is represented by a fuzzy set, a set of numbers, which is associated with a membership function. The membership function is a set of numbers between 0 and 1 representing the degrees of membership with 1 standing for complete belonging and 0 standing for complete not belonging. Hence, the partial belonging to a set is the key difference between FST and the crisp set theory which is based on complete belonging or not complete belonging to a set (Liu et al. 2002).

According to Dikmen et al. (2007b), FST provides a useful way to deal with complex problems in situations incorporating vagueness. However, they claimed that one of the reasons why FST is not widely used in practice is its computational complexity. Kangari and Riggs (1989) mentioned three main limitations of the FST:

1. A problem of assigning the membership values of a fuzzy set to represent a linguistic variable. This problem reflects the difficulty in interpreting or understanding the true meaning of linguistic variables by different people. This reminds with the difference in understanding linguistic terms illustrated by Conrow (2000) which is, by itself, composing another dimension of uncertainty,

2. complexity in performing arithmetic operations, and
3. problem of associating the final fuzzy set, after aggregating individual assessments, with a linguistic variable to represent risk level. Kangari and Riggs (1989) mentioned that this is usually done by calculating the Euclidean distance between the fuzzy set under question and a set of benchmark fuzzy sets. Based on the distance, the fuzzy set under question takes the linguistic term of closest set among the benchmark fuzzy sets. Hence, the result is reduced into a specific benchmark set and then interpreted in the associated linguistic term. Such an interpretation is not necessarily accurate as the result is not represented in a unique term; it is represented by the closest benchmark terms. Hence, the difference between the benchmark term and the required unique term represents a hidden error in the analysis.

Similar limitations have been listed by Liu et al. (2002) besides the flexibility of FST which could result in “little guidance on how to solve a given problem” (Liu et al. 2002). Tah and Carr (2001) mentioned the limitation of FST in aggregating risk assessments. According to them, the conventional method for aggregation, the fuzzy union operator, produces an average assessment which may not be suitable for producing a representative overall risk assessment. This aggregation rule will weaken the effect of the influencing risk factors (Cox 1999). This limitation in FST is very critical especially when employing FST for assessing the project risk level as a decision criterion. Finally, Liu et al. (2002) argued that FST was more suitable for qualitative reasoning, and classification rather than for quantitative estimation of uncertainty. Hence, FST can be a very effective approach for assessing risk qualitatively rather than quantitatively.

These are the main shortcomings and limitations of FST that need to be considered when using it for assessing risk. The drawbacks of FST should trigger the search for a more suitable theory or framework of dealing with the subjectivity of construction risk assessment.

4.4 The limitations of AHP

AHP have been widely used by researchers in an attempt to tackle the problem of ill-defined and ill-structured decision making and risk assessment tasks (Taroun and Yang 2011). It was developed by Saaty (1980) and received a worldwide recognition as a MCDM tool. It organises the different factors affecting decision making in a systematic way and provides a structured and clear solution to the decision making
problem (Skibniewski and Chao 1992). One of the core attributes of AHP is that it facilitates the personal judgement of the decision maker in quantifying relative priorities of a given set of alternatives on a ratio scale. It also considers the importance of different criteria and stresses the consistency when comparing between different alternatives (Al-Harbi 2001). According to Saaty (2008), one can use AHP to make a decision by following the following four steps:

1. Problem definition; objectives and type of knowledge sought.
2. Structuring a decision hierarchy; decision goal at the top, the main objectives, decision criteria, through the intermediate levels and the alternatives at the lowest level.
3. Constructing a set of pairwise comparison matrices.
4. The comparison results, priorities, are aggregated to obtain the final priorities, ranking, of the alternatives.

The literature review which is presented in the previous chapter illustrates how AHP has received remarkable attention for decision making and risk analysis. However, this does not mean that AHP is a perfect methodology for such purposes. In one of the earliest attempts to use AHP in construction industry, and the first use of it specifically for assessing construction risk, Mustafa and Al-Bahar (1991) found it providing valuable support for the decision making processes especially because of the systematic thinking environment it offered. However, they mentioned three concerns regarding the efficient usage of it:

1. Building the hierarchy with (7 ± 2) elements under any node in order to preserve consistency was recommended by the founder of AHP himself. Mustafa and Al-Bahar (1991) illustrated a solution to this case by grouping the elements in clusters.

2. The number of judgments required to derive relative priorities is a concern. AHP needs (n - 1) judgments to compare one element with the remaining (n - 1) elements. According to Sen and Yang (1998), the large number of judgments required often causes inconsistency problem. This will also make conducting sensitivity analysis very difficult and impractical (Belton and Stewart 2002).

3. The comparison approach is quite difficult when decision makers are dealing with intangible criteria. Mustafa and Al-Bahar (1991) argued that in these cases, decision maker will no longer be certain about the numerical value that best represents his or her judgment.
The previous concerns have been mentioned by researchers from a practical perspective. Nonetheless, there are other concerns from a theoretical point of view. The major theoretical problems in the AHP as mentioned in literature are:

1. Rank reversal problem; in certain situations the introduction of a new alternative, which does not change the range of outcomes on any criterion, may lead to a change in the ranking of the other alternatives (Belton and Gear 1983; Belton and Stewart 2002). As a result, when new alternatives are added to AHP, the assessments that are already done on the old alternatives have to be discarded and a new assessment has to start from the beginning taking into account the whole alternatives (Xu and Yang 2001).

2. Problem in the 1-9 scale used for measurement (Pöyhönen et al. 1997). According to Belton and Stewart (2002), literature reports some concerns regarding the appropriateness of the conversion from semantic to a numeric 1-9 scale. According to them, the extreme points of the scale defined semantically as “absolute preference” is more consistent with a numeric ratio of 1:3 or 1:5 than the 1:9 used in AHP.

3. Sen and Yang (1998) criticised the implicit assumption that elements at any single level in the hierarchy except the bottom one, the alternatives, are preferentially independent. They argued that evaluating an attribute in a real MCDM problem may, most probably, depend upon the achievement level of other attributes.

The limitations of AHP do not underpin its practicality and usefulness. However, they have been reviewed in order to stimulate the search for a more innovative usage of it or to research a better alternative for decision making.

4.5 The limitations of the existing DSSs and tools

A considerable number of decision support systems are available to assist construction professionals in risk analysis or decision making. Unfortunately, they are rarely used in practice (Laryea and Hughes 2008; Ahmed et al. 2004; Wong and Hui 2006; Chan and Au 2007). Several DSS development techniques have been used such as rule-based expert systems; case-based expert systems; model-based expert systems; neural network based systems; and genetic algorithm based systems (Baloi and Price 2003). The reviewed literature shows that simulation tools such as MCS were used widely for
analysing construction risk. These techniques are not free of limitations especially when it comes to the issue of fit for purpose. For instance, Moselhi et al. (1993) used a rule based-expert system to estimate the bid mark-up value, whereas Li et al. (1999) applied the artificial neural networks (ANN) technique for the same target. Both of expert systems and ANN have limitations. Rule-based expert systems have a limited applicability as it is almost impossible to define generic rules for any possible scenario in a dynamic bidding environment, and ANN has a disadvantage of being perceived by users as a black box as its reasoning process is concealed from the decision-maker (Dikmen et al. 2007a). To avoid such limitations, Dikmen et al. (2007a) adopted the case-based reasoning technique for bid mark-up estimation of international construction projects. However, this technique also has a shortcoming of being in need for a reliable and big library of cases to support decision making which could hardly be available in all situations. Such limitations provide a good example of the potential reasons of the low take up of the available DSSs.

Although simulation techniques are very popular risk analysis tools, Akintoye and MacLeod (1997) documented the reasons that prevented construction professionals from using them. According to them, the barriers against using simulation tools like MCS for construction risk analysis were:

- lack of familiarity with the techniques,
- the degree of sophistication involved in such methods,
- the required time,
- lack of suitable information and knowledge to be used as inputs,
- doubts about the applicability of such techniques,
- the project size and sophistication level,
- the subjective nature of construction risks

The usability and the practicality of the available DSSs in construction industry is definitely an important matter of consideration. The practicality issue may explain the continuous reliance on experience for risk analysis and decision making in construction. Diekmann (1992) argued that the existing risk analysis tools were either too simplistic so they were unable to deal with risk properly or complex and over complicated so they required an expert to operate them. As a result, practical minded people “are reluctant to use too simplistic tools…and managers are equally reluctant to allocate scarce resources to the hiring of risk-analysis experts.” Diekmann (1992) concluded that one would like to have risk analysis procedures that “are able to model risky situations, but that hide their inherent computational complexity from the everyday
user”. It seems that situation has not improved dramatically over years. Almost the same position was taken by Han et al. (2008) who argued that one key problem with present risk quantification methods is that they are “too analytical or mathematics-oriented approaches which are not easy to adopt in real business.” Laryea and Hughes (2008) argued that the models and the tools that are proposed to deal with risk when tendering were time-consuming, too complex and insensitive to the commercial exigencies of bidding practice. They argued that the proposed tools had a common shortcoming of being “desk-based and analytically derived” lacking the information which is commonly used in practice. They called on appreciating what contractors actually do when tendering.

Byrne (2005) gave an explanation of the low take up of the DSSs. He referred to the inability of these tools of including and measuring the intangible factors that are believed to generate a lot of benefits. A similar argument was made by McCowan and Muhamed (2002) who argued that qualitative and non-monetary risks used to be neglected when providing a risk assessment. They urged for considering the effect of these risks when estimating contingencies by providing an appropriate quantification of their effects.

To conclude, the aforementioned limitations can explain, to a large extent, the limited adoption of RM tools by practitioners and the heavy reliance on their judgment and practical experience. They should direct the efforts towards producing more practical and usable DSSs. In fact, there are calls in literature towards more innovative, applicable and acceptable approaches and DSSs to handle construction risk assessment (Baloi and Price 2003; Ward and Chapman 2003). I think that, besides the reliability of the tool and the accuracy of its results, practicality and the inclusion of the end users’ perspective and practical experience on how things are done, should be a main feature of any DSS. This attitude comes in alignment with the conclusion of Chapman and Ward (2000) that a “simple, timely, transparent models are often of more value in practice than sophisticated “accurate” methods”.

4.6 Discussion

The limitations of the existing tools flag up the need for a better alternative. This research aims to develop a DSS for aiding construction professionals in assessing project risk and decision making during the pre-tendering stage of the PLC. Although
the potential users of such a DSS are the construction clients or contractors, this research project, due to time and resource constraints, considers the contractor’s perspective only for data collection. Moreover, the key objective of building the DSS is supporting risk assessment and project evaluation although it can be used for aiding other decisions such as procurement route selection. In order to enhance the usability of the DSS, the experience and the professional judgment of the users should be utilised when devising it. I think that a “belief-based” DSS can provide a viable alternative. Dempster Shafer Theory of Evidence (DST) would offer a great potential in serving as a theoretical basis for the aimed DSS. It has an advantage over PT and FST because of its ability to represent ignorance, which is a typical problem in construction risk assessment and decision making. Moreover, it is more appropriate for domains with hierarchical structures (Liu et al. 2002) which is exactly the case of risk assessment. Furthermore, adopting DST would avoid all the limitations of AHP that were illustrated previously. The revised Dempster’s rule of evidence combination (Yang 2001; Yang and Xu 2002) will be a novel alternative to the averaging approach for aggregating risk assessments and generating project risk level. Notably, DST has never been used to assess construction project risk level (Taroun et al. 2011). Indeed, researching the potential applications of DST in risk analysis and decision making in construction industry may be an original contribution to knowledge. It might help raise future research questions regarding other applications in different construction management domains. For further clarification, a detailed illustration of the DST merits and limitations is to be delivered in a designated chapter later in this thesis.

4.7 Summary and Conclusions

In this chapter, the limitations of the theories and tools that are very often used for risk analysis were reviewed. Obviously, there is no perfect theory or tool. However, the suitability, usability and fit for purpose of the tool should always be given a high priority when devising it. Reviewing the limitations of the theories and techniques used for analysing construction risk is very useful for investigating the potential causes of heavy reliance on experience and personal judgment. It is also useful for researching better alternatives for aiding risk assessment and decision making. It can be concluded that the special nature of construction projects, the subjectivity associated with construction risk and the reliance on personal experience and judgment could be better handled by deploying DST.
The next chapter is concerned with project evaluation and selection. It reviews the theory behind it and the tools and techniques that are used for such a purpose. The coming chapter is logically linked to the current one as risk assessment is the first step towards evaluating different projects or proposals before making any strategic decision in the design of the tendering stage.
Chapter 5: Project Appraisal, Comparison and Selection

5.1 Introduction

Project evaluation is inherently related to risk analysis as it is usually conducted in the case of uncertainty. Risk analysis, in turn, is conducted as a step towards project evaluation and comparison. Project evaluation is crucial for choosing the right construction project to construct or bid for. From a contractor perspective, deciding on which project to bid for is a conventional decision making problem. A lot of research has been done in an attempt to identify the key factors affecting this decision problem (Egemen and Mohamed 2007; Lin and Chen 2004; Lowe et al. 2004; Lowe and Parvar 2004; Wanous et al. 2000; Wanous et al. 2003; Moselhi and Hegazy 1993; Shash 1993; Ahmad 1990; Ahmad and Minkarah 1988). The scope of this research goes beyond the bid/no-bid decision making problem towards providing a DSS for aiding construction risk and benefit assessment before tendering and comparing between different projects or proposals before making any strategic decision at this stage of the PLC. This chapter presents the techniques that can be used for project appraisal, ranking and selection. It illustrates the theory of MCDM and the available tools as a theoretical basis for project evaluation and selection problem. It concludes that construction project evaluation and selection can be handled effectively by adopting an evidential reasoning framework capable of facilitating the practical experience and personal judgment of the decision makers.

5.2 Definitions

Project appraisal\(^8\) is a “process of exploration, review and evaluation taken on by the decision maker as the alternative options for development are defined within the project planning process” (Rogers 2001, p.1). It is mainly a comparison of different options on the basis of an agreed criterion or a set of criteria in the early stages of the PLC. The purpose of this task is to assess the merits of each alternative against a set of criteria that can be economic, technical, social or environmental (or any combination of them) depending on the nature of the evaluation (Rogers 2001).

\(^8\) In this research, the term “project appraisal” is interchangeable with “project evaluation”.

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Project appraisal could be looked at as part of a wider process of selecting a portfolio of projects or programs which satisfy specific criteria and deliver strategic objectives to an organisation. However, it is worth differentiating it from the conventional concept of portfolio management which has its origins in (Markowitz 1952).

Portfolio management theory is widely used in finance for building the optimum investment portfolio(s) that meet all logical and physical constraints and managing them in order to maximise return and minimise risk. In the project management context, portfolio management is defined as "the selection and management of all of an organisation’s projects, programs and related business-as-usual activities taking into account resource constraints" (APM 2006, p.6). According to APM (2006), portfolio management, within the project management context, involves project screening, project prioritising and selecting, continuous monitoring and control and, finally, adjustment according to the constraints, risks or expected return. This sequence of activities means that project evaluation and prioritisation is the second step of a portfolio management scheme. Such a scheme is performed as periodic and repetitive activity administered usually by management committee at regular intervals (Ghasemzadeh and Archer 2000; Archer and Ghasemzadeh 1999; Linton et al. 2002). The idea is to keep searching for opportunities and altering the existing project portfolio in order to maximise the benefits for the organisation.

5.3 Project evaluation and selection

Organisations usually have limited resources due to physical and financial constraints. As a result, choices must be made in order to optimise resource allocation and compose the most beneficial project portfolio. According to Ghasemzadeh and Archer (2000) selecting a portfolio of projects should always "meet an organization’s stated objectives without exceeding available resources or violating other constraints". However, the problem of project selection is inherently multi-objective since various factors, such as the available budget, the chance of success, and the efficient allocation of project teams must be considered simultaneously (Gabriel et al. 2006). It is a multi-criteria optimisation problem where reasonable trade-off between risk and return must be considered (Dong et al. 2004). However, the selection process and any compromise or trade-off must comply with the business strategic planning process (Liberatore 1988). Archer and Ghasemzadeh (1999) argued that risk analysis is crucial
for project evaluation in order to have a balanced portfolio by avoiding an over-commitment to high risk projects that may “jeopardize the future of the organization.”

Therefore, project evaluation has a profound impact on project selection or any later decision or action. It should follow a clear methodology and use appropriate tools for assessing the performance of each project against the criteria that are deemed to be the most influential factors on the selection decision; it is a typical MCDM problem under uncertainty and usually takes place at the early stages of the PLC with relatively little amount of precise information available.

**5.4 Multi-Criteria Decision Making**

Decision making is an inevitable task throughout the PLC. The type and the criticality of the decisions differ according to the stage of the PLC and the managerial position of the decision maker. Usually, decision making is an intuitive and easy task when considering decision problems with a single criterion. However, it becomes very complicated and requires sophisticated methods when evaluating different alternatives or actions with multiple criteria (Tzeng and Huang 2011). Under these circumstances, decision maker aims to reach the most successful decision by balancing the conflicting objectives or criteria (Belton and Stewart 2002). The term MCDM is used as an “*umbrella term that describes a collection of formal approaches which seek to take formal account of multiple criteria in helping individuals or groups explore decisions that matter*” (Belton and Stewart 2002, p.2). According to (Hwang and Yoon 1981; Zimmermann 2001), MCDM problems can be classified, based on the different purposes and different data types, into two main categories:

1. Multiple attribute decision making (MADM) problems: evaluation of a definite set of alternatives according to a predefined set of evaluation attributes.
2. Multiple objective decision making (MODM) problems: achievement of the optimal or aspired goals by considering the various interactions within the given constraints (Tzeng and Huang 2011).

Usually, MCDM problems are complex and ill-structured. Whatever the nature of the MCDM problem is, decision making processes involve the following main steps: problem identification, preference construction, alternative evaluation, and alternative ranking (Simon 1977; Keeney and Raiffa 1993). Belton and Stewart (2002) saw the
MCDM process as an integrated part of a wider perspective of problem structuring and resolution. According to them, MCDM process is composed of three main steps:

1. Problem structuring: understanding the problem, the surrounding environment, the key stakeholders, values, goals, etc.
2. Model Building: defining preference measurement scales, defining evaluation criteria and specifying decision alternatives.
3. Model using: challenging the original intuition and thinking by conducting sensitivity analysis and testing the process outcomes.

These three steps, which are linked to each other by feedback loops, end up with final action plan.

Under this umbrella of MCDM process, the main quantified and formal procedures are:
1. identification of evaluation criteria, 2. evaluation of decision alternatives according to every criterion, and 3. establishing the overall preference for every alternative by aggregating the evaluations across the criteria (Stewart 2003).

### 5.4.1 MCDM problem features

The most commonly used method for representing a MCDM problem is the decision matrix. The rows of the matrix stand for decision alternatives and the columns for the criteria. The decision matrix cells are filled with the decision maker’s assessment of the performance of every alternative against decision criteria. Xu and Yang (2001) listed the common features of any MCDM problem:

1. Decision criteria are usually organised in a hierarchical structure with more detailed sub-criteria are listed under the top major criteria;
2. There is very often a conflict between the different criteria which makes satisfying all of them without any compromise almost impossible;
3. The criteria are hydride in terms of: their different measurement scale, quantitative vs. qualitative or deterministic vs. probabilistic nature.
4. There is always uncertainty associated with MCDM problem due to the subjective judgment of the decision maker or the lack of enough information to support his or her evaluation.

These features characterise the difficulty associated with making decisions with multiple criteria. From this premise, one can appreciate that the outcome of a MCDM
problem cannot fully satisfy all stakeholders. A compromise between attributes is almost inevitable and the decision maker may always aim to achieve a balanced and fair compromise. This leads to the different types of solutions or outcomes of a MCDM problem listed by (Hwang and Yoon 1981):

- an ideal solution: a solution that satisfy all the criteria
- a non dominant solution: a solution in which one criterion at least is better satisfied by other solution
- a satisfying solution: a solution that satisfies a specified minimum requirements on all its attributes, and
- a preferred solution: the one that meets all the expectations of the decision maker.

5.4.2 MCDM Approaches

Stewart (2003) classified the MCDM approaches under three main categories:

1. Value measurement approaches: the preference of the decision maker is measured by means of values or scores for every alternative according to the evaluation criteria. The values are aggregated, usually by appreciating the different weights of the criteria, in order to generate an alternative overall preference. Such an aggregation assumes the compensation principle between the criteria and reflects tradeoffs between them according to their relative importance. Multiple attribute utility theory (MAUT), multiple attribute value theory (MAVT), AHP and the Evidential Reasoning (ER) approach are among the most popular tools in this approach.

2. Goal and reference point approaches: the decision maker sets clear goals and aspirations for the evaluation criteria as a desirable benchmark and evaluates the alternatives according to their closeness to this ideal alternative. Obviously, the best available alternative is the closest one to the ideal alternative. Goal programming and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method belong to this category.

3. Outranking approaches: they are mainly popular in continental Europe (Stewart 1992). They try to avoid the compensation principle which is assumed in the previous two approaches. Alternatives are compared according to every criterion in order to gather evidence to support or oppose assertions like "alternative 1 is at least as good as alternative 2". ELECTRE and PROMETHEE are the most famous tools in this approach.
Obviously, there are other tools and techniques for multi-criteria decision making. However, the compensation principle is believed to be a defining principle for classifying the different tools and techniques. For instance, Hwang and Yoon (1981) classified the available tools under two main categories; Compensatory and non-compensatory tools. Compensatory methods allow tradeoffs between attributes; a slight decline in one attribute can be compensated by some enhancement in one or more other attributes. It is entirely opposite to the non-compensatory tools where comparisons are made on an attribute-by-attribute basis (Xu and Yang 2001).

### 5.5 Project evaluation tools

A wide range of decision making tools has been used for supporting project evaluation and prioritisation. Although construction projects were considered, the main focus was on comparing different R&D or information systems (IS) projects. AHP was a major decision making tool for comparing and prioritising different options (Liberatore 1986; Liberatore 1988; Muralidhar et al. 1990; Mohanty 1992; Mahdi and Alreshaid 2005; Dey 2006). Analytical Network Process (ANP) was also adopted for such purposes. It was used by Meade and Presley (2002) for comparing R&D projects and Lee and Kim (2001) integrated it with Delphi method and 0-1 Goal Programming in order to support IS project selection. FST was used by Carlsson (2007) together with integer programming for R&D portfolio selection in a corporate environment. It was also integrated with AHP by Huang et al. (2008) for evaluating R&D projects.

Other MCDM tools and techniques were used for project evaluation; Stewart (1991) adopted the reference point MCDM approach and built a DSS to aid selecting the most favourable R&D projects for a large electricity and utility company, Moselhi and Deb (1993) used the multiple attribute utility theory (MAUT) to compare between different construction projects. In some cases, MCDM tools were integrated with optimisation tools for evaluating alternative projects. Mavrotas et al. (2003) combined the outranking tool ELECTRE-TRI with integer programming (IP) for selecting electricity project in Greece. Mavrotas et al. (2006) integrated the outranking tool PROMETHEE-V with integer programming for ranking projects applying for financial support and public fund. Santhanam and Kyparisis (1996) used the nonlinear 0-1 programming technique in order to aid evaluating and selecting information systems projects, whereas Eilat et al. (2008) integrated data envelopment analysis (DEA) with balanced score cards technique for comparing between R&D projects. As Chu et al. (1996) built a DSS
based on time-cost trade-off analysis and dynamic programming for evaluating different R&D projects, Ye and Tiong (2000) proposed a new method, net present value at risk (NPV-at-risk), for evaluating infrastructure projects and comparing between them as different investment opportunities.

5.5.1 Discussion

Researchers have investigated very different decision making tools and tried to integrate them together in order to overcome their limitations. In general, these tools can be classified under two categories; optimisation tools like: Linear/Nonlinear Programming, Integer programming and Dynamic Programming, and analytical tools like: AHP, ANP and FST. Each of these tools, however, has limitation which may affect its applicability or usability in specific application domains. Hess (1993) argued that management science tools failed to effectively aid in project selection problems. He explained by saying that “we have proposed more and more sophistication with less and less practical impact”. Mathieu and Gibson (1993) argued that optimisation techniques have largely failed to gain user acceptance. One of the main reasons for the failure of optimisation techniques to attract users is that “they prescribe solutions to portfolio selection problems without allowing for the judgment, experience and insight of the decision maker” (Mathieu and Gibson 1993). Mavrotas et al. (2008) mentioned another limitation in the optimisation methods. They argued that projects are compared and selected to form the optimum portfolio without special consideration of the project's individual ranking. Hence, they recommended an approach for project selection where a final selection is guided by: satisfaction of certain segmentation, policy and/or logical constraints, and assurance that the individual evaluation of the projects is respected to the maximum degree. They supported their approach by insisting that in decision making situations, “we do not seek for the best combination of proposals… but we try to select the best projects that comply with the segmentation constraints”.

The above limitations of the optimisation techniques, together with the limitations of the analytical tools which were illustrated in the previous chapter, lead to the following conclusions:

1. In order to be widely used by practitioners, project evaluation support tools must incorporate and use the practical experience and personal judgment of the decision makers
2. The tool should allow potential users to structure the evaluation process in a transparent way, so every project or alternative is fully analysed and investigated individually against a pre-defined benchmark set of attributes.

3. The tool should give decision makers full control on the evaluation process.

4. Simplicity of analysis and ease of use is a key feature; the decision support tool should always strike the right balance between accuracy and practicality.

Pongpeng and Liston (2003) recommended that a MCDM approach should always have the capability of incorporating subjective inputs of multiple decision-makers, including elements of risk and uncertainty and adapting to changes of subjective inputs via computer interaction. These three elements are considered as essentials for a state-of-the-art MCDM tool. They emphasise the importance of the personal judgments and the practical experience of the decision makers. They also appreciate that in most cases MCDM is a group decision making problem which implies a longitudinal process of thinking of the problem and deciding on the right inputs. Appreciating the integrated risk in decision making is, in fact, essential in order to reach a more informative decision. The MCDM tool should have an interactive platform that allows decision makers to express their personal judgment and reflect the surrounding environment and its influencing factors on the final decision. These features, together with the previous conclusions, would provide an effective recipe for enhancing the applicability and the acceptance of a desired DSS for aiding project evaluation.

5.6 Construction project evaluation

Construction project evaluation has a theoretical foundation in project portfolio management theory. However, the question is whether this theory is fully applied in the construction sector. Reviewing literature reveals the dearth of portfolio management publication in construction. One could argue that the concept and procedures of portfolio management might not be applicable straightaway in this domain. For instance, as mentioned earlier, portfolio management process includes screening, project prioritising and selecting, continuous monitoring and adjustment. The final activity, adjustment, could hardly be applied in the construction industry. Construction projects could be screened, evaluated and selected before tendering. However, it is very difficult to adjust an ongoing portfolio of projects by dismissing or cancelling the unsatisfying ones after signing a contract. Portfolio management is a very powerful tool in dynamic industries where R&D project selection is extensively conducted in order to
decide whether to go ahead with the new products or simply terminate the project. Such a turnaround is very difficult and costly in construction. Huge financial commitment is incurred to any of the contract parties who decide not to continue with a project. This may be a key reason for not adopting the formal structure of portfolio management widely in construction. However, for the same reason, project evaluation is critical.

In the construction sector, project selection task is conducted by contractors before making the bid/no-bid decision and by clients for evaluating different project proposals. For instance, contractors may screen a list of potential projects by assessing the attractiveness level of each of them. Level of attractiveness can be determined by estimating potential profitability and strategic importance of the project for the company (Dikmen et al. 2007b). According to Rogers (2001) the tools that are used for evaluating engineering projects can be classified under two main categories: engineering economics-based methods and multi-criteria methods based on the “compromise” principle. The financial attributes or the economic qualities of construction projects used to be, in many cases, the main evaluation criterion. In fact, the conventional way of evaluating construction projects used to be based on economic measures like the profitability, the net present value (NPV) of the project and the payback period with less focus on the non monetary attributes (Tavares 2002). However, this approach is not ideal for dealing with the evaluation problem and cannot give realistic results. A number of non-financial criteria such as project risk level and intangible benefits are usually neglected in the conventional economic-based evaluation approaches.

One may argue that dealing with construction project evaluation as a MCDM problem is more appropriate and realistic approach. Such an approach is very convenient especially in the case of analysing strategic projects where different stakeholders have different interests and objectives and a large number of criteria, besides the economic measures, must be considered. A MCDM approach for construction project evaluation can provide an ideal option for comprehending the evaluation problem especially in complicated situations and strategic projects.

5.7 DSS for risk assessment and project evaluation:

As mentioned earlier, risk assessment is the most complex but useful part of the RM
process. Moreover, evaluating construction projects or alternative proposals before tendering is crucial for making any strategic decision. These two tasks are interrelated to each other as such strategic decisions are usually made in the case of uncertainty. In fact, project evaluation criteria can be classed under two main categories: project risks and benefits. For this reason, assessing project risks can be done as an integrated part of the project evaluation process. A simultaneous assessment of project risks and benefits is necessary. Risk and opportunity are believed to be two sides of the same coin (Loosemore and Raftery 2006), consequently, assessing one of them will not generate a representative result without considering the assessment of the other.

Although there are calls in literature to include opportunity assessment in the formal risk management process (Hillson 2002), to the researcher’s knowledge, no research has been done to integrate the assessment of both project risks and benefits systematically and to use them for comparing between different projects. It seems that project risk has a “relative nature”; it is a project criterion that cannot be assessed without considering the coexisting project benefits. Subsequently, assessing project risk and evaluating projects accordingly is meaningless without associating such analysis with assessing the project benefits. When comparing between two projects, one can never decide which project is riskier than the other without considering the amount of co-existing benefits of each of them that may compensate taking risk. When appreciating this principle, decision maker can be more realistic in their judgement and the decision making process will be more reliable, transparent and comprehensive.

Such an evaluation process is of great importance not only for composing a project portfolio but also for choosing the most suitable project proposal or procurement method. The construction industry has witnessed significant changes in procurement methods (Baloi and Price 2003) with risk sharing philosophy between the contracting parties is being a key element of differentiation among them. The traditional procurement system is still the most popular one, however, other procurement systems such as: “Design & Build”, “Public-Private Partnership” and “Partnering” are increasingly becoming popular. Although selecting a procurement method is a habitual action (Lædre et al. 2006), choosing the most suitable procurement approach is essential for better risk sharing and RM. Kumaraswamy and Dissanayaka (2001) claimed that the decisions to choose procurement approaches are very often subjective. For instance,

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9 In RM literature, the terms “Threat” and “Opportunity” are usually used to describe the up and down sides of a risk. They are suitable terms to describe the “gambling” nature of taking risk. In this research the terms “Risks” and “Benefits” are used to describe the different types of project attributes.
the final procurement decisions may be triggered by the most recent problems or apparent successes experienced by a decision maker. On this note, structuring the experience of decision makers in a DSS that considers the different project attributes would have a positive impact on choosing the most suitable procurement route. Such a DSS would respond to the calls for innovation in selecting the suitable procurement routes made by Lædre et al. (2006).

This research presents a belief-based MCDM approach for supporting construction project risk and benefit assessments and project evaluation. The focus is on providing a methodology for structuring the practical experience and the professional judgment of the decision makers through an interactive DSS. The proposed DSS is intended to respond to the criticisms of the existing DSSs and tools by devising a simple and user-friendly tool that allows the potential users to reflect their experience when providing inputs in order to enhance its usability and acceptance.

5.8 Summary

In this chapter, the theory of project portfolio management and the tools and techniques that are used for project evaluation were reviewed. As the evaluation process is believed to be a typical MCDM problem, the theory of MCDM and the features of a MCDM problem were covered. It is proposed that construction project evaluation can be conducted as a typical MCDM problem with decision criteria classed under two main categories: risks and benefits. This chapter ended with a conclusion that a DSS is needed to facilitate risk and benefit assessments and project evaluation. Similar to the previous chapter, a conclusion was drawn that a belief-based MCDM approach will be an effective framework for supporting risk assessment and project evaluation.

Next chapter covers the DST and the evidence-based reasoning for decision making. It investigates the merits and shortcomings of the DST and examines its suitability for serving as a theoretical basis of a decision making framework for risk assessment and project evaluation in construction. Researching the potential of DST for risk assessment and decision making in construction could be a genuine contribution to knowledge due to the scarce application of this theory in this area.
Chapter 6: Dempster-Shafer Theory of Evidence and the Evidential Reasoning Approach

6.1 Introduction

In this chapter, Dempster-Shafer Theory of Evidence (DST) is presented with its merits and limitations. The Evidential reasoning approach (ER) for multi-criteria decision making is also exhibited. The potential usage of DST as an alternative framework and the evidential reasoning approach for handling subjectivity in construction risk assessment is investigated. The suitability of DST and ER for structuring the practical experience of construction professionals and their ability of representing ignorance are demonstrated.

6.2 Dempster-Shafer Theory of Evidence (DST)

6.2.1 Basic ideas

DST was formally established by Shafer (1976) as a mathematical tool for reasoning with incomplete and uncertain information. It has its roots in the work of his teacher Dempster (1967) on the theory of probabilities with upper and lower boundaries (Beynon et al. 2000). The idea of upper and lower probability boundaries is used to model uncertainty by means of a range with upper and lower probabilities instead of using a single probability value (Liu et al. 2002). Instead of specifying a probability value, DST allows one to put constraints and boundaries of the probability value by using belief functions (Yager et al. 1994).

As mentioned in a previous chapter, Dempster proposed his new way of dealing with uncertainty because of the following two shortcomings in probability theory: the difficulty of representing ignorance, and the requirement of subjective belief in an event and its negation to sum to one (Liu et al. 2002). As a result, DST is a generalisation of Bayesian theory of subjective probability (Shafer 1990; Shafer 1992) with a remarkable ability to represent ignorance, lack of information, and differentiating it from uncertainty by means of belief functions (Beynon et al. 2000). Belief functions can be looked at as generalisation of probability functions with less rigid axioms. This gives DST more flexibility to deal with cases that are outside the conventional territories of probability.
theory. Probability functions are a subclass of belief functions, and “the theory of evidence reduces to probability theory when the probability values are known” (Liu et al. 2002).

DST is based on two main pillars: the idea of obtaining degrees of belief in one hypothesis from subjective probabilities for related hypotheses, and Dempster’s rule of evidence combination that is used for aggregating the degrees of belief of independent pieces of evidence (Shafer 1990; Shafer 1992). These two pillars were explained by Shafer (1992) by the following example:

Suppose that a friend of mine tells me that a limb fell on my car. The subjective probability that my friend is a reliable person is 0.9, and the subjective probability that she is unreliable is 0.1. Her testimony can be looked at as: 0.9 degree of belief that a limb fell on my car and a degree of belief of zero that no limb fell on my car. The zero degree of belief that no limb fell on my car, and not 0.1, comes from the fact that the testimony of my friend gives me no reason to believe that no limb fell on my car. As a result, the subjective probability about my friend’s reliability is used to construct a belief function, composed of the 0.9 and the zero degrees of belief, in the hypothesis that a limb fell on my car. The other pillar in DST, the evidence combination rule, is illustrated by assuming that another friend tells me independently from the previous friend that a limb fell on my car. The degree of belief in the new testimony is also generated from my subjective probability of the reliability of my friend. Dempster’s rule of evidence combination is used to aggregate the testimonies of both of my friends and give the overall degrees of belief in the hypothesis of a limb falling on my car. The independence between the different sources of evidence, in this case my two friends, is one of the assumptions which should be assumed when applying Dempster’s rule of evidence combination.

The witnesses’ testimonies and the attempt to aggregate these testimonies in order to create an overall judgment about the case is very successful analogy of the evidence-based reasoning which is the cornerstone of the DST. Beynon et al. (2000) provided a very good example to illustrate DST. In this example, one of three suspicious people is expected to be a murderer; Peter, Paul and Mary. These three compose a set of hypotheses or “frame of discernment”, {Peter, Paul, Mary}. If the only available evidence is a witness who is 80% sure that the killer is man i.e., P(man)=0.8. This measure of uncertainty is known in DST terminology as a “basic probability assignment” (bpa). Hence we have a (bpa), say \( m_1 \), of 0.8 given to the focal element.
{Peter, Paul} i.e., \( m_1(\{\text{Peter, Paul}\}) = 0.8 \). Since we know nothing about the remaining probability, it is allocated to the whole of the frame of the discernment i.e., \( m_1(\{\text{Peter, Paul, Mary}\}) = 0.2 \). These basic probability assignments are used to generate our belief in the case under analysis. They can also be aggregated with other probability assignments.

If another witness testifies that he is 60% confident that Peter was not in the country when the killing happened, this would be understood as another basic probability assignment, say \( m_2 \), of 0.6 must be given to the focal element \{Paul, Mary\}. Again, since we know no more information about the remaining probability 0.4, it is given to the whole frame of discernment i.e., \( m_2(\{\text{Paul, Peter, Mary}\}) = 0.4 \).

After assigning subjective probabilities, in terms of testimonies, to the two propositions, Dempster’s rule of evidence combination can be used to combine these independent sources of evidence. The combination is simply a multiplication rule. Hence, the combination of two basic probabilities \( m_1 \) and \( m_2 \) assigned to the two propositions is a new probability \( m_{12} \) assigned to the intersection of the two propositions. Table (6-1) illustrates the combination process:

<table>
<thead>
<tr>
<th>1st piece of evidence</th>
<th>2nd piece of evidence</th>
<th>( m_1({\text{Peter, Paul}}) = 0.8 )</th>
<th>( m_1({\text{Peter, Paul, Mary}}) = 0.2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m_2({\text{Peter, Mary}}) = 0.6 )</td>
<td>( m_2({\text{Peter, Mary}}) = 0.6 )</td>
<td>( m_{12}({\text{Peter}}) = 0.48 )</td>
<td>( m_{12}({\text{Peter}}) = 0.12 )</td>
</tr>
<tr>
<td>( m_2({\text{Peter, Paul, Mary}}) = 0.4 )</td>
<td>( m_2({\text{Peter, Paul, Mary}}) = 0.4 )</td>
<td>( m_{12}({\text{Peter, Paul}}) = 0.32 )</td>
<td>( m_{12}({\text{Peter, Paul, Mary}}) = 0.08 )</td>
</tr>
</tbody>
</table>

Table 6-1: the multiplication rule of two pieces of evidence

It is clear from the above table that DST follows the principles of sets theory by representing the combination of two pieces evidence as sets intersection. DST, essentially, assigns subjective probability to the combination of evidence, the intersection of sets, by multiplying the probabilities of the original sets.

The next step is generating the level of belief in any set of propositions by summing up all the probabilities of its subsets (Beynon et al. 2000). For instance, the level of belief \( (Bel) \) in the proposition that the killer is Peter or Mary in the previous example is:
Bel({Peter, Mary}) = m_{12}(\{Peter\}) + m_{12}(\{Mary\}) + m_{12}(\{Peter, Mary\})

= 0.48 + 0 + 0.12 = 0.6

and the level of belief that the killer is Peter Bel(\{Peter\}) equals 0.48 as in this case: Bel(\{Peter\}) = m_{12}(\{Peter\}).

DST has received considerable attention by many researchers who investigated its potential application in artificial intelligence, image and pattern recognition, assessment, and decision making (Hua et al. 2008; Beynon 2005; Buechner et al. 1997; Luo and Caselton 1997; Hilhorst et al. 2008; Bloch 1996; Kawade 1995; Vasseur et al. 1999; Xu et al. 1992; Engemann et al. 1996). However, it is still not very popular like the PT for instance; it has great potential which is still to be exploited (Beynon et al. 2000). DST has a great potential in construction risk assessment and decision making. But first of all, it is better to provide clear definitions to the terminologies and concepts that are used in the DST literature in order to explain the theory of evidence accurately.

6.2.2 Definitions

According to Bloch (1996), DST is able to handle imprecision and uncertainty by means of two functions; “belief” (Bel) and “plausibility” (Pla) which are both derived from the “mass function” (m). Mass function is a probability function defined on the power set of the “frame of discernment”.

6.2.2.1 Frame of discernment (f)

It is a set of all possible answers to the question under analysis. For instance, in the previous example of finding the murderer, the frame of discernment is a set composed of the three suspicious people; Paul, Peter and Mary. The frame of discernment is usually denoted as Θ. A set is called a “frame of discernment” if it contains mutually exclusive and exhaustive possible answers to a question (Liu et al. 2002). Hence, the set of answers to any decision making problem are required to be collectively exclusive and exhaustive in order to use the DST.

6.2.2.2 Mass function (m)

Mass function is a probability function defined on the power set\(^\text{10}\) of the frame of

\(^\text{10}\)The power set is the set of all subsets of Θ. It is usually denoted by \(2^\Theta\)
discernment. It is usually represented by \( m: 2^\Theta \rightarrow [0, 1] \). A mass function on the frame of discernment \( \Theta \) should satisfy the following conditions:

1) \( m(\emptyset) = 0 \); and
2) \( \sum m(A) = 1 \) where \( \emptyset \) is an empty set and \( A \) is a subset of \( \Theta \).

These two conditions are understood as all the assigned probabilities must sum to unity and there is no belief in the empty set (Liu et al. 2002). The probabilities assigned to any set according to this mass function are called basic probability assignments (bpa). The basic probability assignment \( m(A) \) measures the belief which is assigned completely and directly to the set \( A \). For instance, it is the testimony of the witness in the previous example that the killer is believed to be a male with 80% confidence \( m_1(\{\text{Peter, Paul}\}) = 0.8 \). The set \( \{\text{Peter, Paul}\} \), for which a basic probability of 0.8 is assigned, is called a focal element. This basic probability \( m_1(\{\text{Peter, Paul}\}) \) with its value of 0.8 stands for the confidence of the witness that the truth, the killer, exists in this set \( \{\text{Peter, Paul}\} \).

A basic probability can be assigned to the whole frame of discernment. It is usually denoted by \( m(\Theta) \) and it represents the amount of belief which remains unassigned to any set of the power set of the frame of discernment; it is also called “global ignorance” (Beynon et al. 2000). Hence, if an amount of belief \( x \) is assigned to a proposition, the remaining belief \( 1-x \) does not need to go to the negation of the proposition. The beauty of DST is that it allows the analyst to assign the remaining belief to the whole frame of discernment as there is no reason to believe that it must go to the negation.

Another important feature of DST is its flexibility which does not ask the analyst to assign his or her total belief in any situation unless he or she has got enough information for such an assignment. Based on the situation and the available amount of information, the right amount of belief can be assigned as basic probabilities that may or may not sum up to unity. This property of DST is very useful as it allows the analyst to account for “ignorance” by providing incomplete assessment to any proposition or situation.

6.2.2.3 Belief function (\( Bel \))

It is important to differentiate between the basic probability assigned to a proposition
and the belief in this proposition. Belief function is a probability function defined on the power set of the frame of discernment. It is usually denoted by $Bel: 2^\mathcal{F} \rightarrow [0, 1]$ and used as a measure of the confidence that the true answer lies in the set $A$. A belief in a set $A$ represents the exact support to the proposition which is represented by the set $A$ (Wang and Elhag 2007); it is calculated by summing the basic probabilities assigned to all propositions that are fully included in the set $A$ (Khatibi and Montazer 2010). By coming back to the previous example, the overall belief of the judge that the killer is a male is $Bel(\{Paul, Peter\})$. It is calculated as follows:

$$Bel(\{Paul, Peter\}) = m_{12}(\{Paul\} + m_{12}(\{Peter\}) + m_{12}(\{Paul, Peter\})$$

$$\implies Bel(\{Paul, Peter\}) = 0.48 + 0 + 0.32 = 0.8$$

The belief function is usually given by the following formula:

$$Bel(A) = \sum_{B_i \subseteq A} m(B_i)$$

Where, all of $A$ and $B_i$ are subsets of the frame of discernment ($\mathcal{F}$). The following figure represents the belief in proposition $A$.

According to figure (6-1) and the previous $Bel$ formula,

$$Bel(A) = m(A) + m(B3) + m(B5)$$
The difference between a basic probability assignment \( m(A) \) and the belief \( Bel(A) \) is that \( m(A) \) is the belief in the proposition \( A \) as a set excluding any of its subsets while \( Bel(A) \) is the degree of belief in \( A \) as well as all of its subsets (Liu et al. 2002). As a result, the belief in the frame of discernment is always 1 and the belief in the empty set is always 0.

6.2.2.4 Plausibility function (\( Pla \))

The plausibility function represents the extent to which a proposition cannot be rejected. \( Pla \) is the total amount of belief which could be potentially placed in the proposition (Wang and Elhag 2007); it is the extent to which one fails to disbelieve a proposition (Beynon et al. 2000). Plausibility in a proposition \( A \) is usually defined by the following formula:

\[
Pla(A) = \sum_{A \cap Bi \neq \emptyset} m(Bi)
\]

Plausibility of a proposition \( A \) is calculated by adding the basic probabilities assigned to all propositions whose intersection with the proposition \( A \) is not an empty set. From the previous figure:

\[
Pla(A) = m(A) + m(B3) + m(B4) + m(B5) + m(B6) + m(B7)
\]

\( Pla(A) \) and \( Bel(A) \) are linked functions; \( Pls(A) = 1 - Bel(\neg A) \) where, \( (\neg A) \) refers to the complement of \( A \) "not \( A \)" and \( Bel(\neg A) \) is often called the doubt in \( A \) (Liu et al. 2002).

There are other two relations between \( Pla(A) \) and \( Bel(A) \) that can be derived:

\[
Bel(A) + Bel(\neg A) \leq 1
\]

\[
Pla(A) + Pla(\neg A) \geq 1
\]

These two inequalities represent a remarkable difference between DST and the PT with its probability function. Actually, both of \( Pla(A) \) and \( Bel(A) \) defines an interval within which the actual probability of the proposition \( A \) may lay. Luo and Caselton (1997) understood \( Bel(A) \) as the minimum probability that can be assigned to the idea that the truth lies in the set \( A \), whereas \( Pla(A) \) is the maximum probability that the truth lies in the set \( A \). Yager (1987) interpreted the meanings of belief and plausibility very
simply; they are the lower and the upper boundaries of the conventional probability \( p(A) \). Hence, \( Bel(A) \leq p(A) \leq Pla(A) \).

DST provides analysts with an effective way of representing ignorance as it allows them to assign probability to the frame of discernment that includes all the possible propositions. In a situation where there is no information available, decision maker can assign a probability value of 1 to the whole frame of discernment (Luo and Caselton 1997). Actually, the degree of ignorance can be measured by length of the evidential interval \([Bel(A), Pla(A)]\) (Liu et al. 2002; Beynon et al. 2000). Liu et al. (2002) provided a very useful interpretation of ignorance and its practical implications by means of the evidential interval as it is shown in the table (6-2).

<table>
<thead>
<tr>
<th>Evidential interval ([Bel(A), Pla(A)])</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0, 1]</td>
<td>Total ignorance about proposition A</td>
</tr>
<tr>
<td>[0.6, 0.6]</td>
<td>A definite probability of 0.6 for proposition A</td>
</tr>
<tr>
<td>[0, 0]</td>
<td>Proposition A is false</td>
</tr>
<tr>
<td>[1, 1]</td>
<td>Proposition A is true</td>
</tr>
<tr>
<td>[0.25, 0.85]</td>
<td>Probability of A is between 0.25 and 0.85, i.e., the evidence simultaneously provides support for both A and ( \neg A ) (the complement of A)</td>
</tr>
</tbody>
</table>

Table 6-2: Interpretation of evidential intervals (Liu et al. 2002)

6.2.3 Dempster’s rule of evidence combination

6.2.3.1 Evidence aggregation

In order to make use of the available information, decision makers should aggregate them and combine all available evidence in order to support his or her decision. In the previous example, finding the killer, the testimonies of the two witnesses were combined together in order to help the judge announce his verdict. As different sources of evidence provide different assessments to the same situation, aggregating them is crucial for generating an overall assessment that takes into consideration all points of view or factors affecting the final decision. Different aggregation tools can be used for combining evidence together in a meaningful way. Averaging is definitely one of most intuitive and popular tool, yet it is not the most suitable one in all cases as it requires all pieces of evidence to be mutually exclusive. In DST, Dempster’s rule of evidence combination is used for aggregating different evidence sources.
Citing from (Dubois and Prade 1992), Sentz and Ferson (2002) mentioned that aggregation rules range between two types; conjunction rules (AND-based) and disjunction rules (OR-based). This means, in sets interpretation, that the aggregation rules range between accepting the common piece of evidence among all sources (the intersections of the sets) and accepting all the available pieces of evidence (union of the sets). Hence, in situations where there are very strict requirements about the impact and the reliability of the sources (all sources should be taken into consideration), the conjunctive AND-based aggregation rule must be adopted (A1 and A2 and A3...). However, in situation with loose conditions (at least one sources of evidence is reliable enough to make the judgment), the disjunctive OR-based rules can be used (A1 or A2 or A3...). A range of different aggregation rules of the two types can be adopted (Sentz and Ferson 2002; Dubois and Prade 1992).

6.2.3.2 The original Dempster aggregation rule
Dempster’s rule of aggregation was proposed as a conjunctive operation (or orthogonal sum operation) with great emphasis put on agreement between sources of evidence (Sentz and Ferson 2002). There is a requirement of the sources of evidence to be independent (the witnesses in finding the killer delivered independent testimonies). The independence enables Dempster’s rule to be a generalisation of the Bayes’ rule of conditional probability when the actual probabilities are known (Dempster 1967). Dempster’s rule combines multiple pieces of evidence through their basic probability assignments and generates a new basic probability assessment (Sentz and Ferson 2002; Huynh et al. 2005). Such a combination is usually represented as: \( m = m_1 \oplus m_2 \oplus m_3 \oplus \ldots \oplus m_n \). The combination process starts with combining two mass functions and the result is later combined with another mass function and so on till the whole combination process is completed. Combining two mass functions \( m_1(A_1) \) and \( m_2(A_2) \) will result in a new mass function \( m(A) \) in the following way:

\[
m(A) = \begin{cases} 
0 & \text{when } A = \emptyset \\
\sum_{A_1 \cap A_2 = A} \frac{m_1(A_1) \times m_2(A_2)}{1 - K} & \text{when } A \neq \emptyset 
\end{cases}
\]

\[
K = \sum_{A_1 \cap A_2 = \emptyset} m_1(A_1) \times m_2(A_2)
\]
The above combination rule satisfies the commutative and associative properties:
\[ m_1 \oplus m_2 = m_2 \oplus m_1, \quad m_1 \oplus (m_2 \oplus m_3) = (m_1 \oplus m_2) \oplus m_3 \]

Dempster’s rule of evidence combination follows a logical approach. That is if concordant bodies of evidence are combined using Dempster’s rule, they will reinforce each other and result in stronger support to the proposition; whereas if conflicting pieces of evidence are combined, they will erode each other and end with weaker support to the proposition (Shafer and Logan 1987; Murphy 2000). This feature of DST is one of the key reasons that makes it a novel alternative for handling the risk aggregation issue.

Unfortunately, Dempster’s rule of evidence combination has a limitation of being unable to deal with completely or highly conflicting evidence. It emphasises a total agreement between different pieces of evidence and ignores complete conflict among them (Sentz and Ferson 2002). The normalisation factor \( K \) is interpreted as a measure of conflict and contradiction between evidence sources (Murphy 2000); it is the probability mass assigned to the empty set if masses were not normalised (Beynon et al. 2000; Liu et al. 2002). In situations with complete disagreement, because of completely conflicting pieces of evidence, \( K \) equals 1 as all beliefs are allocated to the null set due to the lack of intersection between the different sources of evidence. When \( K=1 \), both the denominator and the numerator in the combination formula will equal 0 and the formula is undefined.

6.2.3.2.1 Development in Dempster’s rule of evidence combination

Dempster’s rule of evidence was criticised because of its inability of accommodating conflict in evidence. This limitation results because the proposed rule distributes the unassigned belief, due to conflict in evidence, proportionally among the elements of the frame of discernment (Sonmez et al. 2002b). Clear and illustrative examples to this problem with numerical calculations can be found in (Zadeh 1984) and (Sonmez et al. 2002b). Actually, this problem was firstly mentioned by Zadeh (1984) and later discussed by many researchers who tried to develop it in order to accommodate situations with conflict in evidence or like (Dubois and Prade 1986; Yager 1987; Inagaki 1991; Yang and Singh 1994; Zhang 1994; Murphy 2000; Smets 2000; Lefevre et al. 2002; Yang and Xu 2002; Yong et al. 2004; Huynh et al. 2005; Liu 2006; Denœux 2008). They came up with different ideas and developed a number of modified versions of
Dempster’s rule. Addressing these developments in Dempster’s combination rule is beyond the focus of this research project. However, one of these rules, the Evidential Reasoning (ER) approach which was proposed by (Yang and Singh 1994) and further developed by (Yang 2001), will be discussed.

### 6.2.4 DST advantages:

The above presentation of DST has shown that it has many features that give it a big potential in handling uncertain situations where no other theory can help. DST provides a flexible way of reasoning under uncertainty; a belief committed to a hypothesis should not necessarily decrease the belief in other ones (Shafer 1990). Moreover, there is no requirement that a belief not assigned to a given proposition must be committed to its negation (Beynon et al. 2000). Furthermore, probabilities, from which belief functions are derived, can be assigned to sets rather than always to singleton propositions (Pearl 1990). Belief itself is considered as a quantity which can be divided, moved around and re-aggregated (Buechner et al. 1997). The flexibility of DST is enhanced because belief functions satisfy weaker axioms than those of probability functions which enables DST to deal with a wider spectrum of situations with different types of uncertainty (Denœux 1999).

DST gives enough flexibility to the analyst not to commit his or her total belief to a set of propositions. It also leaves room for doubt by allowing the analyst to allocate belief to the whole frame of discernment when lack of information prevents a more accurate allocation. It is a very good tool for representing ignorance, which deemed to be a major difficulty in any decision making process. Ignorance is dealt with by not forcing the analyst to provide a complete assessment in which the basic probabilities sum to unity. DST allows the use of incomplete assessments where the sum of the assigned probability is less than 1. The suitability of DST to handling ignorance and its ability to dealing with diverse subjective assessments coming from different sources encouraged Yang and Singh (1994) to adopt it in their ER approach for multi-criteria decision making. The author believes that the above-mentioned attributes of DST are very useful in practical applications like risk assessment. As illustrated later in this thesis, DST is deployed in an innovative way for assessing construction project risk and evaluating different projects according to multiple attributes. Liu et al. (2002) summarized the key advantages of DST as follows.

1. It has a flexible way of modelling information without requiring a probability to be assigned to each element in a set.
2. Dempster’s rule of evidence combination provides a convenient and simple mechanism for combining two or more pieces of evidence.

3. It can model ignorance explicitly.

4. Belief function does not require satisfying the law of additivity as required in the case of probability functions.

6.2.5 DST disadvantages

Although it was applied in very different domains and proved to generate very good outcomes, DST has limitations, which need to be appreciated and dealt with carefully when deploying it for uncertainty modelling or decision making. According to Beynon et al. (2000) DST might not have a full mathematical justification as the PT has. The assumption of independent sources of evidence is always a matter of criticism as it is not appropriate to model the reality. Liu et al. (2002) summarised the disadvantages of DST that were documented in the published literature as:

1. the theory assumes that evidence bodies are independent; it is not always a realistic or reasonable assumption

2. the computational complexity of its rule of evidence combination

3. DST only works on exclusive and exhaustive sets of hypotheses; not all sets have these properties.

DST has another major disadvantage of being not very popular. The unpopularity of DST may cause difficulty in understanding the concept of belief function and the difference between it and the classical probability function. Unless one is specialised in uncertainty modelling, he or she may find it difficult to draw boundaries between these concepts and appreciate the real meanings of belief and plausibility. In contrast, the classical probability theory is very easy to digest as a ratio between frequency of occurrence and a total number of observations. Indeed, Baloi and Price (2003) mentioned that the main shortcoming of DST was the elicitation and interpretation of belief function.

Despite the aforementioned limitations, DST can provide a vital alternative to the PT or the FST for modelling construction project risk. It is very suitable to deal with the subjectivity issue and the problem of lack of information, which is a major problem in construction management especially at the early stages of the PLC. Dempster’s rule of
evidence combination and its modifications can provide a viable alternative to the averaging method that is widely used for aggregating project risk. The flexibility of DST, its ability to represent ignorance and the philosophy behind the rule of evidence combination are very encouraging to investigate the potential of DST in construction risk assessment domain. Next chapter presents an innovative deployment of DST for assessing construction risk and estimating project risk level. The philosophy of DST and the ER approach are used for assessing project risks and benefits within a belief-based decision making framework for the purpose of project evaluation. Before that, the ER approach is exhibited in order to further justify the choice of DST and ER as a theoretical basis for the proposed approach of risk assessment and project evaluation.

6.3 The evidential reasoning (ER) approach

6.3.1 Introduction

Evidential reasoning is a term used to denote a methodology of decision-making based on available evidences. It is defined by Lowrance et al. (2008) as a body of tools and techniques that supports automated reasoning from evidence based on DST. The ER approach is a multi-criteria decision making approach developed by (Yang and Sen 1994; Yang and Singh 1994; Yang 2001) as a reasoning tool capable of aggregating different types of assessments, quantitative and qualitative, handling various forms of uncertainty and representing ignorance and incomplete assessment. It is a unique approach to deal with MCDM problem with uncertainty as it offers a rational and reliable way of aggregating uncertain or incomplete data (Li and Liao 2007).

The ER approach is the latest development in MCDM area; it is different from traditional MCDA methods in that it uses an evidence-based process to reach a conclusion (Xu and Yang 2005). It uses belief structures to provide the assessments of the problem alternatives against the evaluation attributes in distributed forms. As a result, the assessment is not a single score; it is a distributed assessment composed of a set of degrees of belief assigned to assessment grades. Because of the distributed nature of the provided assessments, the conventional decision matrix becomes a special case of the extended decision matrix (Yang 2001). The advantages of using a distributed assessment include the ability of modelling precise data and capturing various types of uncertainties (Xu and Yang 2005). Different forms of uncertainty can
be consistently modelled in the ER framework (Guo et al. 2007). The ER approach is the only available methodology so far capable of handling MCDM problems with uncertainties and assessments of hybrid nature systematically and consistently (Yang and Xu 2002). The ER approach can aggregate assessments of hybrid nature through utility or rule-based mechanisms. These mechanisms are fully illustrated in (Yang 2001). A distributed assessment provides a flexible way of expressing ignorance as it frees the analyst from allocating his or her total belief in any proposition unless he or she has enough information to do so. Moreover, it allows room for doubt by not providing complete assessments. The ignorance, which is defined as the amount of unassigned belief, is aggregated and later used when making the final decision.

The ER approach has received considerable attention. It has been adopted by many researchers and applied in different domains. Its merits have proven to be suitable for modelling uncertainty and supporting decision making in different areas like personal assessment, quality assessment, safety assessment, risk analysis, product development, product selection, contractor pre-qualification and cost estimation (Sönmez et al. 2002a; Ruan et al. 2005; Li and Liao 2007; Xu and Yang 2003; Chin et al. 2009; Chin et al. 2008; Xu 2006; Yang et al. 2001; Khokhar et al. 2006; Ruan and Li 2007; Wang et al. 2006; Yang et al. 2011; Xie et al. 2008; Yang et al. 2009; Wang et al. 1995; Wang et al. 1996).

6.3.2 The distributed assessment and the extended decision matrix

In the ER approach, every alternative is assessed against a set of criteria by means of distributed assessments. Suppose there is a decision making problem with \( m \) alternatives, \( A_i \) \((i = 1, \ldots, m)\), to choose from and \( l \) criteria, \( C_j \) \((j = 1, \ldots, l)\), to consider. \( S(A_i(C_j)) \) represents the distributed assessment of the performance of alternative \( A_i \) against the criterion \( C_j \). \( S(A_i(C_j)) \) is a distributed assessment composed of a set of assessment grades to which degrees of belief can be assigned. For instance, the quality of a car engine can be assessed according to the distributed assessment concept in the following form: the car is “good” with confidence level of 40%, “average” with confidence level of 30% and “poor” with confidence level of 30%. Such a type of assessment is required for every cell in the decision matrix. As a result, the decision

---

11 In this research, the term “ignorance” is used to represent the case of lack of information and the inability to provide complete assessment for whatever reason. It can be due to lack of evidence, lack of enough information or difficulty in obtaining the results due to the complexity of the situation.
matrix is called an extended decision matrix. The extended decision matrix is displayed in table (6-3).

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>...</th>
<th>C{l}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>S(A1(C1))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S(Ai(Cj))</td>
</tr>
<tr>
<td>Am</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6-3: The extended decision matrix

Coming back to the example of assessing the quality of a car engine, the measures “good”, “average” and “bad” are defined as “assessment grades”. And the ratios 40%, 30% and 30% are defined as degrees of belief. The assessment of the car engine can be denoted as:

\[ S(A(C)) = \{(\text{good}, 0.4), (\text{average}, 0.3), (\text{bad}, 0.3)\} \]

The assessment grades are required to be mutually exclusive and collectively exhaustive (Yang 2001). They formulate a frame of discernment denoted as:

\[ H = \{H1, H2, \ldots, Hn\} \]

Obviously, the number of assessment grades depends upon the problem in question and the required level of detail for assessment. The general formula for assessing the performance of the alternative \( A_i \) against the criterion \( C_j \) according to a set of assessment grades \( H_n \) is:

\[
S(Cj(Ai)) = \left( Hn, \beta_{n,i}(Ai) \right), \quad n = 1, \ldots, N, \quad i = 1, \ldots, m, \quad j = 1, \ldots, l
\]

\[
\beta_{n,i}(Ai) \geq 0, \quad \sum_{n=1}^{N} \beta_{n,i}(Ai) \leq 1
\]

Where:
- \( N \): number of assessment grades
- \( m \): the number of alternatives
- \( l \): the number of evaluation criteria
- \( \beta_{n,i} \): the degrees of belief

In the above example, the sum of the degrees of belief is 100%. In this case, the analyst has got enough information to distribute all of his belief among the assessment...
grades. In the ER approach, this case is known as a “complete assessment” case. In other cases, though, the analyst may be forced to provide “incomplete assessment”. For instance, the analyst may provide the following assessment of the quality of the car engine: the engine is “good” with confidence level of 40%, “average” with confidence level of 10% and “poor” with confidence level of 20%. The sum of degrees of belief in this case is 70%, not 100%. This is actually a practical interpretation of the axiom:

\[ \sum_{n=1}^{N} \beta_{n,i}(Ai) \leq 1. \]

It is worth noting that the incomplete assessment can also result from the novelty and complexity of the problem under analysis which prevents the analyst from providing precise assessments (Yang 2001).

6.3.3 The ER algorithm for assessment aggregation

The distributed assessments are used to generate the extended decision matrix. The next step is, usually, aggregating the assessments together and generating an overall score for every alternative. The ER approach is different from the other MCDM approaches regarding assessment aggregation. It uses the ER algorithm which is a modified version of Dempster’s rule of evidence combination developed in order to account for the conflicting evidence problem. In the ER approach, evaluation criteria are structured in a hierarchy. The sub-criteria on the lowest level of the hierarchy are assessed directly by degrees of belief. The ER algorithm is used to aggregate these belief degrees.

![Figure 6-2: Graphical illustration of the ER aggregation algorithm (Yang 2008)](image-url)
Based on the nature of the problem under analysis, the decision-maker can conduct a disjunctive (OR-based) evidential aggregation or a conjunctive (AND-based) evidential aggregation.

6.3.3.1 Disjunctive (linear) evidential aggregation
Disjunctive aggregation is used for a linear aggregation of assessments. Assessments are aggregated as a union of sets with assumption of complete compensation, evidential independence and judgemental independence\(^\text{12}\). The overall belief in an assessment grade is an accumulation of all evidential sources (belief degrees) which are assumed to be homogeneous. It is generated as a weighted sum of the degrees of belief associated with the assessment grade in the sub-criteria:

\[
\beta_n = \sum_{i=1}^{I} \omega_i \times \beta_{i,n}
\]

Where:
- \(\beta_n\): the aggregated degree of belief assigned to the assessment grade \(H_n\)
- \(\omega_i\): the importance weight associated with the criterion \(i\)

6.3.3.2 Conjunctive (non-linear) evidential aggregation
Conjunctive aggregation is used for a non-linear aggregation of degrees of belief coming from homogeneous sources of evidence. Degrees of belief are combined together in a strict AND-based aggregation rule with assumption of limited compensation and mutual judgemental independence. This aggregation rule is the ER algorithm which is a modified version of Dempster’s rule of evidence combination as mentioned earlier. It is different from the original one in terms of how ignorance is distributed among the evaluation attributes. According to the ER algorithm, ignorance is distributed among the attributes not equally, as originally suggested by Dempster, but according to their importance weight (Yang 2001;Sonmez et al. 2002b). In a hierarchy

\(^{12}\)Evidential independence means that each attribute is assessed by means of totally exclusive factual evidence. For instance, assessing an employee performance could be assessed by means of assessing his efficiency and customer service. The employee’s efficiency can be assessed by means of the processing time he consumes to produce one unite, and customer service skills can be assessed by means of his ability to understand the customer inquiry and respond to it quickly. In this example, the two assessment criteria are assessed by means of totally exclusive measures, for this reason they can be considered evidentially independent.

Judgemental independence can be understood by the following example. When comparing two employees according to the previous two criteria, if the two employees have the same score for efficiency the one with better score in customer service skills is preferred. Or, if they have the same score on customer service, the one with better efficiency score is preferred.
of two levels, the aggregation of the distributed assessments of $l$ criteria at the lower level is conducted according to the following steps:

1- Assign importance weights $\omega_i (i=1,\ldots,l)$ to decision criteria. The weights must be normalised, so that $0 \leq \omega_i \leq 1$ and $\sum_{i=0}^{l} \omega_i = 1$.

2- Transform the degrees of belief into basic probability assignments by multiplying them with the importance weights:

$$m_{n,i} = m_i(H_n) = \omega_i \beta_{n,i}(A_m) \quad n = 1,\ldots,N, \ i = 1,\ldots,l.$$  

$m_{n,i}$ represents the probability mass assigned to the evaluation grade $H_n$ when considering the criterion $C_i$. $N$ is the number of assessment grades.

3- Calculate the probability mass assigned to the whole frame of discernment (a set of $N$ evaluation grades) on every criterion by:

$$m_{H,i} = m_i(H) = 1 - \sum_{n=1}^{N} m_{n,i} \quad i = 1,\ldots,l.$$  

This probability mass can be split into two parts:

- $\overline{m}H, i = 1 - \omega i$ caused by the weight of the criterion $C_i$ and
- $\overline{m}H, i = \omega i \left(1 - \sum_{n=1}^{N} \beta_{n,i}(A_i)\right), \ i = 1,\ldots,l$ caused by the incompleteness of the assessment.

4- Aggregate the probability assignments by means of the following equations:

$$m_n = k * \prod_{i=1}^{l} (m_{n,i} + \overline{m}H, i + \overline{m}H, i) - \prod_{i=1}^{l} ( \overline{m}H, i + \overline{m}H, i), \quad n = 1,\ldots,N$$  

$$k = \frac{1}{\sum_{n=1}^{N} \prod_{i=1}^{l} (m_{n,i} + \overline{m}H, i + \overline{m}H, i) - (N - 1) \prod_{i=1}^{l} (\overline{m}H, i + \overline{m}H, i)}$$  

5- Aggregate the probability masses assigned to the whole frame of discernment:

$$\overline{m}H = k * [\prod_{i=1}^{l} (\overline{m}H, i + \overline{m}H, i) - \prod_{i=1}^{l} (\overline{m}H, i)]$$  

$$\overline{m}H = k * [\prod_{i=1}^{l} (\overline{m}H, i)]$$

6- Transform the aggregated probability masses into an aggregated belief structure in the shape of $S(C_j(A_i)) = \left(H_n, \beta_{n,i}(A_i)\right)$. Such a transformation
requires calculating the belief degrees $\beta_n (n = 1, \ldots, N)$ using the following equation:

$$\beta_n = \frac{m_n}{1 - \bar{m}H} \quad n = 1, \ldots, N$$

7- Calculate the aggregated degree of ignorance $\beta_H$:

$$\beta_H = \frac{\bar{m}H}{1 - \bar{m}H} = 1 - \sum_{i=1}^{N} \beta_n \quad n = 1, \ldots, N$$

The aggregation result is an overall belief structure. In this belief structure, the overall degrees of belief $\beta_n$ together with the degree of ignorance $\beta_H$ always sum to unity which is perfectly logical.

In order to compare between different alternatives, the overall assessment should be transformed from its distributed form into a representative score. Yang (2001) proposed calculating an expected utility for every alternative $u(S(A_j))$ as follows:

$$u(S(A_j)) = \sum_{n=1}^{N} u(H_n) * \beta_n \quad n = 1, \ldots, N$$

By agreeing upon utility values for every evaluation grade, an expected utility value for every alternative can be estimated. In the case of incomplete assessment, the degree of ignorance can be utilised in order to generate a utility interval with upper and lower levels (Yang 2001) as follows:

$$u_{max} (A_j) = \sum_{n=1}^{N-1} \beta_n * u(H_n) + (\beta_N + \beta_H) * u(H_N)$$

$$u_{min} (A_j) = (\beta_1 + \beta_H) * u(H_1) + \sum_{n=2}^{N} \beta_n * u(H_n)$$

$H_1$ is the assessment grade with the lowest utility value and $H_N$ is the assessment grade with the maximum utility value. $u_{min}$ and $u_{max}$ can be easily averaged in order to rank the alternatives according to their average utility level. However, using the average utility for comparison is not always reliable. According to Yang (2001), alternative $A1$ is preferred to alternative $A2$ if: $u_{min}(A1) > u_{max}(A2)$ and they are indifferent if $u_{min}(A1) = u_{min}(A2)$.

According to Yang and Xu (2002), the ER aggregation algorithm is a rational way of aggregating information that satisfies the following axioms:
- If no sub-criterion is assessed to an evaluation grade, the general criterion should not be assessed to the same grade either.
- If all sub-criteria are precisely assessed to a specific grade, the general criterion should also be precisely assessed to the same grade.
- If all sub-criteria are completely assessed to a subset of the evaluation grades, the general criterion should be completely assessed to the same subset as well.
- If any assessment of a sub-criterion is incomplete, the assessment of the general criterion should also be incomplete.

Hence, the aggregation result is an overall belief structure composed of aggregated belief degrees assigned to the evaluation grades and an overall degree of ignorance kept separate for later deployment. The aggregated ignorance plays a crucial role for transforming the panoramic results into single figures that can be used for comparison and decision making as will be illustrated in the next section.

6.3.4 The ER approach as a generalised MCDM approach

The aforementioned algorithm for assessment aggregation is the first step towards alternatives evaluation and decision-making. The aggregation result in its distributed form reflects the overall performance of an alternative after considering all the evaluation criteria. It is worth noting that the criteria are not always from the same nature; they can be quantitative or qualitative. Moreover, the assessment grades may not be the same for all criteria; we may use one assessment grade for some criteria and three assessment grades for the rest for instance. The ER approach is the only MCDM tool that can effectively handle attributes and assessment grades of hybrid nature. The ER approach adopts a rule-based or a utility-based methodology for transforming different assessments into a common form with universal assessment grades and generates the corresponding degrees of belief. A full illustration of the transformation mechanism, as mentioned previously, can be found in Yang (2001).

The panoramic shape of the obtained result is very informative; it gives a rich picture showing the degree of belief in every evaluation grade together with the amount of unassigned belief, degree of ignorance. For instance, the result of evaluating three cars based on five attributes (Price, Brand, Engine quality, Warranty and Fuel consumption) can be presented in the following format:
Table 6-4: An example of a distributed assessment result of evaluating three cars

Table (6-4) presents the aggregated degrees of belief assigned to the four assessment grades (Poor, Average, Good, Excellent) for the three alternative cars after considering the five attributes. Obviously, the attributes have different natures and can be assessed quantitatively or qualitatively (fuel consumption vs. brand for instance). The assessment grades have been transformed into four universal grades (Poor, Average, Good, and Excellent) and the aggregated degrees of belief have been generated accordingly via the ER approach.

Although the distributed results are very useful in showing the distribution of belief among the possible grades, unfortunately we are obliged to transform them into representative scores in order to compare between the three cars. According to Yang (2001), the transformation can be done by calculating an expected utility for every alternative. Hence, for every car we calculate the expected utility using the following equation:

\[ u(S(C_j)) = \sum_{n=1}^{N} u(H_n) * \beta_n, \quad n = 1, ..., N \]

Evidently, this requires agreeing upon utility values for every evaluation grade. This formula is suitable for calculating the expected utility and ranking alternatives accordingly only in cases of complete assessment. In the case of incomplete assessment, the degree of ignorance is utilised in order to generate a utility interval with upper and lower levels as it was illustrated previously. The upper utility level is obtained by assigning the degree of ignorance to the evaluation grade with the highest utility value, whereas the lower utility level can be generated by assigning the degree of ignorance to the evaluation grade with the lowest utility value. When the degree of ignorance is zero, there will be no utility interval and the two levels of utility will be the same and equal to the expected utility \( u(S(C_j)) \). Coming back to the previous example, by assuming that the utility values of the evaluation grades are:

<table>
<thead>
<tr>
<th>Car</th>
<th>Poor</th>
<th>Average</th>
<th>Good</th>
<th>Excellent</th>
<th>( \beta_\pi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car 1</td>
<td>0.11</td>
<td>0.21</td>
<td>0.5</td>
<td>0.1</td>
<td>0.18</td>
</tr>
<tr>
<td>Car 2</td>
<td>0.23</td>
<td>0.40</td>
<td>0.17</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td>Car 3</td>
<td>0.15</td>
<td>0.19</td>
<td>0.40</td>
<td>0.25</td>
<td>0.01</td>
</tr>
</tbody>
</table>
The expected utility of car1 is:
\[ u(C1) = 0.15 \times 0.11 + 0.45 \times 0.21 + 0.65 \times 0.5 + 1 \times 0.1 = 0.3475 \]

The maximum utility of car1 is:
\[ u_{\text{max}}(C1) = 0.15 \times 0.11 + 0.45 \times 0.21 + 0.65 \times 0.5 + 1 \times (0.1 + 0.18) = 0.5275 \]

The minimum utility of car1 is:
\[ u_{\text{min}}(C1) = 0.15 \times (0.11 + 0.18) + 0.45 \times 0.21 + 0.65 \times 0.5 + 1 \times 0.1 = 0.3745 \]

The average utility of car1 is:
\[ u_{\text{average}}(\text{Car1}) = \frac{0.5275 + 0.3745}{2} = 0.451 \]

By following the same approach, the average utilities of car2 and car3 are:
\[ u_{\text{max}}(\text{Car2}) = u_{\text{min}}(\text{Car2}) = u_{\text{average}}(\text{Car2}) = 0.525 \]
\[ u_{\text{max}}(\text{Car3}) = 0.628, \quad u_{\text{min}}(\text{Car3}) = 0.6195, \quad u_{\text{average}}(\text{Car3}) = 0.623 \]

Based on these results, the three alternative cars can be ranked. By following the comparison rules of Yang (2001), we have:
\[ u_{\text{min}}(\text{Car3}) > u_{\text{max}}(\text{Car2}) \rightarrow \text{Car3} > \text{Car2} \]
\[ u_{\text{min}}(\text{Car2}) > u_{\text{max}}(\text{Car1}) \rightarrow \text{Car2} > \text{Car1} \]

Hence, the ranking of the three cars is: Car3 > Car2 > Car1.

### 6.3.4.1 Utilising ignorance

Yang (2001) proposed a way of dealing with ignorance by calculating upper and lower utility levels. However, the degree of ignorance can be allocated in different manners. For instance, Huynh et al. (2005) adopted the principle of insufficient reason and proposed distributing the degree of ignorance equally among the assessment grades. In theory, the degree of ignorance can be allocated to any assessment grade and in
any form of distribution. It is down to the decision maker who carries the responsibility of the final decision to choose the most convenient way of allocation. However, in this research the approach of generating a utility interval is advocated as it can denote optimistic and pessimistic scenarios when DST and the ER algorithm are employed for assessing project risk level, as will be illustrated in the next section of the thesis.

6.4 Summary and conclusions

This chapter presented the DST, the ER approach and the ER algorithm for evidence combination. The merits and shortcomings of DST were covered. The ER approach for multiple criteria decision making was introduced with special focus on the ER algorithm for combining individual assessments and generating an overall assessment of a general criterion.

The unique properties of the DST and the powerful ER algorithm are very encouraging to investigate their applicability in a new domain. They can provide a novel approach for handling risk assessment and project evaluation in construction industry. They are suitable for representing subjectivity in construction risk assessment. They are particularly effective in accounting for lack of information which is a typical problem at the early stages of the PLC. An evidence-based framework for risk assessment and project evaluation could provide a novel alternative to the PT, FST and AHP. Such an approach enables practitioners to express their practical experience and personal judgment and utilise them in a rather objective manner.

Next chapter discusses an innovative deployment of DST and the ER algorithm for construction risk assessment. A new risk model and a new risk and benefit assessment framework within an evidence-based MCDM approach are presented. The proposed methodology for risk assessment immensely deploy the cumulative practical experience of the decision maker in an attempt to respond to the practitioners’ aspirations in having practical and usable DSSs (Taroun and Yang 2011).
7.1 Introduction

In this chapter, a new risk model and a new approach for assessing construction risk are presented. Firstly, a new model for construction risk \( R = L \times P \times I \) is presented and justified. The new model is believed to provide a more informative picture about the nature of risk and its potential impact by introducing a third parameter; probability of impact materialisation \( P \). Secondly, an innovative deployment of DST and the ER algorithm is proposed as a new approach for assessing construction risk. The concept of decision matrix is borrowed to assess risk impact on different project objectives and the concept of distributed assessment is employed to reflect the uncertainty surrounding the assessment of risk impact. This chapter, together with the next chapter, formulate the theoretical contribution of this research to the literature of risk management and project evaluation. They provide a basis upon which a DSS is developed for aiding construction practitioners in risk assessment and decision making.

7.2 A new construction risk model

Risk modelling is essential for a realistic risk assessment. Despite its limitation, literature review revealed that Probability-Impact (P-I) risk model is prevailing. It is a common model but not the best (Chapman 2006). Literature review showed different attempts of improving construction risk model as it was discussed in detail in chapter three. These attempts are fully appreciated and considered as a starting point in researching a better alternative.

To recap, Aven et al (2007) and Zhang (2007) urged for considering risk “manageability” and project “vulnerability” when assessing risk without giving any specific method to do that. Jannadi and Almishari (2003), Cervone (2006), Zeng et al. (2007), and Han et al. (2008) extended the P-I model and incorporated other dimensions; Dikmen et al. (2007b) incorporated manageability as a influencing factor on project risk level; Cagno et al. (2007) considered ‘risk controllability’ as measure of the feasibility of mitigation strategies. Among these approaches, it seems that the notion of extending the P-I model of construction risk by incorporating additional explicit
parameter(s) is more convenient and effective. I think that risk can be better modelled by incorporating additional parameters able to:

1. reflect the practical experience of the analyst in mitigating its downside impact and turning it into opportunity
2. account for interdependencies between the identified risks and,
3. consider the effect of the surrounding project environment on risk impact

These three considerations are very important as they determine the true size of risk impact. The logic behind the need for such incorporation is that the actual risk impact does not necessarily equal the expected impact when analysing risk. Risk may or may not occur and when it occurs its impact may not materialise in its worst scenario. Hence, together with risk likelihood of occurrence and its potential impact, risk model may better include a third parameter that measures the probability of the actual impact. Thus, the potential impact in the conventional P-I model is replaced by the expected impact. From this premise, construction risk could be modelled as follows:

\[ R = L \times P \times I \]

Where:
- \( R \): risk level
- \( L \): likelihood of occurrence
- \( I \): maximum Impact magnitude
- \( P \): probability of impact materialisation

The new dimension, probability of impact materialisation (P), can be generated from the values of three coefficients: project features (F), controllability (C) and Dependency (D). These three coefficients reflect the three considerations mentioned above.
However, in order to appreciate the novelty of the proposed model, its parameters need to be clearly defined in the first instance.

7.2.1 Likelihood of occurrence (L)

Likelihood of occurrence is defined in the same way it used to be defined in risk management literature. It is the probability that a risk factor happens. It takes a proportional value between 0 and 1.

7.2.2 Impact (I)

Risk impact is defined as the maximum amount of loss or damage incurred on a specific project success objective if the risk happens. Consequently, it is the worst-case scenario of risk effect on a specific project objective. In this research, the impact is proposed to be assessed as a percentage of the project initial cost as illustrated in detail later in the chapter.

7.2.3 Probability of Impact materialisation (P)

It reflects the probability that the actual impact of a risk on a specific project objective materialises in its worst scenario. In other words, it is the probability that the actual risk impact equalises the expected amount (I). Probability of impact materialisation serves as an adjustment factor that enables the analyst to discount the maximum possible impact, if required, after considering the ability of the management to mitigate it and after appreciating the effect of the surrounding environment and the mitigation strategies to deal with interdependent risks. As it can be seen from figure (7-1), project specifications and its environment, the capability and the experience of the management team who is in charge of managing risk impact and the interdependencies between the risk in question and the other identified risks affect the actual risk impact. These issues have been considered through the usage of three adjustment coefficients; Project Features (F), Controllability of risk impact (C) and risk Dependency (D).

7.2.3.1 Project Features (F)

This factor reflects the specifications, surrounding environment, criticality and the unique nature of the construction project. The value of this coefficient is determined by the risk analyst based on his or her previous experience in dealing with the risk under
analysis. He or she should refer to the project specifications and its surrounding environment and analyse the supportive impact it may have when mitigating the impact of the risk which is under analysis. It is proposed that the value of this coefficient is a proportional figure which falls in the range [0-1]. If it is believed, for instance, that project environment has a very supportive role that may help the management team to mitigate the maximum risk impact, the analyst can assign a high value, for example 0.7, to the parameter (F). Such a value is interpreted as follows: the features of the project and its surrounding environment are very supportive to the extent that risk management team can reduce the maximum possible impact by 30%. However, if it is the opposite case where project features and its surrounding environment cannot offer any support to mitigate the impact, the value of 1 can be assigned to (F). This means that there is no supportive effect of project features on mitigating risk impact at all. As such, deciding on a suitable value of F is not an easy task. It requires thorough understanding and analysis of the project and rich experience in previous projects and similar risks. Ideally, deciding on a value for F should be the outcome of a group decision-making process that may include experts when analysing complex projects. Table (7-1) further illustrates the concept of project features and the possible values of this parameter according to different situations. The values are suggested by the author as guidance; they can be modified by risk analyst according to a project under analysis.

<table>
<thead>
<tr>
<th>Value of project feature coefficient (F)</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project environment and specifications has no positive effect on mitigating risk impact at all</td>
</tr>
<tr>
<td>0.85 – 0.999</td>
<td>Project features have a fairly supportive role in mitigating risk impact</td>
</tr>
<tr>
<td>0.7 – 0.849</td>
<td>Project specifications, location and the surrounding environment are supportive in mitigating risk impact</td>
</tr>
<tr>
<td>0.4 – 0.699</td>
<td>Project specifications, location and the surrounding environment are very supportive in mitigating risk impact</td>
</tr>
<tr>
<td>0.00 – 0.399</td>
<td>Project environment is extremely supportive; it can, in theory, help risk management team to eliminate risk impact</td>
</tr>
</tbody>
</table>

Table 7-1: The value of project feature coefficient (F)

7.2.3.2 Controllability (C)
Controllability coefficient reflects the experience of risk management team, their familiarity with the risk and the extent to which the team is capable of mitigating its downside impact. Controllability can also be looked at as a means of reflecting the
nature of a risk factor as some risks are more manageable than others (Aven et al. 2007). Hence, it is a reflection of risk nature and a measurement of the experience and the competency of risk management team. Similar to the project features coefficient, controllability is an adjustment coefficient whose value falls in the range [0-1]. For instance, assigning a value of 1 for controllability coefficient means that risk management team has no previous experience in managing the risk, which means that risk analyst would expect that the actual risk impact will equalise the expected one (I). Table (7-2) provides guidance for assigning proper values to the controllability coefficient. Again, the values are suggested as guidance; they can be modified by risk analysts to suite the specific case under analysis.

<table>
<thead>
<tr>
<th>Value of controllability coefficient</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The project is very unique and the management team has no previous experience in managing the risk.</td>
</tr>
<tr>
<td>0.85 – 0.999</td>
<td>The management team has limited experience in mitigating the impact of risk.</td>
</tr>
<tr>
<td>0.7 – 0.849</td>
<td>The management team is familiar with similar projects and has a good experience in managing the identified risk.</td>
</tr>
<tr>
<td>0.4 – 0.699</td>
<td>The management team is very familiar with this type of construction projects and has a very good experience in managing the identified risk.</td>
</tr>
<tr>
<td>0.00 – 0.399</td>
<td>The project is standard, the company is specialized in this type of projects, and the risk management team has excellent experience in managing the identified risks and, possibly, eliminating its impact.</td>
</tr>
</tbody>
</table>

Table 7-2: The value of controllability coefficient

7.2.3.3 Dependency Factor (D)
Assuming that the identified risks are independent of each other is not realistic. This may lead to an exaggeration in impact assessment, which may produce an over-estimated project risk level. To tackle this problem, the dependency coefficient (D) is introduced as an adjustment factor for discounting risk impact after considering the co-existing risks. The rationale behind this introduction is that mitigating any risk impact may, directly or indirectly, mitigate the impact(s) of other risk(s). As mentioned earlier in chapter three, researchers have considered vertical interdependencies between risks on different levels of risk hierarchy. However, the horizontal interdependencies between risks on the same level of the hierarchy have not received enough attention. The proposed dependency coefficient can address the horizontal dependency in an explicit and clear way.
Risk dependency is an adjustment coefficient with a proportional value between 0 and 1. For instance, when a number of the identified risks have the same cause and impact, handling one of them may eliminate the impact of the rest. In this case the coefficient (D) may take a value of 0. Thus, when analysing a number of risks classified under the same category in project risk hierarchy, risk analyst is required to think of them collectively and study the interaction between them and the way by which treating one of them may benefit treating the rest. Based on this investigation, the analyst can assign a value to the coefficient (D) for each of them to reflect their mutual interaction and influence. Table (7-3) shows an example of a set of possible scenarios with the corresponding values of (D).

<table>
<thead>
<tr>
<th>Value of dependency coefficient</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Risks are totally independent with no interdependencies between them at all</td>
</tr>
<tr>
<td>0.90 – 0.999</td>
<td>There are limited interdependencies between the risk under analysis and the co-existing risks</td>
</tr>
<tr>
<td>0.7 – 0.899</td>
<td>There are considerable interdependencies between the identified risks</td>
</tr>
<tr>
<td>0.2 – 0.699</td>
<td>Risks are strongly interdependent with very similar impact</td>
</tr>
<tr>
<td>0.00 – 0.199</td>
<td>The risk can be disregarded due to the consideration of other risks</td>
</tr>
</tbody>
</table>

Table 7-3: The value of dependency coefficient

It is important to note that the proposed values of F, C and D in the previous tables are not definite. They are suggested as a guidance to ensure consistency and reliability of risk analysis. Hence, defining these coefficients and agreeing upon the ranges of their values and the corresponding scenarios is crucially important. Every organisation may have different definitions and assign different values to these coefficients. That is perfectly acceptable as far as the same values are consistent throughout the whole analysis. The same organisation can use different values and definitions to suite different project types, sectors or procurement systems. For this reason, it is not a matter of concern to produce a universal definitions and corresponding values. The key point is the methodology of risk analysis and the consistency throughout the process.

7.2.3.4 Calculating the value of \((P)\)
The value of probability of impact materialisation is calculated based on the values of the three coefficients \(F\), \(C\) and \(D\). As the function of \(P\) is discounting the maximum potential impact, its value will be a proportional figure between 0 and 1. The author
proposes calculating the value of $P$ as a weighted sum on the values of $F$, $C$ and $D$. Assuming that the three coefficients have the same importance weights makes the value of $P$ equal to the average of the values of $F$, $C$ and $D$. Hence:

$$P = \frac{F + C + D}{3}$$

The risk analyst can make different assumptions regarding the importance weights based on his or her attitude towards the risk under analysis. However, for simplicity of calculation the three coefficients are assumed as equally important.

### 7.3 Discussion on the proposed risk model

The proposed risk model provides a clear picture of the nature of a risk, its surrounding environment and the capability of risk management team. It provides measures of the likelihood of occurrence, maximum potential impact and the probability that the maximum impact materialises. It considers explicitly all arrangements and security measures put in place to mitigate risk impact. The direct implication of this model will be a new concept to construction risk management literature introduced as *project safety level*.

Potentially, there is a huge number of risks affecting a project. However, they may or may not happen. Even if they all happen, this does not necessarily mean that their worst possible impact should materialise. The identified risks provide a picture about the riskiness of the project. However, due to the consideration of the $F$, $C$ and $D$ coefficients when assessing them, the risk level of the project can be looked at from a different perspective: *a project safety level*. In other words, a project may be highly risky due to the initial assessment of its key risks based on the conventional P-I risk model. However, such an assessment does not show the extent to which the project is safe in achieving its objectives. In order to do this, analysing project risks should always consider the security measures put in place and the available resources for managing the risks. *Looking at project risk analysis from this perspective leads to approaching project risk analysis by examining the safety level of achieving project’s objectives rather than investigating how risky the project is.*

This argument has its counterpart in the safety management domain. When analysing
a hazard, its potential damage may claim a number of casualties and a loss of hundreds of thousands of pounds. However, due to safety measures specified by the safety management systems and the professionalism of the safety management team in detecting early signs of possible causes, the likelihood of occurrence of an accident may be significantly reduced. Moreover, the quick, professional and effective response to an accident when it happens can significantly minimise its damages. The inclusion of the probability of impact materialisation coefficient, with its three coefficients F, C and D, would provide a similar function and lead towards a more realistic assessment. It can overcome any exaggeration in risk assessment that may have a profound impact on any risk-related decision such as project costing, bidding, and contingency estimation. The inclusion of probability of impact materialisation in construction risk model could be a genuine contribution to modelling construction risk. A similar coefficient, *failure consequence probability*, is used in the safety modelling literature. Thus, it is worthwhile highlighting the theory of safety assessment to further justify the introduction of (P) as a third parameter in construction risk model.

### 7.3.1 Safety modelling and analysis

Safety analysis can be defined as the study of the *“probability that an item performs a required function under stated conditions for a stated period of time and the consequences of its failure in terms of possible damage to property, injury or death of people, and/or the degradation of the environment”* (Wang et al. 2004). Safety analysis is mainly concerned with industrial process and operations. It is particularly important in risky industries like offshore industries, engineering industries, chemical industries and oil and gas industries, etc. In order to analyse the safety of an engineering system in these environments, Wang et al. (1996) mentioned four steps:

1. the whole system is represented as a hierarchical structure of sub-systems and sub-components,
2. failure modes are identified and linked to the sub components; failure modes are located at the lowest level of the hierarchical structure,
3. each failure mode is analysed in terms of failure likelihood, consequence severity and failure consequence probability, and
4. the analysis results are aggregated in order to generate the safety level of the system as a whole.

It seems that safety analysis is conducted in a very similar manner to assessing project risk level. However, safety is modelled in a different way from modelling risk. In the
safety and reliability analysis literature, safety is modelled as a function of three parameters: failure likelihood ($L$), consequence severity ($C$) and failure consequence probability ($E$) (Wang et al. 1996; Wang et al. 1995; Wang and Yang 2001; Wang et al. 2004; Yang et al. 2001). The failure likelihood and the severity can be easily defined in a similar way of defining risk likelihood and impact, whereas failure consequence probability can be regarded as the probability that the potential consequence will occur given that the failure has happened. Failure consequence probability was defined by Wang (1997) as the “likelihood that failure effects will occur given the violation of the safety rule.” It is the likelihood that the potential effect of a specific failure mode actualises given that the failure mode has happened (Wang et al. 1995). It seems that consequence probability has a similar function to the probability of impact materialisation parameter proposed in this research as a third dimension in a risk model. This similarity gives the proposed risk model a theoretical underpinning and justifies the inclusion of $P$ in risk model.

7.3.1.1 Safety in construction
In construction management literature, safety management is commonly referred to as managing the hazards and accidents that may affect the labour during the construction phase of the PLC. Although the term safety is also used for handling structural safety of buildings, the first use is the dominant one in literature. Hughes and Ferrett (2008) defined safety as the protection of people from physical injury. They have also provided clear distinctive definitions for hazard, accident and risk. Risk is defined as the likelihood of a substance, activity or process to cause harm. Interestingly, risk is defined in safety management literature in a rather different way from project risk management literature.

Safety management in construction has attracted a considerable attention. A lot of research has been done for identifying hazards in construction industry, reviewing the health and safety regulations, managing safety in work sites, evaluating safety management performance and developing integrated safety management systems (Helander 1991; Thomas Ng et al. 2005; Baxendale and Jones 2000; Teo et al. 2005; Behm 2005; Gürcanli and Müngen 2009; Teo and Ling 2006; Jannadi and Almishari 2003). It looks as if construction safety management is dealt with as a separate domain from RM. It mainly focuses on accidents and personal injuries in site. However, reliability analysis and engineering systems safety looks more similar to RM. As a result, the term “safety” can be borrowed and used in a rather novel usage. As
mentioned earlier, the new risk model reflects the nature of the risk and the security measures put in place to mitigating its impact. Assessing construction risk based on this model and aggregating the assessments will yield a “project safety level” instead of the conventional project risk level. Project safety level reflects project risk level after considering project environment and features and the ability of risk management team of mitigating risk impact. It is, then, the outcome of aggregating the individual assessments of the identified risks based on the proposed risk model. The next part of this chapter demonstrates a new methodology for assessing construction risks and aggregating the assessments in order to generate project safety level.

7.4 Risk assessment framework

7.4.1 Assessing risk by pricing it

Reviewing the literature of construction risk assessment showed that a comprehensive framework that appreciates different risk impacts on project success objectives, such as time, cost and quality, was lacking. It was concluded that the absence of such a framework could be attributed to the lack of a common scale for assessing the different types of risk impact on project objectives. Literature review showed also that risk cost was recommended as a possible common scale by many researchers. However, no systematic approach has been developed based on this recommendation so far even though estimating contingency allowances is a well-established practice. Moreover, risk impact is perceived by many researchers as an extra cost to repair the damage incurred because of the occurrence of a risk. For instance, Cioffi and Khamooshi (2009) perceived risk impact as the required funding to put the project back on its planned track after the occurrence of a risk. Risk cost is a convenient and effective scale as it is a common language understood by all parties. It can make the risk assessment process more practical from practitioners’ perspective. In order to achieve that, risk impact can be presented as a percentage of the initial project cost. Subsequently, project risk level will be presented as a percentage of the initial cost estimate.

7.4.1.1 Justifying the use of risk cost for measuring risk impact

It is believed that every risk has a price (Mulholland and Christian 1999). However, calculating the price of a risk is definitely not an easy task. It is the main problem in RM (Chan and Au 2008). Although one may argue that risk cost might not be a suitable
scale for all types of risk, the researcher believes that it can be used for such purposes but with extra care and attention from risk analyst. Such a point of view is supported by the fact that construction practitioners used to consider the residual risks, the unknown unknowns, collectively by providing a contingency allowance. As they are able to do so, they should be in a better place to assess the identified risks, the known unknowns, by means of monetary equivalent. For instance, risk impact on project quality or duration can be assessed in financial terms after considering the items in the contract that cover the financial penalties for execution delay or quality violation. Practitioners used to set aside an amount of money to cover the residual risks. This contingency sum, which is usually around 5%-10% of the initial project cost, is used to be allocated in a rather arbitrary way and mainly based on the judgment and experience of risk analyst (Mak and Picken 2000; Adams 2006; Tah et al. 1993; Smith and Bohn 1999). This behaviour is regarded as a standard practice in construction (Raftery 1994). However, such a methodology of hedging unknown unknowns is criticised by many researchers due to its weaknesses that have been fully illustrated by Mak et al. (1998). One of the obvious outcomes of its weaknesses is the difficulty to justify the contingency figure or explain the logic behind choosing it as it is based on the judgment of the estimator (Yeo 1990). As a result, researchers recommended estimating contingency sum in a more objective and transparent way by appreciating the potential risks that may happen, estimating their financial impact and likelihood of occurrence and then calculating an expected value of the contingency sum (Smith and Bohn 1999; Tah et al. 1994; Mak et al. 1998).

PMI (1992) recommended a similar methodology for pricing project risks and calculating their expected values before adding them to the initial project cost. Risk impact was referred to as “amount of stake” measured in US dollars. It was regarded as a “comprehensive and convincing” way of estimating contingency allowance. This methodology is a simple and practical way for approximating the cost of project risks. However, the cost is presented as the sum of the expected values of the identified risks. This implies the assumption that all the risks are totally independent which is not realistic. Nonetheless, this method can be used as a starting point for providing a more sophisticated and accurate methodology for assessing project risks.

It is worth mentioning that pricing risk is a well established approach for hedging them financially. In insurance industry, risks are always assessed in financial terms. Construction professionals are used to covering some unexpected accidents and risks by insuring them and paying insurance premium. It is interesting that risk pricing is also used for assessing social, environmental, and even life loss risks. According to Aven
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and Vinnem (2005), expected cost per expected saved lives statistically can be estimated in order to provide information about the effectiveness of implementing a risk reducing measure or in an attempt to compare a number of alternatives strategies. Ersdal and Aven (2008) argued that losses of lives, injuries and environmental damages used to be transformed into monetary sum when evaluating different system designs by means of cost-benefit analysis. They argued that Rackwitz (2001) included the social loss due to lives losses in a cost-benefit analysis by estimating an equivalent cost. Rackwitz (2001) calculated the equivalent cost by multiplying the number of expected fatalities and the amount of money invested to avoid a fatality. Apart from debating the morality of such costing, it seems that even such types of risks can be assessed by means of monetary equivalent. This leads to the result that pricing risk, as a means of assessing its impact, is difficult but achievable.

To summarise, construction practitioners are able to deal with the unknown unknowns by providing a contingency sum. In other words, they are able to assess uncertainty in monetary terms. As they are able to do so, they should assess and price the known unknowns, project risks, and provide an equivalent monetary sum for them. Pricing project risks could be a better alternative to the existing risk assessment methodologies that are barely used in practice. It is a convenient and practical way of assessing project risk as it follows a simple logic and uses a language that is understood by everyone in construction industry. Moreover, such an approach provides a common scale for assessing the different risk impacts on project objectives as illustrated in the next section of this chapter.

7.4.2 Evidence-based risk assessment

According to the proposed risk model, risk assessment requires risk analyst to provide assessments to risk impact, risk likelihood of occurrence and the coefficients F, C and D in order to calculate probability of impact materialisation (P).

7.4.2.1 Risk impact assessment

Assessing risk impact can be dealt with in the same way of approaching a MCDM problem. The problem of risk impact assessment can be represented by a risk impact assessment matrix displayed in figure (7-2). However, different from a MCDM problem where the decision maker is required to evaluate alternatives against a set of attributes, in the case of risk impact assessment the analyst is required to provide an assessment
of the impact of every risk on every project success objective (project cost, duration, quality, etc). To make it simple, a risk impact assessment matrix is composed of rows, each stands for a risk, and columns, each stands for a project objective. For instance, risk impact can be assessed on project cost, duration, quality and any other strategic objective. Hence, four columns can be used in the risk impact assessment matrix to consider these four objectives. The fourth objective called “others” may represent, according to the case under analysis, environmental impact, impact on health and safety, impact on company reputation, etc. Actually, it is up to the analyst to choose the project success objectives when analysing risk impact.

Let $O_i$ stand for objective $i$, $R_j$ for risk $j$, and $S(RI_j(O_i))$ for the assessment of the impact of the risk $R_j$ on the objective $O_i$. In order to reflect the uncertainty surrounding risk impact, the impact is assessed in a distributed form according to the following formula:

$$S(RI_j(O_i)) = \{(G_n, \beta_{n,i,j}), \quad n = 1, \ldots, N\}, \quad i = 1, \ldots, m, \quad j = 1, \ldots, l$$

$$\beta_{n,i,j} \geq 0, \quad \sum_{n=1}^{N} \beta_{n,i,j} \leq 1$$

Where:
- $N$: number of assessment grades
- $m$: number of project success objectives
- $l$: number of risk factors
- $\beta_{n,i,j}$: the degree of belief that the impact of risk $R_j$ on project objective $O_i$ equals the grade $G_n$.

<table>
<thead>
<tr>
<th>$O_1$ Project Cost</th>
<th>$O_2$ Project Duration</th>
<th>$O_3$ Project Quality</th>
<th>$O_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>$S(RI_1(O_1))$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_3$</td>
<td></td>
<td>$S(RI_2(O_1))$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_4$</td>
<td></td>
<td></td>
<td>$S(RI_2(O_m))$</td>
</tr>
</tbody>
</table>

Figure 7-2: Risk impact assessment matrix
7.4.2.1.1 Assessment grades
In the proposed assessment approach, evaluation grades are considered to be percentages of the project initial cost. For instance $Gn$ can be 1%, 2%, 3% or any percentage. This means that the impact of risk $Ri$ may equalise 1%, 2%, 3% or any percentage of the project initial cost. It is a common language that everyone in construction industry can understand. Choosing the grades in a meaningful way is important as they are used as the common scale for measuring risk impact on different project objectives. The evaluation grades can also be chosen to reflect the uncertainty surrounding risk impact magnitude or to represent different scenarios of risk impact.

7.4.2.1.2 Degrees of belief
Risk analyst can express his or her confidence in the size of risk impact by assigning a degree of belief to every assessment grade. Hence, the total belief can be assigned to one proposition, for instance risk impact equals 1% of the initial project cost, or distributed among the assessment grades. Such a panoramic assessment of risk impact on every project objective provides a very rich and informative picture of risk impact. The degrees of belief are a reflection of the analyst's past experience and professional judgment. Clearly, the assignment of degrees of belief may not be complete due to lack of enough information or previous experience. Such an assessment approach is a powerful tool for providing a realistic and detailed risk assessment.

7.4.2.2 Assessing likelihood of occurrence
Assessing risk likelihood of occurrence can be done by using distributed assessment in a similar manner to assessing risk impact. The likelihood of occurrence can be presented by the following formula:

$$S(L_j) = \{(γj_1,G1), (γj_2,G2), (γj_3,G3),..., (γj_k,Gk)\}$$

Where:
- $Gi$: the assessment grade $i$
- $γij$: the degree of belief that the likelihood of occurrence of risk $Rj$ equals the grade $Gi$.

The assessment grade $Gi$ represents a possible likelihood of occurrence; it can be 10%, 40%, 65% or 100% for instance. These assessment grades are used to reflect
the uncertainty in specifying an accurate likelihood of occurrence of a specific risk. The extent to which each of these probabilities is the most realistic likelihood of occurrence is measured by the degrees of belief $\gamma_{ij}$. For instance, a risk likelihood of occurrence can be 10%, 40%, 70% or 100% with degrees of belief of 0.3, 0.5, 0.2 and 0 respectively. Although this method of assessing risk likelihood of occurrence provides a detailed assessment, likelihood of occurrence can be assessed by means of a single figure as it is usually done. This is merely for practicality in risk analysis. Assessing likelihood of occurrence by means of a single figure reduces the number of required inputs and, subsequently, the required time for project risk assessment bearing in mind the large number of risks to be considered. There is a question of balancing the level of detail in risk analysis and the practicality of the assessment methodology.

7.4.2.3 Calculating probability of impact materialisation (P)
As mentioned earlier, probability of impact materialisation can be assessed as the average of the values of project features coefficient ($F$), controllability coefficient ($C$) and dependency coefficient ($D$). According to their definitions and the tables provided previously, these three adjustment coefficients can be assessed as single proportional figures or as distributed assessments in a similar way to assessing likelihood of occurrence. Again, it is a matter of balancing between accuracy and practicality. It depends on the criticality of the situation under analysis and the required level of detail of risk analysis.

In this research, likelihood of occurrence and the three coefficients $F$, $C$ and $D$ are assessed as single figures. Risk impact, on the other hand, is assessed in a distributed form. By combining the assessments of the likelihood and the adjustment coefficients with the distributed assessment of risk impact, a risk analyst can get risk assessment in its distributed form as illustrated below.

7.4.2.4 Risk assessment
In order to obtain a risk assessment on every project objective, risk analysts should multiply the likelihood of occurrence and probability of impact materialisation with the degrees of belief in the distributed assessments of risk impact on the different objectives. A new set of degrees of belief is generated and associated with the same assessment grades of risk impact. Hence, a distributed assessment of risk size “cost” is obtained in the following form:
\[
S(R_j(O_i)) = \{(G_n, \beta'_{n,i,j}), \quad n = 1, \ldots, N\}, \quad i = 1, \ldots, m, \quad j = 1, \ldots, l
\]

\[
\beta'_{n,i,j} = L_j \cdot P_j \cdot \beta_{n,i,j}
\]

Where:
- \( N \): number of assessment grades
- \( m \): number of project success objectives
- \( l \): number of risk factors
- \( Gn \): risk assessment grade
- \( \beta'_{n,i,j} \): the degree of belief that the cost of risk \( R_j \) on project objective \( O_i \) equals the grade \( G_n \).
- \( \beta_{n,i,j} \): the degree of belief that the impact of risk \( R_j \) on project objective \( O_i \) equals the grade \( G_n \)
- \( L_j \): the likelihood of occurrence of the risk \( R_j \)
- \( P_j \): probability of impact materialization of the risk \( R_j \)

The same assessment steps are repeated for every risk on every project objective. Usually, the key risks are organised in a hierarchical structure with a number of main risk categories (financial risks, operational risks, technical risks, etc). Under every category a number of key risks are classified. The aforementioned risk assessment methodology is conducted at the lowest level of this hierarchy. In order to make any informative decision regarding project risks, the individual assessments need to be aggregated. Hence, the following step is aggregating the individual risk assessments towards the top of the risk hierarchy.

**7.4.2.5 Assessments aggregation**

In order to generate an overall risk assessment on the project, risk assessments on the different success objectives should be aggregated. Moreover, project risk level can be obtained through aggregating the individual risk assessments. Obviously, risks are different in terms of importance. The importance issue is usually reflected by associating every risk with an importance weight \( \omega_i \). The importance weights of every risk group, classified under a specific category, must be levelled so their values sum up to unity. The analyst has the total freedom to use any methodology for generating the weights, such as the eigenvector method that is adopted in the AHP.
Due to its characteristics and superiority on averaging, the ER algorithm is proposed for aggregating individual risk assessments. The aggregated assessments will generate an overall assessment in a distributed form \( S(R(Oi)) \):

\[
S(R(Oi)) = \{ (\beta'1,G1), (\beta'2,G2), (\beta'3,G3),..., (\beta'N,GN) \}
\]

- \( \beta'k \): the aggregated degree of belief in the assessment grade \( G_k \).

\( \beta'k \) is calculated by means of the ER algorithm based on the degrees of belief assigned to the grade \( G_k \) of the aggregated risks in a lower level of the hierarchy. Such an aggregation can be conducted for aggregating risk size, cost, on every project objective up to any level in the risk hierarchy. The aggregation may continue to the top of the hierarchy in order to produce overall assessments of project risk on every objective and ultimately to obtain an overall project risk level “project safety level.”

7.4.2.6 Risk assessment process
Risk assessment is proposed to be carried out according to the following sequence:
1. Identify the key risks affecting the project under analysis
2. build a project risk hierarchy and categorise the risks under unique categories
3. assign relative weights to the risks \( (\omega_i) \); the weights must sum to unity under every category
4. for every risk, estimate the likelihood of occurrence \( (L_i) \)
5. for every risk, estimate the values of \( F_i, C_i, D_i \) and then calculate the values of probability of impact materialisation \( (P_i) \)
6. choose the assessment grades of risk impact (different percentages of the project initial cost)
7. assess risk impact on every project objective by assigning degrees of belief to the assessment grades
8. for every risk, multiply likelihood of occurrence and probability of impact materialisation with the degrees of belief of risk impacts
9. repeat the previous steps for every risk under all risk categories
10. aggregate the risk assessments, obtained in step 9, to generate an overall assessment of every risk category on every project objective by means of the ER algorithm
11. the results of step 10 can be further aggregated a project risk level on every success objective
12. the results of step 11 can be aggregated in order to obtain the overall project risk level “project safety level”

Aggregation results would be obtained as distributed assessments. These assessments can easily be transformed into a percentage of the project initial cost by summing the multiplications of the assessment grades and the associated degrees of belief. The aggregated degree of ignorance can be used for generating upper and lower boundaries of risk cost. The upper limit of risk cost is generated by allocating ignorance to the worst assessment grade. For instance, in the case of having the following assessment grades 1%, 1.5% and 2%, the degree of ignorance would be allocated to the aggregated degree of belief associated with the 2% grade. On the other hand, the lower limit of risk cost is obtained by assigning the ignorance to the best assessment grade; in this example the 1%. The distributed assessments can be transformed into single percentages and later averaged to obtain an average risk cost.

7.4.2.7 Novelty

The above-illustrated methodology provides a novel alternative for assessing risk in construction. It generates distributed assessments of the size of every risk on every project objective. Moreover, the proposed aggregation rule enables risk analyst to aggregate individual assessments without averaging them or losing their panoramic shape. As presented earlier, risk analyst can aggregate risk assessments to any level of the risk hierarchy on every project objective or on the whole project. This will provide decision maker with a very clear and detailed picture of project risk.

Reviewing the literature demonstrates that DST or the ER approach has not received enough attention from researchers in construction management domain. Literature review shows that the ER approach was used by Sonmez et al. (2002a) for pre-qualifying construction contractors. It has also been deployed by Wang and Elhag (2007) for assessing bridge safety from a structural point of view. The evidence-based reasoning has not been properly utilised for risk assessment or project evaluation in construction industry yet. It may be an original contribution to construction management literature investigating the suitability and applicability DST and the ER approach. The proposed assessment methodology invests in the cumulative practical experience and personal judgment of risk analyst. The tool, essentially, assists the risk analyst in structuring the problem and provides venues for expressing his or her
experience in risk assessment and decision-making as well as rooms for doubt and ignorance which is crucial for a realistic analysis.

The way by which the ER approach is deployed is a bit different from the original approach proposed by Yang (2001). The ER approach, as a decision making tool, allows the analyst to provide his or her assessments in any format or shape. It is a powerful tool in transforming the different assessment types into a common set of assessment grades and degrees of belief via rule-based or utility-based transformation. However, the analyst is required to agree upon suitable transformation rules. This is a very critical point, as the transformation rules may not perfectly reflect the actual assessments in their different formats; it is a rather subjective task. Hence, the analyst must be very careful in choosing the right transformation rule. In this research, a different approach was followed. Here, the analyst is forced to use common assessment grades for all risks and then decide on the suitable degrees of belief to be assigned. Although one may argue against this approach, the analyst is not requested to decide on suitable transformation rules. This means that extra care, time and effort are required at the beginning to appreciate the problem and to decide on suitable assessment methodology. The participants in this research, who found the assessment methodology forcing them to think thoroughly in the risks before providing any assessments, appreciated this virtue.

### 7.5 Summary and Conclusions

In this chapter, a new risk model and an innovative deployment of DST and the ER approach for risk assessment were presented. The proposed risk model considers risk nature, project features and the experience of risk management team by a parameter named probability of impact materialisation. The proposed model is used in a new risk assessment methodology. Risk cost was used as a measurement scale of risk impact. This allows assessing the different impacts of the same risk on every project objective. Risk impact assessment was presented in a distributed format in order to account for the uncertainty and ignorance. The ER algorithm was deployed as an aggregation rule. A new concept, *project safety level*, was defined as the project risk level after assessing its risks according to the proposed risk model.

The proposed risk model and assessment methodology were discussed with reference to other theories and application domains. An initial conclusion was drawn that they
may provide viable alternatives to the existing ones. However, they need more investigation and research to examine their merits, shortcomings and suitability for construction risk assessment. In order to do that, primary research with professionals in construction industry is conducted and the results of this research are presented in coming chapters. In the next chapter, however, the wider methodology of construction project evaluation is discussed. Risk analysis is an integrated element of project evaluation as project risk assessment cannot be appreciated without assessing the coexisting project benefit. Project risk and benefit need to be assessed together and according to their assessments, different projects or proposals can be evaluated and compared.
8.1 Introduction

Project evaluation is an important task for any business. It can be looked at as a typical MCDM problem as it was discussed in detail in chapter five. Project criteria can be classified in many different ways; in this research, they are categorised under two main categories: risks and benefits. This proposition was made in alignment with the fact that there is always an opportunity attached to a risk. Hence, risk assessment may not be complete unless the coexisting opportunities are investigated and appreciated. From this premise, assessing the benefits and risks of any project and aggregating them together is a logical approach for project evaluation and comparison.

This chapter discusses the relativity in risk assessment and presents a methodology for assessing project risks and benefits simultaneously using monetary equivalents. The assessments of project risks and benefits provide decision maker with a comprehensive picture about the risky nature of a project and enable him or her to make an informative trade-off between them when evaluating different projects, balancing a project portfolio or ranking different proposals.

8.2 Relativity in risk assessment

Risk assessment could hardly be looked at as an absolute assessment. It is related to the co-existing opportunities, the analyst perception, the project specifications and the ability of the management team to deal with its downside impact. Therefore, assessing risk without appreciating the relativity item in it is not a complete or representative assessment. The relativity issue in risk assessment can be appreciated on two levels: micro and macro ones.

8.2.1 Relativity in risk assessment on a micro level

On a micro level, risk assessment is a relative assessment due to many influencing factors. For the same risk, both of its likelihood of occurrence and impact vary remarkably according to the features of different projects in terms of their complexity, uniqueness, size, etc. (Shenhar et al. 2001). Risk perception is another dimension of
the relativity of risk assessment on a micro level. Risk assessment is affected by the perception of risk analyst and his or her subjectivity, which is believed to have a profound impact of the assessment. The underlying assumptions and the attitude towards risk is rather different from one person to another (Dikmen et al. 2004). Singavi (1980) gave a very interesting metaphor for this issue by arguing that “risk is like beauty; it lies in the eyes of the beholder.” According to him, under the same external and internal conditions different people and different organisations may draw very different pictures of the same risk. For this reason, risk model should reflect the relativity issue on its micro level in order to yield a more representative risk assessment. The relativity in risk was, actually, a key driver for proposing the new risk model and assessment framework. The inclusion of the project features coefficient (F) in the proposed model accounts for the first dimension of relativity on the micro level and the distributed assessment of risk impact provides a venue for accommodating different perceptions and assumptions.

8.2.2 Relativity in risk assessment on a macro level

Project risk is a project attribute that needs to be assessed in light of the assessments of other attributes. Usually, project risks are organised in a hierarchical structure. Assessing risk factors and aggregating their assessments towards the top of the hierarchy generates project risk level. Project risk level can be looked at as a score assigned to the attribute “project risk”. This score cannot be utilised in any decision making process in isolation from the scores of the other attributes. In other words, it may be inadequate and misleading to only say, for instance, that project risk level is “high”. It may be more accurate and informative to say that a project risk level is “high” and its benefit level is “moderate”, for instance. Hence, the relativity of risk assessment on a macro level comes from the need to appreciate the project’s attributes that may compensate its risk level. Considering both project risk level and project benefit level would yield a more informative and representative picture of the risky nature of the project. Decision makers can utilise the scores of both project risk and benefit when evaluating different projects, ranking them or making selection decisions. For this reason, it is important to assess both project risks and benefits using a common measurement scale. This enables decision maker to compensate between project risk level and project benefit level objectively when making any multi-criteria decision such as bid/no-bid decision, for instance. Thus, embedding risk assessment in a wider decision making framework for project evaluation would be a viable approach for better
risk assessment. The next section presents a multi-criteria decision making framework that envelops the previously illustrated risk assessment approach.

8.3 An evidence-based decision making approach for construction project evaluation

The attributes of a construction project can be organised in a hierarchical structure under two main categories; risks and benefits. In the previous chapter, an evidence-based approach for assessing project risks and generating project risk level was discussed. In this section of the thesis, a similar approach for assessing project benefits and aggregating them for generating an overall project benefit level is covered.

8.3.1 Tangible and intangible benefits of a construction project

In the early stages of the PLC, a construction project must pass a number of gateways for insuring that the project meets minimum requirements from different evaluation perspectives. Financial appraisal and economic measures are usually the most common tools and influencing factors on the decision to go with a project (Rogers 2001; Cooper and Chapman 1987). However, there are many non-financial criteria that add value to the project need to be assessed and considered. Dikmen et al. (2007b) said that such criteria, together with the financial ones, determine an attractiveness level of a construction project. The attractiveness level of a project plays a crucial role in the bid/no-bid decision making after screening a number of potential projects.

Project benefits can be classified under two main categories: tangibles and intangibles. Tangible benefits stand for the financial and economical gains of a construction project. Intangibles, however, include different benefits such as increasing market share, keeping staff at work, improving company’s reputation and enhancing its competitive advantages, securing a long term partnership, keeping specific clients, etc. Analysing the financial and economical benefits of a project may be, relatively, an easier task when compared to analysing the intangibles. Practitioners usually analyse the financial and economical aspects of construction projects and use them as the main evaluation criteria. However, assessing intangible benefits in a transparent and objective manner is a rather difficult task. The difficulty comes from the fact that they are too subjective and can hardly be combined with other evaluation criteria. However, they are considered implicitly when evaluating different projects of proposals.
This research focuses on assessing the intangible benefits of a construction project as their assessment may be problematic. An assessment methodology is proposed for assessing them individually and generating a project benefit level. Project benefit level can be combined with project risk level in order to generate an overall score that can be used, together with the conventional financial and economical measures, for evaluating different alternatives. This endeavour may contribute to the existing construction management literature, which, according to my knowledge, does not have a clear approach or methodology for assessing intangible benefits and including them in project evaluation process. Researching this area and providing a tool for assessing project intangible benefits could be a genuine contribution to project evaluation literature. The proposed approach may or may not be applied in practice, it might also be criticised by practitioners and researchers. However, this attempt may create an academic debate venue and may stimulate further research in this area.

### 8.3.2 Assessment of project intangible benefits

Before assessing an intangible benefit, the analyst has to identify the key benefits that compose the attractiveness feature of the project under analysis. Similar to risk identification, intangible benefits can be classified under a number of categories and organised in a hierarchical structure. The key intangible benefits at the lowest level of project benefit hierarchy are assessed directly by the analyst. Individual assessments can be aggregated later towards the top of the hierarchy in order to generate a project benefit level. In the early stages of the PLC, decision makers may not be able to provide an accurate assessment of project benefits because of lacking enough information and precise data. Hence, assessing an intangible benefit may be conducted by assessing its perceived size and assessing the probability of its materialisation in its perceived size.
As intangible benefits are of different types, they require a common measurement scale. It will be great if intangible benefits can be assessed using the same measurement scale of project risks. This will enable combining their assessments together and comparing different projects accordingly, thus, assessing the size of an intangible benefit is proposed to be through providing a monetary equivalent. The confidence of the assessor in achieving the benefit in its perceived size can be reflected by an adjustment coefficient; Achievability coefficient.

![Figure 8-2: Modelling project benefits](image)

Hence, the assessment of a project intangible benefit can be presented as follows:

\[ B_i = M_i \times A_i \]

Where:
- \( M_i \) : the equivalent monetary sum of the intangible benefit \( B_i \)
- \( A_i \) : the achievability coefficient value of the intangible benefit \( B_i \)

It should be noted that the same assessment methodology could be applied for assessing tangible benefits. In other words, project profitability, net present value or any other economical measure can be associated with achievability coefficients in order to reflect the probability of the actual profitability or the actual NPV of a project materialising in their perceived values.

8.3.2.1 Pricing intangible benefits

Project intangible benefits can be assessed by means of a financial scale. Such a measurement scale can assess the different types of project intangible benefits and
allow for assessment aggregation. Yet, one may argue against such a proposal and challenge its suitability and applicability. The difficulty surrounding assessing intangible benefits accurately via financial terms is definitely a matter of consideration. However, it is achievable and applicable because such an approach is firmly underpinned by the practice of valuing companies’ intangible capitals\(^\text{13}\) and the economics of art and culture.

Valuing companies’ intangible assets is a rather difficult task whereas, pricing them is a well-established practice in accounting. Businesses are struggling to value intangible capitals correctly and the conventional accounting principles are unable to capture their values and include them in the company’s book value (Murphy and Simon 2002). Yet, the share of the intangible assets, the non-book value of the company, of the overall value has increased remarkably in parallel with the movement from a product or service-based economy towards a knowledge-based economy (Boulton et al. 2000). Despite the difficulty of valuing a company’s intangible capital and the lack of agreement on a systematic way of valuation between different stakeholders, Hunter et al. (2005) concluded that the most suitable way for valuing many different types of intangible capitals is using financial terms. A similar conclusion was drawn by Hofmann et al. (2005) who argued that such a systematic valuation of company’s intangible capital would generate a more realistic valuation which would increase the investors’ return. They recommended an income approach (calculating the potential cash return from an intangible asset) as the most suitable approach for pricing company’s intangible assets.

In a similar way to assessing company’s intangible capital, financial terms are used for valuing cultural capital. Throsby (1999) argued that the cultural value can be measured by means of financial terms. He explained that cultural value contribute to the overall economic value of a cultural asset, a historical building for instance, as people may be willing to pay for the embedded cultural value in it. The cultural value of such a cultural asset gives it a higher economic value than the economic value of its physical entity alone. According to Throsby (1999), in some cultural assets, like paintings for instance, the cultural value is the only element of its economic value as the physical worth of

\(^{13}\) The intangible capital of a company is comprised of its intangible assets. The new International Accounting Standard (IAS 38) defines an intangible asset as an identifiable non-monetary asset without physical substance held for use in the production or supply of goods or services, for rental to others or for administrative purposes (Murphy and Simon 2002). These intangible assets include: copyrights, intellectual property, patents, goodwill, organisational structure, inter and intra-organisational relationships, staff knowledge and skills of procedures for producing existing goods and services, etc.
such an artwork is almost nothing. According to Hutter and Throsby (2008), the price is
effectively represented by a price according to them. The translation of value into price, despite its difficulty, is
straightforward and everyone can understand it (Hutter and Throsby 2008;Throsby 2003). Throsby (2003) explained how the cultural value of an artistic work is interpreted
as a price. According to him, by adopting the mind-set of the neoclassical economist, the cultural worth of an artwork is determined by a negotiated process similar to an
ordinary negotiation process in a simple exchange market. Artwork consumers appreciate and evaluate the content of the work and then discuss and exchange their
assessments. Finally, if a consensus is reached, the artistic value could be interpreted
as a cultural price. The cultural price is dependent on the economic price of the
artwork. They are related to each other and are subject to change over time because of
reassessments by different consumers. In summary, art has a price and the price reflects its cultural and economical value (Throsby and Withers 1985;Throsby 2003).

From the above argument, one can conclude that pricing intangible capital and cultural
value are well-established practices. These practices justify the proposal of assessing
the intangible benefits of construction projects by pricing them. Assessing the intangible attributes of a construction project will not be more difficult than valuing a
piece of art for instance. However, the provided price may not be precise due to lacking
enough information at the early stages of the PLC. For this reason, the price of an intangible benefit could be better represented in a distributed form.

8.3.2.1.1 A distributed assessment of a project intangible benefit price
In order to reflect the uncertainty surrounding the price of a project intangible benefit, a
distributed form of assessment is proposed. In a similar way to assessing risk impact,
the equivalent monetary sum can be presented as a set of assessment grades (percentages of the project initial cost) associated with the assessor’s degrees of belief.
The price of an intangible benefit is assessed by asking the decision maker about the
monetary sum equal to securing the benefit under question. Because he or she may
not be sure about the exact price, the decision maker can provide his or her confidence
levels (degrees of belief) in a number of potential prices (different percentages of the
project initial cost). Hence, the price of an intangible benefit \( B_i \) can be modelled as:

\[
P(B_i) = \{(a_{i1}, G_1), (a_{j2}, G_2), (a_{i3}, G_3), \ldots, (a_{im}, G_m)\}
\]
Where:

- \( G_i \) : assessment grade (a percentage of the project initial cost)
- \( a_{il} \) : the degree of belief that the price of the benefit \( B_i \) equals the grade \( G_i \).

For every identified intangible benefit the assessor is required to produce such a distributed assessment. In addition, the assessor is required to decide on a value of the achievability coefficient for every intangible benefit.

8.3.2.2 Achievability coefficient (A)
Apart from the uncertainty surrounding assessing intangible benefits, it is unrealistic to assume that securing a project benefit is guaranteed. For any reason the project may fail to deliver the potential benefits as perceived in the tendering stage. Moreover, the extent to which the secured benefits are obtained in their expected sizes is another matter of consideration when assessing project intangible benefits. Thus, in order to have a more realistic assessment of project intangible benefits, the probability of fully achieving them in their expected values needs to be considered. Therefore, an adjustment coefficient, \( \text{Achievability coefficient} \), is proposed to reflect this issue. It will play a similar role to the roles of the adjustment coefficients \( F, C, \) and \( D \) that are proposed for better risk assessment.

The achievability coefficient (A) can be defined as an adjustment factor reflecting the degree to which an analyst believes that the project benefit under analysis will be secured in its expected value during the tendering stage. This coefficient also reflects the ability of the project management team in appreciating the potential benefits of a construction project and delivering them effectively. Achievability coefficient also reflects the amount of detailed information about the final product described in the project brief. The value of (A) is proposed to be a proportionate value falls in the range \([0, 1]\). The analyst is required to choose a suitable value for it according to the situation under analysis and according to his or her experience and personal judgment. Table (8-1) illustrates the potential values of (A) in different situations proposed as guidance. Obviously, every organisation has complete freedom of choosing its own assessment standards based on project type, sector, client or procurement system, etc.
From the above table, it is clear that the value of the achievability coefficient is positively correlated with the confidence level and the ability of materialising the expected benefits. In this case, the bigger the value the better the situation in terms of securing project benefits. It is different from the case of the adjustment coefficients of the proposed risk model where small values reflected better ability of mitigating risk impact.

8.3.2.3 Intangible benefit assessment
In order to provide an assessment of a specific intangible benefit, the degrees of belief assigned to the assessment grades must be multiplied by the achievability coefficient. Thus, the assessment will take the following format:

\[ S(B_i) = \{(a_i'1, G_1), (a_i'2, G_2), (a_i'3, G_3), \ldots, (a_i'm, G_m)\} \]

\[ a_i'1 = a_i1 \times A_i \]

Where:
- \( G_i \) : assessment grade (a percentage of the project initial cost)
- \( a_i'1 \) : the degree of belief that the benefit \( B_i \) equals the grade \( G_i \).

8.3.2.4 Assessment aggregation
Having assessed the identified benefits individually, the analyst may aggregate them in order to obtain a project intangible benefit level. Different benefits have different levels
of importance. In a similar approach to aggregating risk assessments, the importance issue is reflected by associating every benefit assessment with a relative weight $\omega_i$. The weights of the benefits of every category must be levelled so their values sum to unity. Benefit assessments are aggregated through the ER algorithm and the result will take a distributed form $S(B)$:

$$S(B) = \{(a_1, G_1), (a_2, G_2), (a_3, G_3), \ldots, (a_m, G_m)\}$$

Where:

- $G_l$: assessment grade (a percentage of the project initial cost)
- $\alpha_l$: the overall degree of belief that the project intangible benefit level equals the grade $G_l$.

8.3.2.5 The process of assessing a project intangible benefit level

Assessing project intangible benefits is proposed to be carried out according to the following sequence:

1. Identify the key intangible benefits
2. Build the intangible benefit assessment hierarchy
3. Assign relative weights ($\omega_i$) to the benefits, the weights must sum to unity under every category
4. Estimate the value of the achievability coefficient for every benefit
5. Choose the assessment grades of project intangible benefits; (different percentages of the project initial cost)
6. Assess the size of the intangible benefit, equivalent price, through assigning degrees of belief to the assessment grades
7. Adjust the assessment of the intangible benefit by multiplying the degrees of belief by the value of the achievability coefficient
8. Repeat step 6 and step 7 for every intangible benefit
9. Aggregate the individual assessments using the ER algorithm, this will yield a distributed assessment of the project intangible benefit level
10. Transform the project intangible benefit level from its distributed form into a single score

The distributed assessments of project intangible benefits may not be complete. Hence, after aggregating the individual assessments, an aggregated degree of ignorance can be obtained. This degree of ignorance can be deployed in order to
generate upper and lower boundaries to the project intangible benefit level. These two boundaries reflect optimistic and pessimistic scenarios and can be averaged if required.

### 8.3.3 Construction project evaluation

In order to compare between different construction projects or proposals, each one needs to be evaluated against a number of attributes. As it was illustrated earlier in this chapter, the attributes are proposed to be categorised in two main categories: risks and benefits. The previous chapter covered the proposed methodology for assessing project risks and aggregating them in order to generate an overall project risk level. This chapter presented a methodology for assessing and aggregating project intangible benefits. Now, in order to compare between different projects based on their risks and benefits, or in order to reflect the relativity in risk assessment on a macro level, both of project risk level and project benefit level need to be combined together.

As it was mentioned earlier in this chapter, comparing between different projects should also consider the financial attributes and the economic measures that ensure the feasibility of a project. However, this research focuses on assessing project risks and intangible benefits and comparing between projects accordingly. Other economic and financial measures can be combined too. For instance, Saaty (2001) proposed a model for combining financial and non-financial project attributes for evaluation and comparison purposes. McCowan and Mohamed (2002) used this model for evaluating different Build-Operate-Transfer (BOT) investment projects in developing countries. Saaty's model, available in figure (8-3), considers the ratio between project cost and project profit as financial feasibility measures and multiply it with the ratio between project opportunity and project risk scores which are non-financial measures. Combining between financial and non financial attributes is beyond the scope of this research.

![Figure 8-3: The project rating model of Saaty (2001), (McCowan and Mohamed 2002)](image)

\[
\text{Project Rating} = \frac{\text{Benefit}}{\text{Cost}} \times \frac{\text{Opportunity}}{\text{Risk}}
\]

*Financial Module*
The reason for not considering such a combination is that different companies may consider, besides project cost and profit, different economic measures like NPV, Internal Rate of Return (IRR), Payback Period (PP), etc. Moreover, there are, usually, hidden policies for evaluating construction project that cannot be clearly modelled or assessed. Politics may play the key role in the final decision regardless of the evaluation results. For this reason, the research main aim is providing a methodology for structuring evaluation problems rather than replacing a decision maker by providing a recipe for a project evaluation task.

8.3.3.1 Combining project risk and benefit levels
There are a number of models that can be used for combining project risk level and project benefit level. No universal model can satisfy the decision maker’s desires in any evaluation task. It is up to him or her to choose a model that best suits his or her requirements in different situations (Dikmen and Birgonul 2006). In order to combine project risks and benefits one can use any of four combination models proposed by Saaty and Ozdemir (2003). These four models are:

1. $\text{ORR} = \frac{\text{OR}}{\text{RR}}$

Where:
- $\text{ORR}$ : opportunity and risk rating
- $\text{OR}$ : opportunity rating of an alternative
- $\text{RR}$ : risk rating of an alternative

This model produces a ratio between project benefits and risks. The model is based on the assumption that project risks must be minimised and project benefits must be maximised, which makes perfect sense.

2. $\text{ORR} = a \times \text{OR} + \frac{b}{\text{RR}}$

Where:
- $a$ : the importance weight of the $\text{OR}$
- $b$ : the importance weight of the $\text{RR}$
This model also assumes that project risks need to be minimised. The inverse of risk rating is added to project benefits rating based on importance weights.

3. \( ORR = a \times OR + b \times (1 - RR) \)

This model assumes that not all risks are bad. The \((1 - RR)\) value is considered as a positive value (Dikmen and Birgonul 2006). This model requires both of \( OR \) and \( RR \) to be proportional figures between 0 and 1.

4. \( ORR = a \times OR - b \times RR \)

This model measures the difference between project risk and benefit levels but with regard to their importance.

Dikmen and Birgonul (2006) proposed a fifth model for linking project risk and opportunity scores. It is given by the following formula: \( ORR = OR \times (1 - RR) \). According to them, the rationale behind this way of combination is that project opportunity level must be reduced in order to account for project risks. Hence, as project risk increases, the deduction of project opportunity must increase. This model also requires both of \( OR \) and \( RR \) to have proportional values between 0 and 1.

All of the above five models can be used for combining the assessments of project risk and benefit levels. They should all generate the same ranking of the alternatives under analysis. It is the decision maker’s duty to choose the model he or she feels more suitable for the problem under analysis. Moreover, he or she should consider the organisation’s strategy and attitude towards risk taking and risk and benefit trade-off as these considerations may favour specific model over the others.

8.3.3.2 Decision support system

The proposed risk and benefit models, assessment methodologies and combination models will only support decision makers if a decision making problem is structured and made transparent and replicable. A spreadsheet-based DSS is built for enabling construction professionals to use these methodologies and models easily. The software has a user-friendly interface and provides the users with illustrative information. It gives them the opportunity to easily analyse different scenarios and
conduct sensitivity analysis. The user is required to utilise his or her experience and personal judgement, with the aid of consultants if required, to provide the right inputs. The tool will automatically conduct all the required calculations for generating individual assessments, aggregated assessments with upper and lower boundaries and an overall score that combines both of project risk and benefit levels. The tool presents the results in numerical and graphical formats. A full illustration of the DSS and the way of operating it are presented in chapter eleven.

8.4 Summary

This chapter covered a novel methodology for assessing project intangible benefits. The methodology is based on identifying the key project benefits, assessing monetary equivalents, assigning achievability values and aggregating individual assessments. A common scale, financial one, is used for assessing project benefits and risks. This enabled combining different assessments together and generating an overall project rating. Project evaluation was looked at as a typical MCDM problem. The combination of project risk and benefit levels, project rating, is used for comparing between different alternatives. It also reflects the relativity in project risk assessment on a macro level.

This chapter and the previous one demonstrated the theoretical contribution towards filling in the research gap. The proposed contribution has a solid theoretical validity as it is built on the basis of well-established theories. However, it still requires practical validation. Practical validation is achieved by investigating the applicability of the proposed models and methodologies in construction industry and researching their suitability for solving real problems. In the coming chapter, the research methodology and data collection are discussed. The field work is conducted to test the merits and shortcomings of the proposed contribution and to seek feedback from construction professionals for further improvement.
Chapter 9: Research Methodology and Data Collection

9.1 Introduction

In the introduction chapter there was a brief illustration of the research methodology. In this chapter, a detailed account is delivered regarding the research methodology and data collection methods. This chapter discusses the research methodology and the philosophical orientation of the researcher. It also presents the data collection techniques used in this research project followed by a justification of these choices. This chapter lays the foundations of the next chapter which is designated for analysing the collected data and making sense of them.

9.2 Basic definitions

Research is a project of academic enquiry conducted for answering valid research questions with a logical sequence of research activities designed to enable answering the raised questions. Subsequently, every research has its unique methodology, philosophical orientation and tools and techniques. Johnson et al. (2007) argued that various research orientations suggest a range of different ontological and epistemological choices. Crotty (1998) argued that the following four questions must be in the mind of the researcher when designing a research project:

- What method to be used?
- What methodology governs the choice and use of methods?
- What theoretical perspective underpins research methodology?
- What epistemology informs the theoretical perspective?

Before we go any further in discussing the methodology of this research, it is important to provide definitions to some terms used above like research methodology, epistemology, ontology, etc.

**Research methodology** is the “strategy, plan of action, process, or design laying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes” (Crotty 1998, p.3). It shows the roadmap of achieving research objectives. Research methodology is different from research
methods which are the tools and techniques used for collecting and analysing data. There is no best research methodology or method that can fit any research. Some research methods are more suitable for answering some research questions than other ones. Hence, it is essential to decide on the research methodology and methods that best answer the research questions and ensure the validity and reliability of the results.

Validity is, simply, the correctness or credibility of a description, conclusion, explanation, interpretation, or any other sort of account (Maxwell 1996). It is a measure of correctness of any type of research findings or results. Reliability, on the other hand, can be defined as the consistency of results after repeating the same process or methodology many times by different people. It measures the extent to which research findings are independent of accidental circumstances (Kirk and Miller 1986). It is important to appreciate the difference in concept between reliability and validity and to appreciate that none of them guarantees the other.

Ontology is the theory of what exists (Sayer 1992); it is concerned with the nature of reality (Saunders et al. 2007). There are two main ontological orthodoxies; objectivism and constructivism. The objective approach assumes that there is an objective truth that is required to be discovered by the researcher. This approach regards the social world as something external to the humans, the social actors, not as something they participate in the process of fashioning it (Bryman 2004). The other orthodoxy, the constructive approach, perceives knowledge as a result of social interaction. It is not objective truth to be discovered, but a construction built by debating and revision.

Epistemology is the theory of knowledge (Sayer 1992); it concerns what constitutes acceptable knowledge in a field of study (Saunders et al. 2007). The two main epistemological orientations are the positivism and the interpretivism. The positivist researcher prefers a rather “scientific” approach when generating knowledge. According to this school of thoughts, methods of natural sciences should be applied when researching social phenomena (Dainty 2008). On the contrary, the interpretive approach advocates the point of view that human phenomena could not be treated as objectives of natural science. The proponents of this approach emphasise the importance of understanding human behaviour (Bryman and Bell 2007).

The different epistemological and ontological approaches have an immense impact on the research design and the tools and techniques for data collection and analysis. It is essential for any researcher to answer a fundamental question about his or her philosophical position and orientation towards their research project.
9.3 Research approaches

Different research approaches can be followed with different philosophical orientations and different tools and techniques for collecting and analysing data.

9.3.1 Extensive research (Quantitative)

Extensive research focuses on studying the social phenomenon at the event level following a very objective way in dealing with the collected data. Researchers who adopt this approach have to avoid intervening in the data and to focus on the similarities and regularities between as many objects as possible of the targeted population. The aim is to obtain general, objective and scientific results able to reflect the whole population and could be generalised over similar ones. Ideally, the researcher examines all the members of the population. However, in practice he or she needs sampling because of the impossibility of examining the whole population. Hence, the researcher will always attempt to get as representative as possible sample.

The quantitative research approach reflects a positivist epistemological orientation with an aim of explaining and predicting based on empirical facts; it avoids any value judgements or subjective interpretation of the researcher (Scapens 1990). Although there is a long-standing debate about the appropriateness of such an approach to study social phenomena, it is a well-established approach as it can generate objective results especially when the aim is testing hypothesis or theories in a deductive research. Quantitative research assumes an objective ontological orientation. The research is mainly concerned with social objects, as objective entities, without any concern to their construction within the social reality.

9.3.2 Intensive research (Qualitative)

Different from quantitative research, which seeks regularities and common properties at the event level, qualitative research studies social events and their causal mechanisms in order to reach their actual causes (Sayer 1992). It investigates how generative mechanism works and describes the interaction between the powers that produces a social phenomenon (Danemark 2002). Although sampling is also needed in this type of research, Danemark et al. (2002) argued that sampling in qualitative research is strategic and the sample is very specific and purposeful not as big and representative as possible. It does not aim to have a statistically representative sample,
but a sample of typical member(s) in an endeavour to discover all, or as many as possible, of the properties that a typical member has.

Qualitative research approach adopts different ontological and epistemological positions. Firstly, qualitative research adopts the interpretive epistemological orientation to judge what knowledge is and how to get this knowledge. The cause of such an orientation is that the application of scientific approach for studying social phenomena is not appropriate. As a result, researchers have to get rich data to fully understand the social phenomenon through interaction with specific members in the targeted population and then understand and interpret the obtained data within their social constitution. Secondly, this research approach adopts the constructive ontological orientation where the reality of a phenomenon is the result of social construction between the interacting social actors. For this reason, researchers might need to fully involve themselves, maybe become actors like the case of ethnography, in order to appreciate the reality and the reach correct explanation or conclusion.

9.3.2.1 Comparing the quantitative and qualitative research approaches
Both of the quantitative and qualitative approaches have advantages and disadvantages. However, they must be looked at as complementing not competing approaches. Harre (1981) argued that the main advantage of the qualitative design is that great deal of properties can be investigated. On the other hand, he noted that there is a risk that the results may be misleading as the results are generated from assumed typical members of the population that may not be typical. Subsequently the results could hardly be extended to the rest of the members so, the main criticism of the qualitative research is its limited ability of generalising the results. Scapens (1990) distinguished between the “theoretical generalisations” in qualitative research which attempt to generalise theories that explain the observations, and the “statistical generalisations” of quantitative research which is concerned with statements about statistical occurrence in a particular population. Maxwell (1992) who differentiated between internal and external generalisability made a similar distinction. According to him, internal generalisability refers to the generalisability of a conclusion within the setting or group studied, whereas external generalisability refers to its generalisability beyond that setting or group.
Qualitative research is mainly concerned with internal generalisability rather than the external one which is of great importance to quantitative research. The generalisation issue is a long standing debate between the proponents of the two research
Qualitative research has an attribute of being flexible in forming the sample and extracting information from it. Sayer (1992) argued that individuals may be selected one by one as the research proceeds and as an understanding of the casual relations is built up. This means that the intensive approach is flexible, dynamic and responsive for the sake of better understanding results. He added that using a less formal and more interactive approach for data collection the researcher has a much better chance of learning from the participants. He differentiated this approach from the quantitative one that demands formal criteria for sampling in order to secure “representative and large enough sample” and standardized data collection and analysis methods for generating objective and bias-free results.

Concerning the type of obtained results, Danemark et al. (2002) emphasised that one advantage of the intensive, qualitative, approach is the rich results which enable the researcher to explain a particular occurrence or a particular object, as well as a larger social phenomenon. He argued that the results of the extensive, quantitative, approach could not answer questions of causation. The type of obtained results was also discussed by Sayer (1992) who gave advantage to the intensive approach that yields more vivid results. However, he admitted that these results are not representative to the whole population. In fact, the validity of results and the ability of testing their objectivity is a key criticism of the qualitative research. Sayer (1992) argued that some researchers are reluctant to admit that they get more, from qualitative research, in terms of explanation for fear of appearing “unscientific”.

The validity of the results of the two approaches is tested differently. The intensive research adopts the corroboration (verification, proof, and authentication) way and the extensive adopts the replication one. These different ways reflect different goals. According to Sayer (1992), replication enables the researcher to see how general the particular findings are in the wider population, whereas corporation shows whether the results really apply to those individuals that are actually studied.
9.3.3 The mixed-methods approach

Having illustrated the advantages and disadvantages of the two main research approaches, a question raised about which one to choose? To be realistic and objective, one should admit that none of the two approaches can be, alone, sufficient to harvest the utmost benefits from a research project.

Mingers (1997) argued that adopting a particular approach is like viewing the world through a particular instrument such as a telescope, an X-ray machine, or an electron microscope. Each instrument produces a different and “seemingly incompatible” representation of the reality. He argued that adopting only one paradigm would prevent a researcher from gaining a more representative view of the phenomenon. For this reason he concluded that it is always wise to utilize a variety of approaches in order to have a better view. Hence, a better strategy would be following a mixed-methods approach in order to overcome the limitations of each approach and to maximise their potentials.

This opinion has been recommended and supported by many scholars. Sayer (1992) claimed that the best that can be produced is a narrative supported by some results of extensive survey and a few intensive case studies. He advocated a “synthesis research” that combines the results of intensive and extensive research. Such an approach would enable the researcher to make generalisations covering a wide range of constitutive structures, mechanisms, and events. Danemark et al (2002) gave an alternative to the traditional “dichotomy” of quantitative and qualitative approaches: a pragmatic combination of methods called “critical methodological pluralism.” They argued that this theme implies the utilisation of intensive and extensive research designs where the different approaches complement each other. They supported their suggestion by claiming that in the practical research process very often both intensive and extensive approaches are needed. Similarly, Harre’ (1993) recommended the “Joint use” of the intensive and extensive research designs explaining that it can overcome the difficulties and disadvantages of both of them and secure depth and breadth of the results. Dainty (2008) also made the same suggestion and called for a “holism” approach that enables researchers to gain richer insights and a more complete understanding of social phenomena.

It is important to emphasise that quantitative and qualitative approaches serve different intellectual goals, but in a complementing not competing manner. The qualitative
approach mainly serve in generating hypotheses through close observations and inductive orientation. In addition, it helps in improving the hypothesis and testing it through critical case studies as Scapens (1990) argued. On the other hand, quantitative research adopts deductive orientation. It helps in testing the generality of the hypothesis and in generating a covering law capable of describing the whole phenomenon.

From the above arguments, one can conclude that the best strategy is to combine the two approaches. Such combination will secure the statistical generalisation and the theoretical generalisation.

### 9.4 Sampling

Data is collected from a sample of participants in the research whose selection is crucially important when designing a research project. As collecting data from every member of the targeted population is impossible, sampling is inevitable whatever the research approach is. The sample size and the representativeness of the sample should always be key consideration. The research approach would affect the sample size and the sampling manner. In quantitative research, the sample size should be as big as possible; the sample is selected statistically. However, in qualitative research the sample is relatively small and strategically composed of typical members of the population. At the beginning, a researcher needs to define the population by setting up a sampling frame which is a list of all cases that form the population (Hoxley 2008). Ideally, the sampling frame should be a complete list of the population members. However, in practice this may be impossible. In this research project, for instance, the sampling frame was a list of UK construction companies obtained from the FAME database.

Having identified the sampling frame, a researcher can choose the sample in different ways. This can be done by random sampling, every member of the sampling frame has equal probability to be included in the sample, or by non-random sampling where criteria are considered for selecting the sample. Non-random sampling techniques include systematic sampling, stratified sampling and cluster sampling.

### 9.5 Data collection methods

Data collection is one of the most important and difficult steps of doing research. The
way in which the data are collected is inherently related to the research question and the philosophical orientation of the researcher. Different tools and techniques can be used for collecting data. The decision of choosing a data collection method very much depends on the research approach and the research objectives and questions. For instance, in quantitative research when researchers aim to test a hypothesis, they usually use the survey technique in order to reach as many as possible of the population members, whereas in qualitative research, where the aim is to explore a phenomenon and understand it fully in its social structure, researchers usually do unstructured interviews to get rich data about the phenomenon. They may apply a case study for the sake of comprehending a specific phenomenon or to explain an organisational behaviour. Qualitative researchers may use different data collection tools like historical records, experiments, action research or ethnography. In mixed-methods approach, researchers may start with qualitative research tools to understand the phenomenon and to formulate a theory. Then, they use quantitative methods for testing the proposed theory or checking its generalisability. On the contrary, they can begin with surveying the population in an attempt to generate hypotheses and then conduct case studies or interviews to test and validate their conclusions. Among different data collection tools, survey (questionnaire or interview) and case study are the most frequently used tools in social science research.

9.5.1 Questionnaires

Questionnaire is a pre-prepared set of questions aimed at research participants to obtain their answers. It is the most common way of conducting a survey. Questionnaires are often used to survey people's beliefs, attitude, feelings, or opinions regarding an issue under investigation. They can be descriptive, describing a phenomenon, or analytical, investigating associations or causality (Hoxley 2008). The questions can be open-ended, closed-ended or categorical. The open-ended questions are useful for exploration purposes, whereas close-ended questions have a specific set of answers and force respondent to choose from a list options. The categorical type of questions is useful for getting general information that can be easily assigned into categories. According to Oppenheim (2000), the quality of a questionnaire is mainly dependant on the wording of questions, data categorizing/scaling/coding and the general layout of the questionnaire. Hoxley (2008) emphasised the importance of considering reliability and validity when designing a questionnaire. He defined reliability as a measure of whether a questionnaire would produce the same results if the study was repeated with a similar sample. Questionnaire validity reflects whether a survey is
measuring what the researcher intended it to measure. It is recommended to discuss questionnaires with colleagues and expert researchers and to pilot it in order to revise it before its formal distribution in order to increase the chance of high response rate.

Questionnaires have an advantage of allowing researchers to reach a large number of respondents in a relatively low cost. It is also easy to analyse data and to avoid any bias by applying statistical analysis to the coded data. However, the disadvantages of a mailed questionnaire, which is the most common way of administering a survey, are delay in getting responses, low response rate, which is typically between 25% and 35% (Hoxley 2008; Fellows and Liu 2008), and the difficulty of correcting any mistake after distributing the questionnaire. Questionnaire can also be administered online. It is a very easy and relatively cheap method for reaching a huge number of people. However, it has a disadvantage of a lower response rate than a mail survey. Another limitation in this method is the difficulty of determining actual response rate when distributing a questionnaire through professional or social communities rather than sending it to a list of e-mail addresses.

9.5.2 Interviews

Interviewing is another tool for surveying the opinions and attitudes of research participants. However, it is conducted in a more engaging format between researchers and participants. It is a very effective tool for eliciting rich data from participants which is crucial for exploring or explaining complex situations or phenomena. According to Haigh (2008), a good interview is the art and science of exploring the subjective knowledge, opinions and beliefs of participants. For this reason, conducting interviews requires more transferable skills for recruiting interviewees and making the utmost from interviewing them. These skills are important in order to exploit the interviewing opportunities conducted face-to-face or on phone.

Interviews can be structured, semi-structured or unstructured. In structured interviews, the researcher comes with predefined questions and interview schedule regarding a research topic. In unstructured interviews, though, an interview is a smooth discussion between the researcher and the interviewees directed by a number of open-ended questions to guide the dialog. It is a very useful way for explaining and exploring complicated situations or for getting advices from experts in their fields. It is usually used at a preliminary stage or exploratory stage, before conducting a more formal and in-depth investigation. Despite its usefulness, it is more difficult than structured
interview to be analysed. Between these two extremes semi-structured interview lies. It contains a mixture of close-ended and open-ended questions discussed through the interviews. This type of interviews combines the benefits of both structured and unstructured interviews. The level of structure depends on the research questions and the researcher’s objective from the interviews.

As a data collection tool, interview has the advantage of providing rich data and deep insights about the research problem and securing a high response rate. However, it has a number disadvantages. It is relatively expensive, time consuming and effort demanding for transcribing and analysing qualitative data. It is also accused of being subject to human bias when analysing and interpreting data.

9.5.3 Case study

Case study is a research strategy and a data collection tool for understanding the dynamics within a specific setting (Eisenhardt 1989). It is an empirical inquiry that investigates a contemporary phenomenon within its real life context using multiple sources of evidence (Yin 2003). The key point of the study is the “case” or the unit of analysis which can be an organisation, an individual, an industry, a project, etc. Case study can be conducted using a single case or multiple cases. It includes data collection techniques like reviewing historical records, interviews, observations and questionnaires. As a result, it provides researchers with a very rich account of data with deep insights about the unit of analysis. Case study can be adopted for different purposes. It can be used in exploratory studies, to provide description, and it can be used for building theories and it can be used for evaluating propositions and testing theories (Eisenhardt 1989). Case study is regarded as a powerful research methodology due to the triangulation element of it. Triangulation means considering different perspectives and using multiple data collection methods from different evidence sources. It is considered as a powerful tool for enhancing the validity of research results and conclusions. Case study has attracted huge attention from researchers who favoured it due to the depth and richness of data it can generate. However, it is always under attack from quantitative researchers who are concerned about generalising the findings’ beyond the studied case(s).
9.6 The design of this research project

This research is designed based on the results of the literature review and the analysis of the research gap. New risk model, risk assessment methodology and framework for evaluating construction projects were proposed and validated theoretically based on the existing theories and the published literature. The research fieldwork is designed to validate these contributions practically. This requires investigating the actual practice of risk assessment and project evaluation and examining the extent to which the proposed models, risk assessment methodologies and project evaluation framework are useful and practical from a construction professionals’ perspective. Hence, this is a deductive type of research where a proposed theory requires testing in practice.

The fieldwork started with a pilot study, an interview and a workshop with a number of construction professionals. The main research approach was a mixed-methods approach: qualitative and quantitative. It included two questionnaires, postal and online, seven semi-structured interviews, two interviews were face-to-face and five on-phone, and four validation case studies. Except the online survey, the whole fieldwork activities were conducted in the UK.

Through the questionnaires, the participants were confronted with a set of statements about specific behaviours and actions related to risk assessments and project evaluation. They were asked to express their opinions and to agree or disagree with the statements using a 7 points likert scale. The objective of administering the questionnaires was to examine the agreement of construction professionals with the theoretical basis of the proposed risk model, assessment methodology and evaluation framework. During the interviews, though, great efforts were put in order to get as much information as possible about the actual practice of risk assessment and project evaluation and the main difficulties in these practices. The proposed approaches for risk assessment and project evaluation were also discussed. In addition, interviewees were asked to provide feedback regarding practicality, suitability and usability. The interviews were crucial for surveying the opinions of different professionals representing various construction companies in terms of size and expertise. They investigated the limitations of actual practices and used tools and helped in eliciting the features of better alternatives; this was very useful for designing the DSS.

Four case studies, validation workshops, were arranged for examining the DSS in practice with four construction companies in the UK. The aim was to show potential
users how to use the tool for analysing real projects and to get their feedback about it. They were asked to validate the tool in terms of ease of use, practicality, usefulness, limitations, etc. They were also asked to provide their suggestions for improvement.

The mixed-methods approach was very suitable for this research. Yet, it was a time consuming and a demanding task, but it did pay off. Very rich data and deep insights from construction professionals were obtained and the different sources of evidence were crucial for validating the research contribution.

9.6.1 Pilot study

The field work started with a pilot study including a workshop with construction professionals in a small construction company with an annual turnover of £15 million. The company is specialised in residential and refurbishment projects. It is based in Greater Manchester. Access to this company was arranged through personal relations with the operational manager. Four managers attended the workshop: the operational manager, the financial manager, the risk and health and safety manager and the contracting and tendering manager. It was an exploratory study for gaining better appreciation and understanding of the real risk analysis and project evaluation practice. The study also investigated the attributes of a good DSS that may appeal to construction professionals. The schedule of the pilot study and the questions discussed are available in Appendix (III).

Together with the findings of the extensive literature review, the pilot study was very helpful in revising the initial research questions, developing the new risk model and new risk assessment methodology and defining the characteristics of the DSS. It was also useful for developing the questionnaire and the interview schedule. The pilot study helped in convincing the company’s managing board to continue their collaboration in this research. In return, they were promised to have a free copy of the DSS and to arrange a training and application session.

9.6.2 Questionnaire design

A good questionnaire design is essential for getting the utmost of administering it and increasing the response rate. A good questionnaire design is, actually, a matter of experience and practice. Research methodology literature provides valuable information about the best practice of designing good questionnaires. According to
Oppenheim (2000), in order to have a good questionnaire design, researchers must take the following issues into consideration:

- questions’ wording (clarity and ease of answering);
- the language (avoiding jargon);
- avoiding double and leading questions;
- avoiding biased questions;
- questions’ sequence;
- questionnaire layout; and
- instructions for completing the questionnaire

As mentioned earlier, the aim of administering the questionnaire is to examine the agreement of construction professionals with the theoretical basis of the proposed risk model, assessment methodology and evaluation framework. The respondents were asked to express their opinions concerning every statement (question) using a 7 points likert scale for a set of statements. The likert scale ranges from 1, (total disagreement), till 7 (full agreement). The questionnaire included two open-ended questions where respondents were encouraged to describe their practice. There was also a designated part for providing general information about the respondents and their organisations.

An initial design was produce. It was later revised and developed after consulting some colleagues and getting their feedback. The supervisory team was also involved in agreeing on the final version of the questionnaire which is available in Appendix (II). The final version was a two-page questionnaire with 33 questions organised in three parts: part one for general information about the respondent and the organisation, part two about risk assessment and part three about project evaluation. When designing the questionnaire layout, part one was moved to the end of the questionnaire and risk assessment questions came first after the introduction and the covering letter. For mail survey, the covering letter was personalised for every selected respondent in order to show respect and to maximise the response rate.

9.6.2.1 The questionnaire
The final version of the questionnaire included the following:

- **Part One: Background, specifications and company information:** This part included 7 questions. Four questions were asked to get information about the education level of the respondents, the current position in the organisations, length of experience and the type of projects the respondent was experienced
in. Three questions were asked about the organisations’ annual turnover and its practice of risk assessment and project evaluation. Respondents were asked to state whether there is designated staff or department for risk management and whether the organisation has a formal approach or protocol for evaluating construction projects. These two questions were of yes/no type with a designated space for detailed explanation.

- **Part two: Risk assessment:** This part included 17 questions in total. Seven questions were asked about the practice of risk assessment, six questions about the idea of using monetary equivalent for measuring risk impact and the suitability of such an idea and four questions were asked about the role of experience and personal judgment in risk assessment.

- **Part three: Project appraisal, evaluation and selection:** This part included 9 questions in total. Five questions investigated the practice of assessing intangible benefits and evaluating construction projects, three questions covered the idea of measuring intangible benefits using monetary equivalent and one question about the reasons of not using decision support systems.

9.6.2.2 Postal questionnaire

9.6.2.2.1 Sampling frame and sample selection

Literature suggests that formal procedures for risk assessment and decision making are more likely to exist in bigger companies. The pilot study confirmed this point. For this reason, data was decided to be collected from big companies as the small ones are taken into consideration through the interviews and one validation case study. The annual turnover was considered as a measure of size. A minimum turnover of £50 million in the last financial year was used to refine the search results. Contact details of UK based construction companies were obtained from the FAME data base. The search focused on the contracting companies which are involving in construction activities rather than companies specialised in other activities like logistics, prefabrication, facilities or construction services. The available contact details were reviewed in order to identify potential participants like construction department managers, people working in project management, contracting and procurement management, bidding management, etc. The search also considered the persons’ background like: construction management, project management, quantity surveying,
civil engineering and architectural backgrounds. As a result, a list of 1034 people was composed as a sampling frame.

A stratified sampling approach was adopted. Due to time and resource limitations, a sample of 420 people was aimed at. The sampling frame was divided into four strata as illustrated in table (9-1). From every stratum, a number of people were randomly selected.

<table>
<thead>
<tr>
<th>Company turnover</th>
<th>Number of potential respondents</th>
<th>Number of randomly selected contacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 1 billion</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>501 million – 1 billion</td>
<td>273</td>
<td>130</td>
</tr>
<tr>
<td>100 – 500 millions</td>
<td>361</td>
<td>140</td>
</tr>
<tr>
<td>50 - 100 millions</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>Sum</td>
<td>1034</td>
<td>420</td>
</tr>
</tbody>
</table>

Table 9-1: Sample and sampling frame of the postal questionnaire

The number of selected people from every stratum was decided to give priority to the bigger companies. For instance, in the companies with annual turnover of more than 1 billion pounds a year, 50% of the identified people were selected randomly, whereas in the case of the companies with annual turnover between £50 million and £100 million, 33% of the identified people were randomly selected. Although a random selection approach was adopted, covering as many companies as possible was taken into consideration. In other words, random selection was applied within the available contacts in every company. However, in the case of companies with one or two available contacts only, the priority was given to covering more companies.

The postal questionnaire ended with a note inviting the respondent for further collaboration in the research. Three people expressed their interest. As a result, two interviews with senior managers in two construction companies and three application case studies were conducted. It was pointed out clearly that a free copy of the DSS will be provided in return for participating in this research.
9.6.2.2.2 The response rate of the postal questionnaire

Within 5 weeks from sending the postal questionnaires, a sum of 94 complete questionnaires and 37 incomplete ones were received. Different reasons were behind not completing the questionnaires as illustrated in table (9-2):

<table>
<thead>
<tr>
<th>Undelivered; change in address</th>
<th>Unfilled due to death</th>
<th>Unfilled without explanation</th>
<th>No policy to participate in surveys</th>
<th>Unfilled due to retirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 9-2: Reasons for not completing the postal questionnaire

As 27 questionnaires were unfilled due to death, change in address or retirements, it was concluded that the FAME data base was not up-to-date. The 37 invalid questionnaires were excluded from the initial 420 and the effective rate of return can be calculated based on remaining 383 questionnaires assuming that they have reached their destinations. With 94 complete questionnaires, the effective response rate was 24.5%. In order to have a better understanding of the respondents, a non-response bias test was conducted. As displayed in table (9-3), the responses cover all the companies’ categories. A very good response rate can be found in the small and giant companies; 32% response rate. The response rates of the other two categories were not that good. However, the absolute numbers claim a considerable chunk of the total number of responses. This gives a considerable representation of these companies in the obtained data.

<table>
<thead>
<tr>
<th>Company’s turnover</th>
<th>no. of distributed questionnaires</th>
<th>no. of responses</th>
<th>% of response</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 1 billion</td>
<td>50</td>
<td>16</td>
<td>32%</td>
</tr>
<tr>
<td>501 million – 1 billion</td>
<td>130</td>
<td>19</td>
<td>14.6%</td>
</tr>
<tr>
<td>100 – 500 millions</td>
<td>140</td>
<td>26</td>
<td>18.6%</td>
</tr>
<tr>
<td>50 - 100 millions</td>
<td>100</td>
<td>32</td>
<td>32%</td>
</tr>
</tbody>
</table>

Table 9-3: Non-response bias test

A response rate of 24.5% was quite good. However, more responses were aimed at in order to cover a wider spectrum of expertise. Moreover, the postal questionnaire surveyed the attitudes and opinions of the construction professionals in the UK. It was thought that investigating the attitude of construction professionals in a wider range was useful. As a result, an on-line survey was arranged for.
9.6.2.3 Online questionnaire
The aim of the online questionnaire was to reach as many construction professionals as possible and to support the findings of the postal one. The same questions were used when developing the on-line questionnaire. However, as the on-line communities may include people with different occupations (professionals, consultants, researchers, etc.) from all over the world, two additional questions were added to the original questionnaires. One question asked the respondent to indicate his or her current occupation and the other one asked for indicating the country or countries from which the experiences were obtained. The questionnaire is available on-line at:
http://FreeOnlineSurveys.com/rendersurvey.asp?sid=f7e8jht9t0k9ban774073

In order to reach potential participants on-line, the on-line questionnaire’s URL was circulated among members in a number of on-line communities interested in construction and project management. Being a member of the Cooperative Network of Building Researchers (CNBR), which is a very famous and active on-line community, and 35 professional groups in the linked-in network was crucial for reaching thousands around the world. As a result, 166 complete questionnaires were received. The response rate cannot be calculated in this case as the number of people who received the invitation to participate in the questionnaire cannot be determined. However, the 166 responses will definitely support the research findings as the total number of respondents will be 260.

9.6.3 Semi-structured interviews
Seven semi structured interviews were conducted with construction professionals in different construction companies in the UK. Interviewing started with two face-to-face interviews with two managers of those who participated in the pilot study. Later, through a common friend, another interview was conducted on phone with a project manager in a very big and famous construction company in the UK. As mentioned earlier, the postal and on-line questionnaires are ended with a statement asking for further research collaboration to anyone interested in the research topic. Five people indicated that they were interested and sent their contact details. As a result, four semi-structured interviews were carried out on phone. The interviews aimed at investigating the same issues surveyed in the questionnaire but in-depth and with focus on understanding the causes and the reasons behind any practice or attitude. The interviews were guided by an interview schedule which is available in Appendix (IV).
9.6.4 Validation cases

In order to validate the DSS practically and to get feedback from construction professionals, four validation case studies were arranged with four construction companies in the UK. The companies varied in size, geographical location and specialisation. Before every application session, a copy of the DSS and a user guide were sent to help the participants in their preparation for the session and to give them an initial idea about the tool and the theory behind it. Every application session started with a brief presentation about the tool, the required inputs, the assessment methodology and the theory behind the tool’s interface. Professionals were informed that the calculations and the aggregation algorithms were hidden from them to make it simple and user-friendly. After presenting the tool, an illustrative example was used to help the participants in comprehending the analysis methodology. The participants were asked to choose a project, from their historical records, to be used as an illustrative example. Unfortunately, only one company did so. For this reason, the inputs of this project were used, without naming the projects or giving any details about the owner, the contractor, the location or any other confidential information in the other application sessions. After displaying how to use the tool for real application, professionals were asked to express their opinions about the proposed analysis methodology and the tool as a whole. A set of evaluation criteria was used and the participants were asked to assess the tool against it. A detailed account of the validation cases and the feedback of the participants will be presented in chapter 11.

9.6.5 Justification of the research design

The literature review suggests that risk analysis and decision making is, mainly, a subjective task based on previous experience. It also shows a clear shift in analysing risk towards more subjective techniques. Hence, the research methodology should reflect these issues and enable investigating the research questions deeply through direct engagement with the practitioners. A qualitative research approach is essential for appreciating the desires and the generative mechanisms when analysing risk and making risky decisions. However, it is also important to research the extent to which these desires and behaviours are common across the sector. Thus, a quantitative approach is required to investigate the extent to which the proposed alternatives meet the aspirations of construction professionals and get their appreciation and acceptance. It is important to obtain their criticism as well in order to further develop the proposals and to enhance their usability and applicability. Indeed, the postal and online
questionnaires were administered in response to these requirements. The proposed risk and benefit models and the assessment and evaluation approaches are utilised through a DSS. The DSS need practical validation in order to figure out any limitations or problems that may face the users when adopting the proposed models and approaches. Thus, a number of validation case studies are vital for testing the tool and getting feedback from potential users.

It seems that a mixed-methods approach is a very effective approach for addressing the research questions. It enables understanding the practices, examining the viability of the proposed models and methodologies statistically and testing them practically. Such an approach can provide a statistical and theoretical generalisation to the research outcomes. As discussed earlier, this research approach is recommended as the best research approach. Moreover, it aligns with my point of view that a researcher should not put him or herself in a philosophical box and try to find suitable research questions for his or her philosophical orientation. In fact, there is no best research approach for all research problems. A researcher should be flexible and ready to blend between the available options in order to enhance the reliability of the research methodology and increase the validity of the findings.

Although the mixed-methods research approach is recommended by many scholars as discussed earlier, this does not mean that no limitations exist. Every research has its limitations that need to be acknowledged. Doing so adds to the credibility of the research findings and clearly identifies the boundaries of their validity. The limitations of this research methodology are discussed in detail in the discussion chapter.

9.7 Summary

This chapter discussed research methodology and presented the different research approaches and tools for data collection. It also highlighted the philosophical orientations that govern the different research approaches. The design of this research project was outlined and justified. It is a mixed-methods approach using a blend of quantitative and qualitative techniques for data collection. This chapter is an introduction to the next chapter, which is designated for presenting the collected data and analysing them. It highlights the results and the key findings of administering the postal and on-line surveys and the semi-structured interviews. Chapter 11, in turn, is designated for presenting the DSS and the results of the validation cases.
Chapter 10: Data Analysis

10.1 Introduction

This chapter is designated for analysing the collected data from the questionnaires and the interviews. It starts by analysing the data collected from the postal and the on-line questionnaires and examining any variance between the responses of different respondent categories. The analysis is conducted through the Statistical Package for the Social Sciences (SPSS) software. The analysis of the interviews' transcripts will then be presented and the findings of this analysis will be compared with the obtained results from the questionnaires in an attempt to explain and enrich them. The analysis results will show the extent to which the proposed contribution for filling in an existing gap in the literature of risk assessment is a viable alternative from a practical perspective.

10.2 Analysing questionnaire’s data

As mentioned in the previous chapter, the questionnaire is composed of three main sections: general information about the respondent and the construction company, the practice of risk assessment and the project evaluation and selection. Analysing questionnaire data will be scheduled according to the sequence of these three sections. The objective of data analysis is providing a description of the participants in the survey and their companies and measuring their attitudes regarding the issues raised in the questionnaire. Data analysis will show any variance in the attitudes according to the size of the construction company, the length of experience, the type of respondents, etc. Such a variance analysis is attainable as the questionnaire included questions with categorical types of answers and questions with likert scales. The analysis will also consider the answers of the open-ended questions.

10.2.1 Descriptive statistics

10.2.1.1 Part One: Background, specifications and company information

10.2.1.1.1 Information about the respondents
The total number of responses is 260; 94 responses to the mail questionnaire and 166 to the on-line one. All the respondents to the mail questionnaires were professionals in British construction companies. However, the online questionnaire was open to
different types of construction-related occupations all over the world. Actually, 95 respondents described themselves as professionals, 19 as consultants, 19 as researchers, 23 as professionals and consultants, 3 as researchers and professionals and 4 as professionals, consultants and researchers. In terms of countries of experience, the respondents to on-line questionnaire named the country or countries from which they gained their experience. 56% indicated that they got their experiences from one country, 19.3% from two countries, 11.4% from three countries and 13.3% from four or more countries.

Among the 260 respondents, 235 people indicated their current positions in their organisations. The majority of them, 102 people, were executive managers, 50 of them were department managers and 45 of them were project managers as illustrated in table (10-1).

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid Project Manager</td>
<td>45</td>
<td>17.3</td>
<td>19.1</td>
<td>19.1</td>
</tr>
<tr>
<td>Department manager</td>
<td>50</td>
<td>19.2</td>
<td>21.3</td>
<td>40.4</td>
</tr>
<tr>
<td>Executive manager</td>
<td>102</td>
<td>39.2</td>
<td>43.4</td>
<td>83.8</td>
</tr>
<tr>
<td>Advisor</td>
<td>28</td>
<td>10.8</td>
<td>11.9</td>
<td>95.7</td>
</tr>
<tr>
<td>Project Engineer or Quantity Surveyor</td>
<td>10</td>
<td>3.8</td>
<td>4.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>235</td>
<td>90.4</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Missing System</td>
<td>25</td>
<td>9.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>260</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10-1: The current positions of the questionnaire respondents

The respondents varied in terms of length of experience in construction industry. The majority of the respondents to the mail survey, 65 out of 93 who answered this question, are executive managers and 64.5% of them have more than 30 years of experience in construction industry. This fact was a key reason for administering the on-line questionnaire. It was aimed to survey the attitudes and the opinions of younger generations of construction professionals who, in theory, should be more up-to-date in terms of using technology and, subsequently, may have different attitudes towards the proposed approach. Table (10-2) shows that the breakdown of the respondents to the mail and on-line questionnaire was more balanced than the respondents to the mail one only. Although the majority of them still have more than 30 years of experience, this majority is 35% of the respondents only.
The respondents have got a wide range of expertise in different types of construction projects. They were asked to tick the types of projects they are experienced in and to mention any other types not mentioned in the questionnaire. Table (10-3) shows that commercial, industrial, residential and infrastructure construction project were the most frequently selected types. Moreover, the table shows a wealth of experiences in very different types of construction projects. This is very helpful for generalising the findings of the research over a wide range of construction domains.

Table 10-2: The length of experience of the questionnaire respondents

<table>
<thead>
<tr>
<th>Valid Length of Experience</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10 years</td>
<td>45</td>
<td>17.3</td>
<td>17.4</td>
<td>17.4</td>
</tr>
<tr>
<td>10 – 20 years</td>
<td>66</td>
<td>25.4</td>
<td>25.5</td>
<td>42.9</td>
</tr>
<tr>
<td>21 – 30 years</td>
<td>55</td>
<td>21.2</td>
<td>21.2</td>
<td>64.1</td>
</tr>
<tr>
<td>More than 30 years</td>
<td>93</td>
<td>35.8</td>
<td>35.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>259</td>
<td>98.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Missing System</td>
<td>1</td>
<td>.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>260</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10-3: The types of projects in which questionnaire respondents are experienced

<table>
<thead>
<tr>
<th>Type of construction project</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential projects</td>
<td>130</td>
</tr>
<tr>
<td>Industrial projects</td>
<td>161</td>
</tr>
<tr>
<td>Commercial projects</td>
<td>165</td>
</tr>
<tr>
<td>Property development projects</td>
<td>102</td>
</tr>
<tr>
<td>Infrastructure projects</td>
<td>120</td>
</tr>
<tr>
<td>Roads, Bridges &amp; Transportation projects</td>
<td>112</td>
</tr>
<tr>
<td>Other projects:</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>3</td>
</tr>
<tr>
<td>Education</td>
<td>2</td>
</tr>
<tr>
<td>Health</td>
<td>3</td>
</tr>
<tr>
<td>Heritage</td>
<td>2</td>
</tr>
<tr>
<td>Fit out</td>
<td>3</td>
</tr>
<tr>
<td>Off-Shore Construction Projects</td>
<td>21</td>
</tr>
<tr>
<td>Geotechnical &amp; Ground projects</td>
<td>24</td>
</tr>
</tbody>
</table>
10.2.1.1.2 Information about the construction companies

Four questions were asked about the respondents’ organisations. Regarding the size of the company, respondents were asked to indicate the annual turnover. 237 people answered this question. The results show that the majority of the respondents, 41.1% of them, work in companies with annual turnovers of less than £100 million and a sizable 18.6% of the respondents work in giant companies with annual turnovers of more than £1 billion.

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>Less than 100 millions</td>
<td>98</td>
<td>37.7</td>
<td>41.4</td>
</tr>
<tr>
<td></td>
<td>100 – 500 millions</td>
<td>56</td>
<td>22.3</td>
<td>65.8</td>
</tr>
<tr>
<td></td>
<td>501 m – 1 Billion</td>
<td>37</td>
<td>14.2</td>
<td>81.4</td>
</tr>
<tr>
<td></td>
<td>More than 1 Billion</td>
<td>44</td>
<td>16.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>237</td>
<td>91.2</td>
<td></td>
</tr>
<tr>
<td>Missing</td>
<td>System</td>
<td>23</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>260</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 10-4: The annual turnover of the construction companies in sterling pounds

The respondents were asked whether or not there was a designated department or staff for RM in their organisations. 247 people answered this question; 42.4% answered positively and 57.5% answered negatively. Another question asked whether or not the companies adopted systematic approaches or formal protocols for evaluating construction projects. Out of the 243 answers to this question, there was 57.2% positive answers and 42.3% negative answers. Tentatively, it seems that the interest in having a designated department or staff for risk management is not as high as having a formal approach or protocol for evaluating projects. This may be attributed to a low interest in RM, under-valuation of its importance or to considering RM as an integrated part of project evaluation protocols without giving it a separate entity. This explanation could be closer to reality as it is supported by the answers to the question that investigated the project evaluation techniques. These answers, displayed in table (10-5), indicate that RM tools and techniques are regarded as project evaluation tools. Out of 70 answers, 17 people considered the formal RM process, risk register and the probability and impact matrix as tools for comparing and evaluating different construction projects. Besides, 10 people mentioned that risk analysis software and simulation tools were used for comparing different projects. In total, 38.6% of the
project evaluation techniques were risk management and analysis tools and only 11.4% of the approaches were formal decision making tools. It seems that risk analysis is inherently related to project evaluation.

<table>
<thead>
<tr>
<th>Data</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board &amp; review Meetings</td>
<td>12</td>
<td>4.6</td>
<td>17.1</td>
<td>17.1</td>
</tr>
<tr>
<td>Scoring</td>
<td>8</td>
<td>3.1</td>
<td>11.4</td>
<td>28.6</td>
</tr>
<tr>
<td>Formal RM steps, PI Matrix &amp; Risk Register</td>
<td>17</td>
<td>6.5</td>
<td>24.3</td>
<td>52.9</td>
</tr>
<tr>
<td>Gateway &amp; Signing offs</td>
<td>6</td>
<td>2.3</td>
<td>8.6</td>
<td>61.4</td>
</tr>
<tr>
<td>Risk analysis Software &amp; Simulation</td>
<td>10</td>
<td>3.0</td>
<td>14.3</td>
<td>75.7</td>
</tr>
<tr>
<td>Decision Making tools; Decision trees</td>
<td>8</td>
<td>3.1</td>
<td>11.4</td>
<td>87.1</td>
</tr>
<tr>
<td>Experience, Lessons from previous cases</td>
<td>7</td>
<td>2.7</td>
<td>10.0</td>
<td>97.1</td>
</tr>
<tr>
<td>Confidential</td>
<td>2</td>
<td>8</td>
<td>2.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>70</td>
<td>25.9</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Missing</td>
<td>100</td>
<td>73.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>260</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10-5: The tools and techniques which are used for construction project evaluation

10.2.1.2 Part two: Risk assessment
The questionnaire included 17 questions about risk assessment. The respondents were asked to express their agreements or disagreements to 17 statements using a likert scale of seven points with 1 standing for total disagreement and 7 standing for full agreement. This part of the questionnaire surveyed the actual practice of risk assessment, the attitudes of construction professionals towards the idea of using monetary equivalent for measuring risk impact and the role of experience and personal judgment in assessing construction risk.

10.2.1.2.1 Risk assessment practice
Seven questions were asked about the practice of risk assessment and contingency estimation. Generally speaking, there is a clear agreement with the statements as it is illustrated in table (10-6). In this table, all the statements had median and mean values above 4 which is the midpoint of the seven-point likert scale that represents a 50% agreement.
It seems that introducing the coefficients of project features, controllability and dependency to the risk model aligns with the actual practice of assessing construction risk. The results also show a systematic risk analysis; identifying the key risks, assessing them separately and then aggregating the assessments in order to obtain a project risk level. The results also confirm the literature suggestion that practitioners allocate contingency sums in a rather simple manner; an approximate sum of money is put aside to cover the project risks collectively without a detailed or formal analysis.

### Table 10-6: The practice of risk assessment

<table>
<thead>
<tr>
<th>Description</th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risks are different in terms of your ability to mitigate their impact when they occur</td>
<td>259</td>
<td>7</td>
<td>6.00</td>
<td>5.60</td>
<td>1.595</td>
</tr>
<tr>
<td>Your ability to mitigate the impact of a specific risk is different from one project to another</td>
<td>260</td>
<td>7</td>
<td>6.00</td>
<td>5.50</td>
<td>1.523</td>
</tr>
<tr>
<td>You discount a possible risk impact when other related and dependent risks have already been accounted for</td>
<td>258</td>
<td>5</td>
<td>5.00</td>
<td>4.30</td>
<td>1.786</td>
</tr>
<tr>
<td>You identify the risks that may affect a project and measure their impacts separately</td>
<td>260</td>
<td>6</td>
<td>6.00</td>
<td>5.25</td>
<td>1.640</td>
</tr>
<tr>
<td>You aggregate the impacts of the identified risks in order to generate a project risk level</td>
<td>260</td>
<td>6</td>
<td>6.00</td>
<td>5.25</td>
<td>1.526</td>
</tr>
<tr>
<td>When preparing your bid, you approximate and allocate a contingency sum to account for possible risks</td>
<td>260</td>
<td>6</td>
<td>6.00</td>
<td>5.43</td>
<td>1.501</td>
</tr>
<tr>
<td>When estimating the contingency sum, you account for project risks collectively not independently</td>
<td>260</td>
<td>6</td>
<td>5.00</td>
<td>4.79</td>
<td>1.875</td>
</tr>
</tbody>
</table>

**10.2.1.2.2 Measuring risk impact in financial terms**

In order to test the suitability of measuring risk impact by a monetary equivalent, six questions were asked. Again, the results, presented in table (10-7), show that the idea is quite acceptable, convenient and practical. It was agreed that this was a well-established practice. However, the results suggest that the respondents found it a bit difficult to provide a monetary equivalent to risk impact on project quality.
Table 10-7: The respondents’ attitudes toward measuring risk impact in financial terms

<table>
<thead>
<tr>
<th>Risk impact can be measured as a monetary sum equivalent to the damage created when the risk happens termed as “Risk cost”</th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>260</td>
<td>5</td>
<td>5.00</td>
<td>4.62</td>
<td>1.739</td>
</tr>
</tbody>
</table>

“Risk cost” is a convenient and suitable way for assessing risk impact

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>The idea of “Risk cost” for assessing risk impact is widely accepted and well-established practice in the construction industry</td>
<td>260</td>
<td>5</td>
<td>4.50</td>
<td>4.42</td>
<td>1.610</td>
</tr>
</tbody>
</table>

It is difficult to provide an equivalent monetary sum for all types of risk

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>260</td>
<td>7</td>
<td>6.00</td>
<td>5.60</td>
<td>1.563</td>
</tr>
</tbody>
</table>

You can measure the impact of a specific risk on project duration in monetary terms

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>260</td>
<td>6</td>
<td>5.00</td>
<td>4.81</td>
<td>1.608</td>
</tr>
</tbody>
</table>

You can measure the impact of a specific risk on project quality in monetary terms

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>260</td>
<td>5</td>
<td>4.00</td>
<td>4.22</td>
<td>1.670</td>
</tr>
</tbody>
</table>

This is not a surprising result as the new approach might look unusual to some people who used to get things done in a different manner. This result may point towards a potential difficulty in implementing the proposed methodology even if it has a sound theoretical foundation. Yet, there is a fairly good agreement with the idea of using risk cost as a common scale for measuring the different risk impacts on project objectives.

10.2.1.2.3 **Role of experience in risk assessment**

The results show a great reliance on practical experience and personal judgment in risk assessment. This highlights the importance of structuring the experience and facilitating it, in a systematic and transparent way, for assessing construction risk. The results also reveal that practitioners maintain their reliance of past experience even when facing complicated situations; they do not necessarily use special tools or DSSs to aid them in assessing risk when facing complex projects. More importantly, they tend to rely mainly on past experience and personal judgment even if such tools are in use. This result raises critical questions about the nature of decisions in construction management and the suitability of the available DSSs for aiding these decisions.
10.2.1.3 Part three: Construction project evaluation and selection

This part includes 9 questions in total. Similar to the risk assessment section of the questionnaire, respondents were asked to express their agreement or disagreement about 8 statements regarding project evaluation using a likert scale. The statements covered the practice of assessing project intangible benefits, construction projects evaluation and the idea of measuring intangible benefits using monetary equivalents. A likert scale of seven points was used with 1 standing for total disagreement and 7 standing for full agreement. An additional question in this section asked respondents to indicate the reasons of not using special tools or DSSs for aiding them in decision-making.

10.2.1.3.1 Practice of project evaluation

Five questions were asked about the practice of construction project evaluation. The results, presented in the table (10-9), showed a potential agreement with the idea of using the achievability coefficient when assessing project benefits. The results also suggest that the financial attributes of construction project are still the main attributes when comparing between different construction projects. Subsequently, using monetary equivalent to project risks and benefits is a common practice in construction.
Table 10-9: Construction project evaluation

<table>
<thead>
<tr>
<th>Description</th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>You discount your assessment of project benefits because they may not be</td>
<td>257</td>
<td>4</td>
<td>4.00</td>
<td>4.21</td>
<td>1.488</td>
</tr>
<tr>
<td>always achievable as they are perceived before tendering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The financial risk and the financial benefit of a project are always the</td>
<td>260</td>
<td>6</td>
<td>5.00</td>
<td>5.01</td>
<td>1.633</td>
</tr>
<tr>
<td>main concern when comparing between projects and making commitment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>decisions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using monetary terms for measuring both project risks and benefits is a</td>
<td>260</td>
<td>5</td>
<td>5.00</td>
<td>4.65</td>
<td>1.454</td>
</tr>
<tr>
<td>common practice in order to compare between different projects or proposals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and to rank them accordingly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>You use special tools and decision support systems to support you in</td>
<td>260</td>
<td>5</td>
<td>4.00</td>
<td>3.96</td>
<td>1.789</td>
</tr>
<tr>
<td>evaluating, ranking and choosing different projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>You rely mainly on your experience, intuition and gut feeling for</td>
<td>260</td>
<td>6</td>
<td>5.00</td>
<td>4.83</td>
<td>1.543</td>
</tr>
<tr>
<td>comparing between different projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Similar to risk assessment, practitioners rely mainly on their past experience and personal judgment for comparing between construction projects. Their reliance on DSSs for aiding the evaluation task seems to be quite limited. It is slightly less than their reliance on such tools for the purpose of risk assessment; a mean of 3.96 compared to a mean of 4.13 in the case of risk assessment. This issue is definitely worth a further investigation. It can be attributed to the nature of construction industry and the complexity of choosing a project to bid for or to add to the company’s portfolio. Such a decision is strategic and highly subjective. Therefore, it can hardly be made using the recommendations of software, whereas risk assessment is more technical task so it can be performed in a more technical manner. In addition, the limited reliance on DSSs for project evaluation can be explained when analysing the reasons for not using such tools.

The evaluation process and the selection decision were investigated in the interviews. It seems that in most cases the evaluation and selection decisions are made by the managing director or senior managers in a rather subjective manner after considering the investigations and the assessments of the tendering team. Analysing the
interviews, as it will be illustrated later in this chapter, revealed that these decisions were subjective and did not follow an objective approach like a multi-criteria decision making process. For instance, decisions are mainly made to suit the organisations, strategic policies even if they were not the optimum ones.

10.2.1.3.2 Measuring intangible benefits in financial terms
The idea of measuring intangible benefits using monetary equivalent did not get strong support from the surveyed professionals as illustrated in table (10-10). The participants found it unsuitable to measure intangible benefits of construction project like reputation or market share using monetary equivalent. They did not agree that such an approach was widely adopted in construction industry.

<table>
<thead>
<tr>
<th>Intangible benefits of a project such as market share, and reputation can be measured by providing equivalent monetary sums</th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>259</td>
<td>2</td>
<td>3.00</td>
<td>3.24</td>
<td>1.567</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equivalent monetary sum is a suitable way for assessing project intangible benefits</th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>260</td>
<td>4</td>
<td>3.00</td>
<td>3.42</td>
<td>1.556</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The method of measuring project intangible benefits in terms of monetary sums is widely acceptable and well-established practice in construction industry</th>
<th>N</th>
<th>Mode</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>260</td>
<td>4</td>
<td>3.00</td>
<td>3.33</td>
<td>1.600</td>
</tr>
</tbody>
</table>

Table 10-10: Measuring intangible benefits using monetary equivalents

This issue needs further investigation in order to find the reasons of not agreeing with such suggestion. This may be attributed to the viability of pricing intangible benefits. In theory, it is possible to do so as it was fully explained in chapter 8. However, it may be not suitable for the construction industry. This result might have been different if the matter had been discussed with the practitioners in more detail using illustrative examples. This issue will be addressed again when analysing the interviews and the validation cases to examine whether or not the professionals’ attitude will change after discussing the idea of pricing intangible benefits using illustrative examples. Whatever the result is, it is up to the practitioners to decide whether or not to use such an approach. It has a theoretical basis and justification in different industries like the art
and culture industry. However, the applicability of such an approach may not be attainable in different sectors.

10.2.1.4 Reasons for not using DSS
The last question in section three of the questionnaire investigates the reason(s) of not using DSSs for aiding decision making in construction industry. In the mail questionnaire, the respondents were provided with six potential reasons, based on the literature review and the pilot study. They were asked to use the same seven-point likert scale to show the criticality of each reason. Participants were encouraged to mention any other reasons for not using DSS. The answers of this question, shown in table (10-11), were not very helpful as the respondents almost selected all the reasons and gave them very similar importance.

<table>
<thead>
<tr>
<th>Reasons for not using DSS</th>
<th>Frequency</th>
<th>Median</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>They are complicated</td>
<td>75</td>
<td>4</td>
<td>3.59</td>
</tr>
<tr>
<td>They contradict your intuition and experience</td>
<td>74</td>
<td>4</td>
<td>3.7</td>
</tr>
<tr>
<td>You lose control over the decision making process</td>
<td>79</td>
<td>5</td>
<td>4.35</td>
</tr>
<tr>
<td>You do not trust them</td>
<td>74</td>
<td>4</td>
<td>3.86</td>
</tr>
<tr>
<td>You are not aware of how the system works</td>
<td>75</td>
<td>3</td>
<td>3.52</td>
</tr>
<tr>
<td>You do not need them because you are experienced</td>
<td>74</td>
<td>4</td>
<td>3.91</td>
</tr>
</tbody>
</table>

Table 10-11: The reasons for not using DSS in the mail questionnaire

The above table shows that losing control over the decision making process was given a slightly more importance than the other reasons. The respondents did not give any other reasons for not using DSSs. This result led to a tentative conclusion that the respondents to the mail questionnaire did not have good experience in using such tools. This explanation can be supported with the fact that 64.5% of the respondents had more than 30 years of experience in construction industry.

In order to enrich the investigation of the reasons for not using DSS, the question was changed in the on-line questionnaire. The respondents were asked to indicate the reason(s) using tick boxes rather than likert scales. They were also asked to mention any other reasons. In this case, the results were more useful. As presented in table
(10-12), the most frequently selected reason was lack of awareness of how the systems worked. The next most important reasons were losing control over the decision making process and the lack of trust in such tools.

<table>
<thead>
<tr>
<th>Reasons for not using DSS</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>They are complicated</td>
<td>17</td>
</tr>
<tr>
<td>They contradict your intuition and experience</td>
<td>17</td>
</tr>
<tr>
<td>You lose control over the decision making process</td>
<td>21</td>
</tr>
<tr>
<td>You do not trust them</td>
<td>19</td>
</tr>
<tr>
<td>You are not aware of how the system works</td>
<td>38</td>
</tr>
<tr>
<td>You do not need them because you are experienced</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 10-12: The reasons for not using DSS in the on-line questionnaire

<table>
<thead>
<tr>
<th>Other reasons</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>They are not available</td>
<td>8</td>
</tr>
<tr>
<td>Human experience is the key factor</td>
<td>3</td>
</tr>
<tr>
<td>They are like a Black Box</td>
<td>1</td>
</tr>
<tr>
<td>Projects are simple, immature risk, no need for DSS</td>
<td>3</td>
</tr>
<tr>
<td>DSS is not sufficient</td>
<td>2</td>
</tr>
<tr>
<td>Not practical, Time consuming, not cost effective</td>
<td>5</td>
</tr>
</tbody>
</table>

22 respondents to the on-line questionnaire gave other reasons for not using DSSs. These reasons are listed in table (10-12). It is clear that the availability of such tools and their practicality and cost effectiveness were the most frequently mentioned reasons. The respondents emphasised the importance of human experience as the key element in decision making and noted the insufficiency of a DSS for replacing human judgment. It is also important to mention that practitioners expressed that they know how to get job done when projects are not that complicated. Hence, they mentioned that they did not use any support tools as there was no need for them. This issue is important as it raises the issue of cost effectiveness of the DSS and the level of project complexity that justifies using such tools. Actually, this may indicate the need of investigating the relation between the usage of DSSs and the size of construction companies. Intuitively, the bigger the company and the more strategic and complicated
the projects are, the more the need for using DSSs. In fact, the reasons of the limited usage of DSSs should be considered when designing any DSS in order to enhance its usability. This, in turn, may lead to improving the practice of risk assessment and decision making in construction industry.

10.2.2 Analytical statistics

After presenting the results of the questionnaire, it is worth investigating the effect of the size of the company on the maturity level of its practice of risk assessment and decision-making. Moreover, it is essential to analyse the variance in the obtained results according to different respondents’ categories, company’s size, length of experience in construction industry, countries of experience and the different maturity levels of risk assessment and decision making. Such an analysis enriches the research findings and further explains the above presented results. The questionnaire included questions with categorical and ordinal data types. In order to analyse the variance in the obtained results, Chi-squared statistical test is used to analyse the relationship between categorical data and non-parametric tests are used to analyse the variance between categorical and ordinal data types as the normality test suggested that the ordinal data was not normally distributed.

10.2.2.1 The effect of company’s size on practice maturity

The relationship between the size of the company and the maturity of RM and project evaluation practice is investigated. A cross-tabulation was conducted between the answers of the company’s size and the existence of designated department or staff for RM and the existence of formal protocols for project evaluation. Chi square analysis was conducted to examine any significant statistical differences between the different categories. Actually, the results showed significant difference in practice maturity according to company size as it is illustrated below.

10.2.2.1.1 The relationship between company’s size and the existence of designated department or staff for RM

The figure (10-1) shows a clear tendency to having designated staff or department for RM in bigger construction companies. Only 22.4% of the companies with annual turnovers of less than £100 million have a designated staff or department for RM, whereas 37.9% of the companies with annual turnovers between £100 million and £500 million, 64.8% of the companies with annual turnovers between £500 million and
£1 billion and 72% of the giant companies with annual turnovers of more than £1 billion do have.

![Figure 10-1: The relationship between company’s size and the existence of RM department](image)

In order to check whether the above result did not happen by chance and to test whether or not a significant statistical difference did exist between the different size categories, chi-squared test was conducted. The chi-squared statistical test showed that the difference was statistically significant: $x^2 = 39.711, p = 0.00 < 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>39.711a</td>
<td>3</td>
<td>.000</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>40.761</td>
<td>3</td>
<td>.000</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>38.474</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>236</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. 0 cells (0%) have expected count less than 5. The minimum expected count is 15.52.

Hence, there is a relation between the size of the construction company and the existence of designated staff or department for RM. This may, to some extent, explain why small companies may not use special tools or DSSs for risk analysis.
10.2.2.1.2 The relationship between company’s size and the existence of formal protocols for project evaluation

The questionnaire results, displayed in figure (10-2), show that only 33.3% of the companies with annual turnovers less than £100 million have formal approaches or protocols for evaluating construction projects, while 52.6% of the companies with annual turnovers between £100 million and £500 million, 63.9% of the companies with annual turnovers between £500 million and £1 billion and 86% of the giant companies with annual turnovers of more than £1 billion do have.

![Figure 10-2: The relationship between company’s size and the existence of formal protocols for evaluating construction projects](image)

Again, Chi-squared test was conducted in order to check whether or not these results happened by chance. The chi-squared statistical test showed that the difference was statistically significant: \( x^2 = 35.425, p = 0.00 < 0.05 \). This means that definitely there is a relationship between the size of the company and the complexity of their decision making process regarding project evaluation. This may suggest that DSSs are more likely to be used in these companies to aid their decision making process.
10.2.2.2 The relationship between the existence of designated department or staff for RM and having formal protocols for project evaluation

The relationship between having a designated department or staff for RM and having formal protocols for project evaluation was investigated. 76.5% of the companies that have designated department for RM do have formal protocols for project evaluation and 65% of the companies that do not have designated department for RM do not have formal protocols for project evaluation.

![Bar chart showing the relationship between designated department or staff for RM and formal protocols for project evaluation](image)

**Figure 10-3: The relationship between having designated department or staff for RM and formal protocols for project evaluation in construction companies**

The chi-squared statistical test showed that there is a statistically significant difference: $x^2 = 40.96, p = 0.00 < 0.05$. This means that there is a clear relationship between the existence of designated staff or department for RM and having formal approaches or protocols for project evaluation. This reflects a logical and expected result as mature companies should have a balanced maturity in their different functions.

10.2.2.3 Analysis of variance

The potential differences in the answers to the questions with likert scales according to the categorical questions were investigated. In order to do so, decisions need to be made about the suitable statistical test to deal with the obtained data. The first step is the normality test.

10.2.2.3.1 Normality test

Assuming a normal distribution for the obtained data without an objective test is not acceptable and may lead to wrong data analysis. Testing normally is essential for
choosing suitable statistical tests. Normality test, or Kolmogorov-Smirnov test, is the widely used way of testing whether or not the data are normally distributed. The results of the test will label the collected data as parametric or non-parametric data. The normality test was conducted and the result showed statistically significant difference (sig < 0.05) between the normal distribution and the actual distributions of all the questions. Hence, the collected data is a non-parametric data. It could have been better to have a parametric data as parametric tests are more powerful than the non-parametric tests in discerning variance (Pallant 2007). However, the collected data is clearly not having normal distributions. As a result, I did not make a normality assumption or tried to manipulate the data to become normally distributed. I decided to deal with the real data and to conduct non-parametric tests. According to Pallant (2007), this option means that both of Mann-Whitney U and Kruskal-Wallis tests can be used to test the variance.

10.2.2.3.2 Variance according to different respondents’ categories
In order to investigate whether different respondents have different points of view regarding the investigated issues in the questionnaire, the Kruskal-Wallis test of variance was applied using the question “your current position” as an independent variable and the 25 questions of section two and section three of the questionnaire as dependent variables.

<table>
<thead>
<tr>
<th>Current Position</th>
<th>N</th>
<th>Mean Rank</th>
<th>Chi-square</th>
<th>Asymp. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk impact can be measured as a monetary sum equivalent to the damage created when the risk happens termed as “Risk cost”</td>
<td></td>
<td></td>
<td>13.557</td>
<td>0.009</td>
</tr>
<tr>
<td>Project Manager</td>
<td>45</td>
<td>117.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Department manager</td>
<td>50</td>
<td>130.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Executive manager</td>
<td>102</td>
<td>123.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advisor</td>
<td>28</td>
<td>75.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Engineer &amp; Quantity Surveyan</td>
<td>10</td>
<td>118.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| “Risk cost” is a convenient and suitable way for assessing risk impact            |    |           | 13.706     | 0.08        |
| Project Manager                                                                 | 45 | 121.39    |            |             |
| Department manager                                                              | 50 | 132.20    |            |             |
| Executive manager                                                               | 102| 115.64    |            |             |
| Advisor                                                                         | 28 | 82.25     |            |             |
| Project Engineer & Quantity Surveyan                                              | 10 | 155.90    |            |             |

| The method of measuring project intangible benefits in terms of monetary sums    |    |           | 14.270     | 0.006       |
| Project Manager                                                                 | 45 | 108.21    |            |             |
| Department manager                                                              | 50 | 126.76    |            |             |
| Executive manager                                                               | 102| 114.98    |            |             |
| Advisor                                                                         | 28 | 104.07    |            |             |
is widely acceptable and well-established practice in construction industry

<table>
<thead>
<tr>
<th></th>
<th>Project Engineer &amp; Quantity Surveyor</th>
<th>10</th>
<th>188.10</th>
</tr>
</thead>
</table>

Using monetary terms for measuring both project risks and benefits is a common practice in order to compare between different projects or proposals and to rank them accordingly

<table>
<thead>
<tr>
<th></th>
<th>Project Manager</th>
<th>45</th>
<th>108.69</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Department manager</td>
<td>50</td>
<td>122.95</td>
</tr>
<tr>
<td></td>
<td>Executive manager</td>
<td>102</td>
<td>118.58</td>
</tr>
<tr>
<td></td>
<td>Advisor</td>
<td>28</td>
<td>102.29</td>
</tr>
<tr>
<td></td>
<td>Project Engineer &amp; Quantity Surveyor</td>
<td>10</td>
<td>173.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10-13: Variance according to different respondent categories

Kruskal-Wallis test was used as the independent variable has more than two levels. In fact, it has five levels namely: project manager, department manager, executive manager, advisor and project engineer or quantity surveyor. With a significance level of 5%, the results indicated significant differences in four areas only as it is displayed in the above table. The variance concentrated around the idea of using monetary terms for measuring risk impact and assessing intangible benefits. It seems that the advisors were less enthusiastic to such an idea, whereas other people were more enthusiastic.

As can be seen from the mean rank column, project engineers and quantity surveyors were, in general, very enthusiastic about using monetary terms as a common scale. Similar attitude was expressed by the department managers, and to some extent project managers, who may seek a practical way for aiding their decisions. The attitude of the advisors may be explained by the fact that they tend to consider a more comprehensive picture with various subjective factors when assessing risks or benefits. Hence, they might have found the idea of measuring risks and benefits using monetary scales limited or inadequate.

Another variance test was conducted in the on-line questionnaire results between the respondents who described themselves as professionals, researchers, consultants and any combination between these three professions. There was no significant difference among these categories. The same test was conducted after collating the respondents to the mail and on-line surveys together and categorising the mail respondents as professionals. Again, there was no significant difference among these categories.
### Variance according to countries of expertise

The effect of culture on the actual practice was investigated. The attitudes of the respondents from the UK and from the rest of the world were compared. The most recent country of experience was considered because many of the respondents to the on-line survey mentioned different countries from which they obtained their experiences. The respondents to the mail questionnaire and the respondents to the on-line questionnaire who named the UK as their sole country of experience or the first country of experience were considered in one category and the rest of the respondents were considered in another category. Categorisation can be done in many different ways as the results cover respondents from all over the world. However, as the primary data collection was conducted in the UK and because the on-line survey was administered to support the mail one, this categorisation was the most logical one.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Rank</th>
<th>Mann-Whitney U</th>
<th>Asymp. Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risks are different in terms of your ability to mitigate their impact when they occur</td>
<td>UK 138</td>
<td>141.32</td>
<td>6787.500</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>117.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>You can measure the impact of a specific risk on project duration in monetary terms</td>
<td>UK 139</td>
<td>121.42</td>
<td>7147.000</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>140.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>You can measure the impact of a specific risk on project quality in monetary terms</td>
<td>UK 139</td>
<td>121.96</td>
<td>7222.500</td>
<td>0.046</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>140.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When preparing your bid, you approximate and allocate a contingency sum to account for possible risks</td>
<td>UK 139</td>
<td>116.76</td>
<td>6500.000</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>146.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intangible benefits of a project such as market share, and reputation can be measured by providing equivalent monetary sums</td>
<td>UK 138</td>
<td>115.23</td>
<td>6311.000</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>146.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalent monetary sum is a suitable way for assessing project intangible benefits</td>
<td>UK 139</td>
<td>113.42</td>
<td>6035.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>150.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The method of measuring project intangible benefits in terms of monetary sums is widely acceptable and well-established practice in construction industry</td>
<td>UK 139</td>
<td>118.33</td>
<td>6717.500</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>144.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using monetary terms for measuring both project risks and benefits is a common practice in order to compare</td>
<td>UK 139</td>
<td>119.58</td>
<td>6891.500</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>Outside the UK 121</td>
<td>143.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
You use special tools and decision support systems to support you in evaluating, ranking and choosing different projects

<table>
<thead>
<tr>
<th></th>
<th>UK</th>
<th>119.96</th>
<th>6945.000</th>
<th>0.014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside the UK</td>
<td>121</td>
<td>142.60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10-14: Variance according to countries of experience

The table (10-14) summarises the areas of significant difference between the two categories according to Mann-Whitney test of variance. It seems that the UK practitioners are less supportive to the idea of using monetary equivalents for measuring risk impact on project duration and quality than practitioners from other countries. The same attitude is exhibited regarding assessing intangible benefits using monetary equivalent. Moreover, people in the UK showed less reliance on structured approaches, like considering multi-criteria and trading them off, for evaluating construction projects. Their reliance on DSSs for aiding decision making process was also less than people with experience from outside the UK.

It seems that the proposed approach for risk assessment and project evaluating has got more support from people with experience from outside the UK. It is very difficult to provide a proper explanation for this result as people with experience from outside the UK cannot be dealt with as a homogeneous group to compare against. However, one can assume that, due to cultural reasons, people in the UK construction industry may follow rules, approaches or protocols to analysing risk and making decisions rather than computerized DSSs. Hofstede and Hofstede (2005) recorded low “uncertainty avoidance” scores in the Anglo and Nordic countries like the USA, the UK, Sweden and Denmark. Dane and Pratt (2007) suggested that people from these cultures may be more likely to favour intuitive judgments in decision making than people from other cultures. Hence, one may explain the results by attributing them to a cultural reason. Moreover, Boddy (2008) suggested that people with low scores on uncertainty avoidance tend to utilise their intuition to manage ambiguous and uncertain situations. This implies a tendency to rely on subjective analysis rather than objective one.

In fact, the above differences can be explained in a rather different way. They can be attributed to the fact that the majority of the UK respondents were senior managers with a very long experience in construction which may suggest that they are less familiar with new technological development in the areas of risk assessment and
decision making and more dependent on their experiences and personal judgments to analyse problems and make decisions.

10.2.2.3.4 Variance according to length of experience

A Kruskal-Wallis test of variance was conducted to explore the effect of the length of experience on the respondents’ attitudes. Six areas of significant difference between the respondents were identified; they are summarised in the table (10-15).

The effect of length of experience was not consistent among these areas which required analysing each of them individually. The effect of experience on the ability of mitigating the impact of different risks was clear and logical; people with longer experience agreed that their capability of mitigating impact was different from one risk to another. However, there was no clear trend regarding the effect of project specification on the ability of mitigating risk impact. The mean rank of people with 10-20 years of experience and people with 20-30 years of experience contradicts the ranks of the other categories which are quite logical. There is no clear explanation for such a result but at least the two extreme cases, people with less than 10 years of experience and people with 20-30 years of experience, give logical results.

<table>
<thead>
<tr>
<th>Length of Experience</th>
<th>N</th>
<th>Mean Rank</th>
<th>Chi-square</th>
<th>Asymp. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risks are different in terms of your ability to mitigate their impact when they occur</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 10 years</td>
<td>44</td>
<td>107.00</td>
<td>15.956</td>
<td>0.001</td>
</tr>
<tr>
<td>10 – 20 years</td>
<td>66</td>
<td>111.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 – 30 years</td>
<td>55</td>
<td>135.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>more than 30 years</td>
<td>93</td>
<td>149.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your ability to mitigate the impact of a specific risk is different from one project to another</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 10 years</td>
<td>45</td>
<td>150.86</td>
<td>11.990</td>
<td>0.007</td>
</tr>
<tr>
<td>10 – 20 years</td>
<td>66</td>
<td>121.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 – 30 years</td>
<td>55</td>
<td>148.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>more than 30 years</td>
<td>93</td>
<td>115.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalent monetary sum is a suitable way for assessing project intangible benefits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 10 years</td>
<td>45</td>
<td>155.12</td>
<td>10.063</td>
<td>0.018</td>
</tr>
<tr>
<td>10 – 20 years</td>
<td>66</td>
<td>139.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 – 30 years</td>
<td>55</td>
<td>119.78</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The method of measuring project intangible benefits in terms of monetary sums is widely acceptable and well-established practice in construction industry

<table>
<thead>
<tr>
<th>Experience</th>
<th>Less than 10 years</th>
<th>10 – 20 years</th>
<th>21 – 30 years</th>
<th>more than 30 years</th>
<th>Total</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>156.43</td>
<td>147.64</td>
<td>113.18</td>
<td>114.64</td>
<td>16.490</td>
<td>0.001</td>
</tr>
<tr>
<td>45</td>
<td>148.59</td>
<td>143.20</td>
<td>108.39</td>
<td>124.42</td>
<td>10.398</td>
<td>0.015</td>
</tr>
<tr>
<td>66</td>
<td>140.41</td>
<td>110.80</td>
<td>110.80</td>
<td>140.85</td>
<td>8.811</td>
<td>0.032</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Using monetary terms for measuring both project risks and benefits is a common practice in order to compare between different projects or proposals and to rank them accordingly

<table>
<thead>
<tr>
<th>Experience</th>
<th>Less than 10 years</th>
<th>10 – 20 years</th>
<th>21 – 30 years</th>
<th>more than 30 years</th>
<th>Total</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>117.38</td>
<td>147.64</td>
<td>113.18</td>
<td>114.64</td>
<td>16.490</td>
<td>0.001</td>
</tr>
<tr>
<td>45</td>
<td>148.59</td>
<td>143.20</td>
<td>108.39</td>
<td>124.42</td>
<td>10.398</td>
<td>0.015</td>
</tr>
<tr>
<td>66</td>
<td>140.41</td>
<td>110.80</td>
<td>110.80</td>
<td>140.85</td>
<td>8.811</td>
<td>0.032</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

You relay mainly on your experience, intuition and gut feeling for comparing between different projects

<table>
<thead>
<tr>
<th>Experience</th>
<th>Less than 10 years</th>
<th>10 – 20 years</th>
<th>21 – 30 years</th>
<th>more than 30 years</th>
<th>Total</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>117.38</td>
<td>147.64</td>
<td>113.18</td>
<td>114.64</td>
<td>16.490</td>
<td>0.001</td>
</tr>
<tr>
<td>45</td>
<td>148.59</td>
<td>143.20</td>
<td>108.39</td>
<td>124.42</td>
<td>10.398</td>
<td>0.015</td>
</tr>
<tr>
<td>66</td>
<td>140.41</td>
<td>110.80</td>
<td>110.80</td>
<td>140.85</td>
<td>8.811</td>
<td>0.032</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10-15: Variance according to length of experience

Regarding the idea of measuring intangible benefits by means of monetary equivalents, it is clear that the younger generations were more enthusiastic about it. The older generations were more conservative in agreeing with this idea. This may explain why the agreement level with this proposition was relatively low bearing in mind the high percentage of people, 57.1% of the respondents, with more than 20 years of experience. The results showed that younger generation, people with less than 20 years of experience, believed that a multi-criteria approach using risk and benefits as evaluation attributes was a common practice. The older generations, however, had a different view. This may be attributed to the fact that younger generations are, presumably, using, or familiar with, DSSs that adopt MCDM approaches. The final area of significant difference was a bit controversial. It is logical that very experienced people would mainly rely on their experience for evaluating construction projects and people with relatively short experience would show less reliance on their experience. The responses of the people with 21-30 years of experience contradicted the intuition based on the responses of the other categories. This can be explained by the possibility that these practitioners have got a good experience with DSSs, or they work in companies that adopt systematic approaches and formal protocols for making
decisions. Hence, they do not usually make decisions based on experience or personal judgment.

10.2.2.3.5 Variance according to company’s size (annual turnover)
Table (10-16) includes the areas of significant difference according to the size of the construction company. All of the areas of difference are related to the role of experience and subjectivity in risk assessment and project evaluation. One can see a common and logical theme among all areas of variance.

<table>
<thead>
<tr>
<th>Current turnover of your organization</th>
<th>N</th>
<th>Mean Rank</th>
<th>Chi-square</th>
<th>Asymp. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your experience and gut feeling play a crucial role in assessing risk impact and the likelihood of its occurrence</td>
<td>Less than 100 million</td>
<td>98</td>
<td>130.07</td>
<td>7.899</td>
</tr>
<tr>
<td></td>
<td>100 – 500 million</td>
<td>58</td>
<td>122.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>501 m – 1 Billion</td>
<td>37</td>
<td>100.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 1 Billion</td>
<td>44</td>
<td>104.95</td>
<td></td>
</tr>
<tr>
<td>When facing complex and unique projects, you use formal tools and software for assessing risk and project risk level</td>
<td>Less than 100 million</td>
<td>98</td>
<td>110.66</td>
<td>9.464</td>
</tr>
<tr>
<td></td>
<td>100 – 500 million</td>
<td>58</td>
<td>109.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>501 m – 1 Billion</td>
<td>37</td>
<td>125.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 1 Billion</td>
<td>44</td>
<td>144.91</td>
<td></td>
</tr>
<tr>
<td>Even if you are using decision support systems, your experience, gut feeling and intuition still play the key role in providing your final assessment</td>
<td>Less than 100 million</td>
<td>98</td>
<td>128.20</td>
<td>17.424</td>
</tr>
<tr>
<td></td>
<td>100 – 500 million</td>
<td>58</td>
<td>136.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>501 m – 1 Billion</td>
<td>37</td>
<td>88.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 1 Billion</td>
<td>44</td>
<td>100.40</td>
<td></td>
</tr>
<tr>
<td>You use special tools and decision support systems to support you in evaluating, ranking and choosing different projects</td>
<td>Less than 100 million</td>
<td>98</td>
<td>105.14</td>
<td>18.396</td>
</tr>
<tr>
<td></td>
<td>100 – 500 million</td>
<td>58</td>
<td>107.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>501 m – 1 Billion</td>
<td>37</td>
<td>133.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 1 Billion</td>
<td>44</td>
<td>152.70</td>
<td></td>
</tr>
<tr>
<td>You relay mainly on your experience, intuition and gut feeling for comparing between different projects</td>
<td>Less than 100 million</td>
<td>98</td>
<td>128.12</td>
<td>16.585</td>
</tr>
<tr>
<td></td>
<td>100 – 500 million</td>
<td>58</td>
<td>135.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>501 m – 1 Billion</td>
<td>37</td>
<td>85.59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 1 Billion</td>
<td>44</td>
<td>104.74</td>
<td></td>
</tr>
</tbody>
</table>

Table 10-16: Variance according to the size of construction companies
It is very clear that people from smaller companies rely more on past experience and personal judgment for risk assessment and project evaluation, whereas people from bigger companies use more objective approaches and DSSs for risk assessment and project evaluation; they have less reliance on past experience or personal judgment. This result is logical as smaller companies tend to work as sub-contractors or execute easier projects in which past experience may be enough for analysing risk and making decisions.

### 10.2.2.3.6 Variance according to the maturity level of RM practice

The effect of having a designated department for RM in the construction companies was investigated in order to test the effect of mature practice on the attitude of construction professionals towards risk assessment and project evaluation. Using Mann-Whitney test of variance, table (10-17) summarises the areas of significant difference (p<0.05).

<table>
<thead>
<tr>
<th><strong>Is there a designated department or staff for RM</strong></th>
<th><strong>N</strong></th>
<th><strong>Mean Rank</strong></th>
<th><strong>Mann-Whitney U</strong></th>
<th><strong>Asymp. Sig. (2-tailed)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>You discount a possible risk impact when other related and dependent risks have already been accounted for</td>
<td>Yes</td>
<td>104</td>
<td>111.42</td>
<td>6128.000</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>141</td>
<td>131.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>245</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When facing complex and unique projects, you use formal tools and software for assessing risk and project risk level</td>
<td>Yes</td>
<td>105</td>
<td>140.00</td>
<td>6241.000</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>142</td>
<td>112.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>247</td>
<td></td>
<td></td>
</tr>
<tr>
<td>You use special tools and decision support systems to support you in evaluating, ranking and choosing different projects</td>
<td>Yes</td>
<td>105</td>
<td>143.00</td>
<td>5774.500</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>142</td>
<td>109.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>247</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your experience and gut feeling play a crucial role in assessing risk impact and the likelihood of its occurrence</td>
<td>Yes</td>
<td>105</td>
<td>112.44</td>
<td>5460.500</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>142</td>
<td>132.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>247</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 10-17: Results of variance test according to the maturity level of RM practice**
Table (10-17) shows that people who work in companies with mature RM practice were not enthusiastic about the idea of discounting risk impact due to considering dependent risks. This attitude is appreciated because these people may follow different approaches and procedures that assume independence between risk factors and does not recommend such actions. Hence, they do not adjust or discount risk impact with regard to other identified risks. However, people in the other category, who do not have such formal approaches for RM, may assess risk impact subjectively and adjust risk impact while considering related risks. The other three areas of difference were very logical as mature practice in RM is usually combined with formal approaches for analysing project risk, high level of maturity in decision-making and low reliance on subjectivity and personal judgment.

10.2.2.3.7 Variance according to the maturity level of decision making
The effect of having well-established protocols and approaches for decision-making and project evaluation was investigated using Mann-Whitney test. Table (10-18) summarises the areas of significant difference (p<0.05). The analysis results show that people who use formal tools and techniques for decision-making and project evaluation have expressed a higher degree of agreement with the idea of risk cost for measuring risk impact than people who do not. However, they have shown a lower degree of agreement with assessing contingency sum by considering project risks collectively than the other people. These results can be explained by the possibility that professionals who use formal tools and techniques for project evaluation may use similar concepts to risk cost. Hence, they found it suitable to measure risk impact. Moreover, because they use structured approaches for decision making it is unlikely to deal with contingency estimation in a rather arbitrary way. Hence, they may follow a systematic way of identifying project risks, analysing risk and then covering them financially. Regarding discounting the assessments of intangible benefits, results show that people from companies with mature decision-making practice were less enthusiastic towards such an idea. This may be explained in a similar way of explaining why practitioners in companies with a high level of RM maturity did not largely agree with discounting risk impact due to dependency issue. In other words, they may follow formal protocols that do not recommend such a discount. The other areas of difference were quite logical. Mature practice in decision making is usually combined with high level of maturity in RM and low reliance on subjectivity and personal experience.
Are there systematic approaches for project evaluation

<table>
<thead>
<tr>
<th>Are there systematic approaches for project evaluation</th>
<th>N</th>
<th>Mean Rank</th>
<th>Mann-Whitney U</th>
<th>Asymp. Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The idea of “Risk cost” for assessing risk impact is widely acceptable and well-established practice in construction industry</td>
<td>Yes</td>
<td>128</td>
<td>130.61</td>
<td>6258.000</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>115</td>
<td>112.42</td>
<td></td>
</tr>
<tr>
<td>When estimating the contingency sum, you account for project risks collectively not independently</td>
<td>Yes</td>
<td>128</td>
<td>112.79</td>
<td>6180.500</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>115</td>
<td>132.26</td>
<td></td>
</tr>
<tr>
<td>When facing complex and unique projects, you use formal tools and software for assessing risk and project risk level</td>
<td>Yes</td>
<td>128</td>
<td>138.12</td>
<td>5296.500</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>115</td>
<td>104.06</td>
<td></td>
</tr>
<tr>
<td>You discount your assessment of project benefits because they may not be always achievable as they are perceived before tendering</td>
<td>Yes</td>
<td>126</td>
<td>109.40</td>
<td>5784.000</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>114</td>
<td>132.76</td>
<td></td>
</tr>
<tr>
<td>You use special tools and decision support systems to support you in evaluating, ranking and choosing different projects</td>
<td>Yes</td>
<td>128</td>
<td>139.60</td>
<td>5107.000</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>115</td>
<td>102.41</td>
<td></td>
</tr>
<tr>
<td>You relay mainly on your experience, intuition and gut feeling for comparing between different projects</td>
<td>Yes</td>
<td>128</td>
<td>111.02</td>
<td>5954.500</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>115</td>
<td>134.22</td>
<td></td>
</tr>
</tbody>
</table>

Table 10-18: Results of variance test according to the maturity level in project evaluation

10.3 Analysing interviews’ data

As mentioned earlier, seven semi-structured interviews were conducted with construction practitioners coming from different construction companies. Two face-to-face interviews were conducted with two practitioners working in a small construction company based in greater Manchester area. Due to distance and time constraints, the other five interviews were conducted by telephone. The interviewees were promised
that no confidential details will be revealed. Hence, only the initials of the interviewees’ names will be used. The table (10-19) shows that the interviewees represent a wide spectrum of construction companies whose operations cover most of the UK geographically. The diversity of interviewees’ experiences and positions provide a fairly representative picture of the practice of risk analysis and project evaluation in the UK construction industry. Five of the interviewees have more than 20 years of experience in construction industry and both of Mr. S and Mr. D have 10 years of experience. The interviewees belong to different generations with different skills. Their familiarity with DSSs and experience in using them is also very dissimilar. The number of interviews is fairly small. Thus, there was no pressing need to use any specialised software for analysing the qualitative data. The interviews were tape recorded and transcribed before data analysis. The transcription was double checked by hearing the recording of the interviews and checking any missing data or misinterpretation. The initial transcription, which includes everything recorded, is kept for records. Extra care was also put in place when cleaning the data and summarising the transcription. The summarised data was later compared with the recorded interviews to search for any missing information or important points. The cleaned and summarised transcripts of the interviews are available in Appendix (V).
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Table 10-19: Details of the semi-structured interviews

<table>
<thead>
<tr>
<th>No.</th>
<th>Interviewee</th>
<th>Current position</th>
<th>Company’s annual turnover</th>
<th>Company’s main projects</th>
<th>Interview type</th>
<th>Interview date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mr K</td>
<td>Operations Manager</td>
<td>£15 million</td>
<td>Residential, refurbishment, public sector</td>
<td>Face-to-face</td>
<td>21/04/2010</td>
</tr>
<tr>
<td>2</td>
<td>Mrs B</td>
<td>Risk, Health and Safety Manager</td>
<td>£15 million</td>
<td>Residential, refurbishment, public sector</td>
<td>Face-to-face</td>
<td>21/04/2010</td>
</tr>
<tr>
<td>3</td>
<td>Mr MK</td>
<td>Project Manager</td>
<td>£1 billion</td>
<td>Residential, Property development and construction services</td>
<td>On phone</td>
<td>09/06/2010</td>
</tr>
<tr>
<td>4</td>
<td>Mr P</td>
<td>Contract administrator</td>
<td>£5.7 billion</td>
<td>Transportation, Engineering and Infra-structure</td>
<td>On phone</td>
<td>27/06/2010</td>
</tr>
<tr>
<td>5</td>
<td>Mr S</td>
<td>Chief estimator, assistant to the Financial Director</td>
<td>£4.3 billion</td>
<td>All types of engineering and construction projects</td>
<td>On phone</td>
<td>17/08/2010</td>
</tr>
<tr>
<td>6</td>
<td>Mr M</td>
<td>Director</td>
<td>£25 million</td>
<td>General contracting and property development</td>
<td>On phone</td>
<td>28/09/2010</td>
</tr>
<tr>
<td>7</td>
<td>Mr D</td>
<td>Chief estimator</td>
<td>£65 million (Part of a group with annual turnover of £9.2 billion)</td>
<td>Ground engineering and foundation projects</td>
<td>On phone</td>
<td>30/09/2010</td>
</tr>
</tbody>
</table>

10.3.1 Analysis methodology

According to Miles and Huberman (1994) qualitative data analysis can be conducted in three steps: data reduction, data display and conclusion drawing & verification. Data reduction is an essential part of the analysis as researcher has to make key decisions about what to include in the analysis and what to pull out. It is a crucial task, as it will affect which chunk of text to code, what pattern can best summarise a number of chunks and what story can be told eventually. Miles and Huberman (1994)
recommended displaying qualitative data using matrices. Through matrices, researchers can conduct a variable-based analysis across cases and see how themes are emerging. This enables researchers to draw conclusions justifiable with evidence. Conclusions are presented in the form of analytical text that describes data, make sense of them, interpret them and justify conclusion based on evidence (Miles and Huberman 1994). The transcriptions were summarised and constructed in two matrices with rows representing the interviewees and columns standing for analysis variables. One matrix was constructed to display risk assessment data and the other one for project evaluation data. A number of analysis variables were investigated across the seven cases. The analysis results supported the findings of the questionnaire and helped to have a better view about the underlining mechanisms that might have direct the respondents when filling in the questionnaire.

10.3.2 Risk assessment practice

10.3.2.1 Risk assessment methodologies
It seems that the practice of risk assessment do differ across the construction companies. In small construction companies it is conducted in a rather simple way, whereas in big companies more sophisticated approaches are followed. Mr. K, for instance, said “… I do everything you mentioned solely through my mind and I do not write down everything which I think something bad… yah, you are absolutely right, because the company is small and because I am a shareholder so I do it in this way... In big companies you cannot do it this way... Actually we do all the things you are talking about but not in a formal and well-documented way.” In big companies, however, there are clear project objectives and formal risk identification and analysis approaches followed through gateways and sign-off procedures. They usually use P-I matrices within risk registers to assess risk likelihood and impact before and after risk mitigation. Mr. MK explained the scoring system they use by saying “We use a scale from 1 – 5. If the risk may have huge impact then we assess the impact as 5… if the likelihood is still high then we assess likelihood as 3 for instance. Now when multiplying these two scores we get 15 which is high and more than the cut-off of 10.” Mr. P mentioned a different approach. He said that they identify the risks and then, using a spreadsheet, calculate the cost of each risk. He said that the costs are generated based on previous experience in similar projects.
It was clear that small companies were not interested in assessing project risk level. Their main concern was to do a basic analysis and to wrap project risks by a contingency sum, as Mr. K explained, or to pass it to their sub-contractors as Mr. M mentioned. Mr. D, however, did mention that they accomplish the assessments to generate an overall project risk level. Yet, it seems that not all big construction companies would necessarily assess an overall project risk level. Mr. MK mentioned that they do not do that. He added: “We identify and assess risks individually and then we submit the bid. So we do not pool the risks together and generate a project risk level. We have the bid settlement meeting with the commercial manager, technical director and managing director. If they are happy with the control measures taken to mitigate the risks then we proceed with the tender.”

10.3.2.2 Risk characteristics

The interviewees differentiated between risks in terms of importance; those who followed formal risk analysis approaches used weights to reflect the importance issue. It was evident that all of the interviewees agreed that risk was not absolute. They agreed that risk assessment was related to project specifications, the experience and the understanding of the assessor, project location, procurement system, and the building method. They also agreed that risks are interdependent on each other and that they consider this issue when analysing project risk. Mrs. B mentioned that “sometimes when you are putting control measures for specific risk you are actually creating new risk.” On the other hand, “mitigating some of them would indirectly affect the other risks” as Mr. K argued.

The effect of project features and project environment on risk assessment is also considered in their assessment practice. Mr. D said “Obviously, some projects have better environments than other ones. Hence, we might reduce our risk assessments accordingly.” We usually provide sub-contractors working on site with some measures to reduce potential risk impacts. According to our control on the site and our responsibilities we can consider a reduction in risk assessment.”

The interviews revealed that the rationale for extending the P-I risk model by including the C, D and F adjustment coefficients has a solid basis in practice. This result comes in alignment with the questionnaire results.

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14 The same concept of using an adjustment coefficient to reflect project features.
15 This is exactly the role of the controllability adjustment coefficient.
10.3.2.3 Risk assessment using monetary equivalent

Using financial terms to assess risk was welcomed by all of the interviewees. Actually, the majority of them mentioned that they use monetary sums for assessing risk. This was the case with the interviewees regardless of the size of the companies. For instance, Mr. S mentioned that in his company they “weight risks in monetary values. The larger the risk in monetary value terms, the higher the need for mitigation.”

Regarding the suitability of the idea of using monetary equivalent as a common scale for measuring risk impact on different project objectives, Mr. M said “it is the easiest management tool to manage the financial aspect of the project. You analyze each section of the project financially and identify the related risks and assess them by the financial exposure. You can also identify the risk affecting duration and then equate that to cost by seeing the cost of delay according to the contract.” However, the interviewees appreciated that it was not an easy task. Mr. MK for instance argued that “there is no mathematical link between a risk score and a financial allowance. It all depends on the specification of the project and the actual situation we are facing.” Hence, providing equivalent money cannot be effective without a thorough understanding of the risk and its environment. I think that this is a key reason why risk assessment is largely a subjective task.

10.3.2.4 Role of experience in risk assessment

As mentioned in literature, and according to the questionnaire findings, experience and personal judgment is crucial for risk assessment. The interviewees showed a great reliance on their past experience when assessing construction risk. However, it is not an individual work. As Mr. MK mentioned, “it is not an individual work but it is a team work. Your initial risk assessment will be reviewed by at least five or six very senior managers before the managing director, who signs the bid off to be presented to the client.” Mr. P insisted that the practical experience is the key, but more importantly the available information coming from people along the project supply chain. He emphasised that such information is the main aid for assessing risk. Mr. D explained the heavy reliance on experience by saying that: “it is easy to sit in the office looking at the drawings and then come up with a risk assessment and a protection measures, but that can be completely unsuitable in the site. Hence, you should ask for someone’s experience even if a person who is working in site and maybe have a conversation with him.” Mr. S provided another reason. He claimed that because of the tendering
process, risk level has to be low in order to be accepted from the client side. He mentioned that they use their experience for assessing monetary values for the risks and then they use MCS for aggregation. He argued that according to the market conditions they could not exceed a threshold of 3% of the initial estimated cost to cover project risk. This threshold is the maximum amount a client may accept to see in the bidding document as a contingency sum. He mentioned that they have to work around the problem in order to reduce the difference between the 3% and the generated figure by running MCS. To summarise, analysing project risks and estimating a contingency sum is mainly based on past experience of reducing the contingency sum and trying not to exceed it in order to maintain the relationships with the clients.

10.3.2.5 Using DSS for aiding risk assessment

Investigating whether or not the interviewees’ companies use any DSSs for aiding risk assessment revealed that only two companies: the companies of Mr. S and Mr. D, used such tools. However, the tools were mainly an extended risk register developed as a spreadsheet-based DSS for generating risk scores. In the case of Mr. S’s company, they also use MCS to aggregate monetary figures and calculate an overall likely sum of money that represents project risk. Mr. MK, in turn, mentioned that in his company they used a formal risk register with a scoring system for assessing risk likelihood and impact. The two scores are multiplied to generate an overall risk rating. Risk rating is then compared with a threshold to decide on suitable mitigation strategies.

When investigating the reasons for not using such tools, the interviewees agreed that risk assessment was a subjective task by nature. Mr. K added that due to the company’s size and the long experience with the clients and the projects, they did not need such tools. However, Mrs B who works in the same company, but with good risk management training, said “I use what I have learnt over years. I have done a lot of training and I use standard and guidance for risk management.” Mr. Mk gave different reason. He mentioned that “risk assessment needs understanding all factors and consequences and measures… the machine cannot structure all of this knowledge. The machine cannot replace decision maker… You cannot rely on a computer for identifying key risks or factors affecting the process; you can only feed the machine with the information you have and the inputs you gathered.” Mr. M said that they do not use special tools for risk assessment because of the size of his company. He elaborated “I do not think that construction industry in the UK is so sophisticated. Basically, there
are two main concerns which are time and cost. Most construction contractors are concerned about them.” Mr. P argued that in his whole career, more than 25 years, he used Mont-Carlo simulation once in one construction project with the railway industry. He argued that “people in construction industry do not tend to use software for risk assessment. They might use it during the tendering stage, but they follow more practical approach when the construction work starts.” He added that risk assessment is usually based on “how knowledgeable practitioners are about risk, how the contract mentions how to mitigate risk and how to consider the time and cost caused by risk.”

These reasons, together with the reasons mentioned in the questionnaire, explain why construction practitioners do not use DSSs for aiding risk assessment. This may also explain why construction industry is blamed to be underdeveloped in risk assessment when compared to other industries like finance or insurance (Layrea 2008).

10.3.3 Practice of project evaluation

10.3.3.1 Project evaluation approaches
Analysing the interview data revealed that in most cases there are no formal approaches or protocols for project evaluation. Apart from Mr D., who described the scoring system he uses for evaluating projects, the interviewees did not mention systematic approaches for evaluating projects. They mentioned the evaluation criteria they consider when evaluating different construction projects rather than procedures or formal protocols. The criteria include, mainly, the client and his financial position and the profitability of the project. Other evaluation criteria may include project features, availability of resource, having experience in delivering the required work and the competition level and the probability of winning the contract.

When investigating whether they consider intangible benefits when evaluating construction projects, they argued that the intangibles are considered indirectly and implicitly. They emphasised that keeping the business running was their top priority. Mr. K put it very clearly by saying: “If it comes that the project which will enhance our reputation with a possibility of not getting paid, getting paid would definitely go first. So, there is no point of having good reputation if the business is no more running.”

The main intangible benefits that may be considered were company’s reputation, keeping the clients happy, and maintaining the relations with key clients. Mr. Mk explained that sometimes intangible benefits are weighted highly because of strategic
reasons. He argued that “If we think that there is a client we need to keep and to build long relation with, we would agree to work for him even if the project would make less return.” Finally, it appeared that project evaluation task was very subjective. The interviewees argued that in most cases it is down to the managing directors or the managing board and their experience in making such decisions based on strategic considerations that affect the whole business.

10.3.3.2 Assessing intangible benefits using monetary equivalents
Although most of the interviewees agreed on the essence of considering intangible benefits when comparing between construction projects, assessing intangibles proved to be a difficult task for them. They were unable to provide an explicit way for assessing intangible benefits and including them in the evaluation process. They argued that the current practice of assessing intangibles is very subjective. Mr. D. added that such an assessment is usually conducted by the board of directors for strategic reasons that affect the whole business. This is different, according to him, from risk assessment which is conducted on lower managerial levels. The interviewees agreed with the rationale of considering achievability coefficient when assessing project benefits. However, they were also not certain how it can be measured. After presenting the idea of assessing intangibles by monetary equivalent, the interviewees generally welcomed it. However, they found it difficult to find a suitable figure to represent the value of an intangible benefit. Mr. K said that “it is difficult to assess intangibles. It is difficult to put a final cost on that. This is because they are very small parts and I am not sure how much they are as a percentage. In theory they add a percentage to the profitability of the project but I am not sure about the exact percentage.” This may explain why the idea of measuring intangible benefits using monetary equivalent did not get enough support from the questionnaire respondents. This can also explain why they did not agree that such an assessment approach was widely accepted in construction industry.

10.3.3.3 Combining risks and benefits
After presenting the idea of assessing intangible benefits as percentages of the project initial cost, a transparent approach for evaluating construction projects, which combines project risks and intangible benefits, was discussed with the interviewees. Actually, the proposed approach triggered a very positive reaction from the interviewees. They envisaged using cost as a common scale for measuring risk and benefit as a straightforward and easy to understand approach. Mr. K found this
methodology “similar to what we used to do. Many times we use man-hour to bring things down to its basic level. It is a common language understandable by everyone... Not easy but it is an understandable way for all parties.” Mr. S quite liked the idea of considering both of risks and benefits for evaluating construction projects, but he mentioned that it is restricted with the availability of enough information. He thought that his organization can improve their risk assessment practice by including benefit assessment in their risk register and using an extended risk and opportunity matrix.

Although this multi-criteria decision making approach received positive feedback, Mr. P emphasised that the actual practice is different. He argued that although it is possible, combining risk and benefit is difficult because “… contractors usually go to the projects that have less risk and make most profit... they do not make such trade-off as you always need to maintain your cash flow in order to keep your business running.” He further explained that he was aware of the theory behind his proposal and he appreciated that companies must be more positive about risk. However, he argued that “…reality is very different. In practice, contractor would always try to avoid risk.”

The issue of avoiding risk and focusing on survival in tough market condition may be a major cause for not using risk assessment DSS in construction industry. It seems that the main focus of construction practitioners is packaging the risk and transferring it to other parties or negotiating a financial cover for it with the client. Mr. D, who welcomed the idea of combining risk and benefits together, favoured using a scoring system to monetary equivalent. He argued that it was “consistent with the company’s preference.” This point of view highlights the importance of risk analysis culture within construction companies which maybe a major barrier against implementing something different. It may, to some extent, explain the low take-up of the available DSSs and some of the less positive results of the questionnaire.

10.3.3.4 Project evaluation tools and the role of experience
The usage of DSS for aiding project evaluation was a major investigation point. The interviewees did not mention any special tool or DSS in use. The actual practice was always based on experience with a set of evaluation criteria and a series of sign-off and review meetings. Experience was considered as the key element by all interviewees. However, we should not understand the reliance on experience or subjectivity as a naïve approach. Mr. Mk said “… we do not use gut feeling. We try to
use the available information and make assumptions based on our experience for making decisions." Mr. P had a similar idea about facilitating experience and using decision-making tools. He argued that practical experience plays a key role in feeding the software with the required inputs. He added that this experience is generated from the people along the construction supply chain and the feedback of the sub-contractors which enable the contractor to give accurate estimates and inputs. Hence, “it is not guessing; it is based on how the supply chain is functioning.” The actual inputs or estimates are generated from the experience and the knowledge of the analyst as Mr. D mentioned. It seems that this practice is very common among construction professionals. The interviewees mentioned that most professionals follow similar approaches and face similar problems when evaluating construction projects.

10.3.3.5 Difficulties and aspirations
The interviewees were encouraged to share their difficulties when analysing project risks and evaluating construction projects. They were also asked to point out the features of a good DSS from their perspectives. All of them agreed that lack of information and lack of enough time to do proper risk analysis and project evaluation before bidding were the major difficulties. This is totally in alignment with the literature. Mr. S added to these difficulties the lack of consistency in managing these activities which can be also attributed to the different amount of available information. Regarding the reasons for not using DSS for aiding project evaluation, the interviewees mentioned similar reasons for not using these tools for aiding risk assessment. However, there were interesting comments and explanations made by them. Mr. K, for instance, said that it is the human nature to always try to beat the machine. Hence, "only after years of using a machine and trying it you will be building trust in it." He gave an example saying that “if a machine says that you should go with a project and I do not think that we should go, I will stick to my experience. I need to check the tool and trust it before I use it.” Mr. S mentioned another reason for not using DSS. He argued that there is a risk of using such tools; the risk that “people are only filling in information and not perceiving it as an aid.” In other words, he mentioned that using these tools will take the thinking element from the process which may result in people “focusing on the numbers and the monetary values instead of thinking about what the actual risk is.” He argued that understanding the risk in order to plan how to mitigate it was the most important part of risk analysis. Mr. M, in turn, raised the issue of company’s size and its effect on its practice. He said “... we do not need a DSS as we tend to do things as
simple as possible...the bigger the company the more sophisticated tools are required and the more risk to be taken on board.” This issue is very important and it comes with clear harmony with the results of the questionnaire.

Finally, the interviewees expressed the features they expect to find in a usable DSS. There was a universal agreement that it should be simple and easy to use. Mrs. B argued that construction professionals are not interested in mathematical complications. They always look for simplicity in processes so everyone can understand them. She said “If I went to the managing director and showed him a figure, risk score, he would not understand what I am talking about. The software has got to be simple and understandable by everybody.” The same point was mentioned by Mr. M who requested the DSS to be as simple as possible. Mr. D added that the DSS should be applicable to all types of projects and usable in every case. He raised the issue of time consumption and mentioned that the tool should provide results quickly. He added: “… at the end we need an effective tool which can conduct assessment for the majority of projects within 15 – 20 minutes or so. Obviously, for complicated projects it may take more than that, but for generic risk assessment it should be very quick and simple.” He suggested that the tool should be a simple spreadsheet as it satisfies the above features. Actually, the proposed DSS is a spreadsheet-based one. It is a Microsoft Excel workbook with a number of spreadsheets in order to be as simple as possible. This choice was made assuming that the majority of construction professionals are familiar with this package. This will increase the usability as it does not require any special platform installed in the PC apart from Microsoft Office which is hardly to find a PC without it installed.

10.4 Summary and conclusions

In this chapter, the collected data from administering a postal survey and an online survey and conducting seven semi-structured interviews were presented and analysed. It was clear that the generated results from the interviews supported the findings of the questionnaire and enriched them by providing personal explanations and practical examples. The obtained results show a clear agreement with most of the ideas proposed in this research for improving risk analysis and project evaluation. Yet, there was a lack of strong support to measuring intangible benefits by means of monetary equivalents. This issue was explained by the interviewees who expressed the difficulty
of providing such values. The interviews were crucial for getting deep insights about the actual practice of risk assessment and project evaluation. In the same time, they played an essential role for identifying the key challenges and the main barriers against using DSS in practice. It can be concluded that the proposed contribution to improving risk analysis and project evaluation has got a promising potential in practice.

It was interesting that risk analysis was always perceived as a synonym of contingency estimation. The issue of estimating an accurate contingency sum was marked as top priority by all of the interviewees. They emphasised the need for packaging the risks and passing them to other parties, insurance companies or sub-contractors. This point is very important as the academic perception of assessing risk as a project attribute may not have its counterpart in reality. It looks as if practitioners are not keen to assess project risk level for comparison reasons; they are very much interested in estimating contingency sums and negotiating them with the client, insuring risks and negotiating their premium with the insurers or passing them to sub-contractors and negotiating the prices with them. This issue highlights the need for further research in the area of contingency estimation. Construction professionals would definitely appreciate an effective methodology or tool for estimating accurate contingency sums. I think that a DSS that aid them in this point would be very much welcomed.

In order to utilise the proposed risk model, risk assessment methodology and project evaluation approach, a spreadsheet-based DSS using Microsoft Excel as a spreadsheet platform is designed. In the next chapter, the tool will be presented in detail. The results of conducting four validation cases will be also discussed. The results of these cases will further enrich the obtained results and highlight the strength, weaknesses and limitations of the proposed approach.
Chapter 11: DSS for Construction Risk Assessment and Project Evaluation

11.1 Introduction

This chapter presents the decision support system that was devised to facilitate the proposed risk assessment methodology and project evaluation approach. The tool's main duty is automating the required calculations for assessing individual risks and benefits, automating the aggregation algorithms for generating project risk and benefit levels and combing the two levels to enable the comparison between different projects. The chapter presents the components of the DSS and illustrates how to operate it in real cases. It also shows the results of four validation cases conducted to evaluate the tool and get feedback from construction practitioners. The tool was introduced to the participants who were trained to operate it using a construction project as an example. They were, later, asked to evaluate the analysis methodology and the tool and to provide feedback for improvement. Before going in detail, a starting point will be a brief introduction to DSSs in general and the project management evaluation process.

11.2 Decision support systems

A Decision support system can be defined as “a computer-based system that represents and processes knowledge in ways that allow decision making to be more productive, agile, innovative, and/or reputable” (Holsapple 2008). It is to be designed as a complement to the experience and the ability of the decision maker by providing information in an efficient manner so it can be relied upon for efficient and effective decision making (Hall 2008). There are different types and forms of DSSs. Power (2008) provided a very comprehensive review to the different types of DSSs and the historical development of them. He categorised them in five categories as follows:

- **Model-driven DSSs** with main function of having access to and manipulation of a quantitative model. The model, or models, is the key element of the DSS architecture. Model-driven DSSs use data and parameters provided by decision-makers to help in analyzing decision problems. They are also designed to enable manipulating inputs and testing the sensitivity of results.

- **Data-driven DSSs** emphasize access to and manipulation of large database of structured data like time series of a company, internal data, or external data
from external databases. In its simplest form, this type of DSSs includes file systems accessed by query and retrieval tools.

- **Communications-driven DSSs** immensely rely on information and communications technologies to facilitate collaboration and support group decision making. Network and communication technologies are the key architectural component in these DSSs.

- **Document-driven DSSs** effectively facilitate computer storage and processing technologies to provide document retrieval and analysis. The core element in document-driven DSS is the search engine.

- **Knowledge-driven DSSs** are interactive tools that recommend actions to managers based on stored knowledge and problem-solving expertise. The knowledge component is core element in these DSSs.

In this research, the proposed DSS belongs to the model-oriented DSS category. It is an Excel workbook devised to automate the calculations of risk and benefit assessments based on the proposed risk and benefit models and to ease conducting assessment aggregation through the ER algorithm. Actually, it can be classified as a spreadsheet-based DSS which is a special type of model-oriented DSSs. According to Seref and Ahuja (2008), spreadsheet-based DSSs analyse data residing in spreadsheets using problem-specific methodologies implemented via spreadsheet functions or a programming language. They also assist the user in making decisions through a graphical user interface. Microsoft Excel spreadsheet package provided the required tools and capabilities for a quick and easy DSS development. It was chosen due to the researcher’s familiarity with it and the fact that it is probably the most popular spreadsheet application development environment (Power and Sharda 2007). Producing a user friendly and simple DSS was given the top priority. It is designed to hide all the calculation complexity and to provide a simple interface with guiding instructions to make it accessible to all construction managers who are presumably non-technical people. The DSS was aimed to meet the interviewees’ expectations by making the decision making process and the tool as simple and clear as possible.

Before illustrating the DSS in detail, the decision making process will be presented from different perspectives. Obviously, construction industry has two main parties: clients and contractors. Every party has to conduct risk analysis and project evaluation but for different objectives and under various circumstances. The decision making process is presented below from construction client and contractor’s sides.
11.3 Decision making process

11.3.1 A client perspective

Construction client has to assess project risk and evaluate different alternatives as an essential element of investment appraisal.

![Decision making process diagram](image)

The figure (11-1) demonstrates how risk assessment and project evaluation can be conducted within an integrated decision making process. From the diagram, one can appreciate the following issues:
The process includes three main stages: input, processing and decision making. The DSS assists the client in the first two stages and provides him or her with analysis results for decision making. Obviously, the client considers the analysis results together with all physical and logical constraints and underlying strategies for making the final decision.

The proposed risk and benefit models and assessment methodologies are adopted and the client is asked to provide values to the various inputs and coefficients.

The tool exempts the client from doing the calculations, which are quite complicated, especially when aggregating assessments.

The client can perform sensitivity analysis by changing the inputs to suit different scenarios.

The same process is repeated for evaluating alternative projects or proposals.

It is worth noting that different procurement routes impact on the identified factors and the input values. Hence, the decision making process can be followed for evaluating different procurement routes, for the same project, and choosing the one which best suite the desires of the client. Finally, public and private clients may have different objectives and desires. Subsequently, risk and benefit factors and the values of the required inputs differ accordingly.

### 11.3.2 A contractor perspective

The contractor’s decision making process is slightly different from the client’s one. The same three stages exist and similar inputs are required, yet there are few differences from the client perspective:

- Contractors identify different project risks and benefits as they look at the problem from a different perspective.

- Project evaluation has different objectives; contractors would compare between projects to choose the most preferable ones to bid for. Hence, decision making process can be used as a bid/no-bid decision support tool.

- The type of client, public or private, heavily affects the whole decision making process and, subsequently, the final decision. The collected data from the interviews showed clearly that the client was a key attribute to be considered when evaluating different projects.

- Contractors, usually, do not choose the most suitable procurement system as it is typically the task of the client.
A selection decision is made based on analysis results, financial constraints, bidding strategies and business development policies.

Figure 11-2: Decision making process, a contractor's perspective

The decision making process, from both perspectives, assumes complete trade-off between risk and benefit. However, the research findings showed that contractors tend not to do such a trade-off. They always look for projects with less risk rather than...
balancing risks and opportunities. The research did not cover the attitude of construction clients concerning this point as its focus is construction contractors only. Clients might or might not have the same attitude. Hence, the DSS should allow different users to customise the process in order to suit their preferences and needs. For instance, a contractor may be interested in analysing project risk and comparing between different projects based on their risk levels only. Another contractor may be interested in a limited number of risks to be considered in the analysis rather than all project risks. The above decision making process, in its two versions, represents a typical MCDM process. The devised DSS, in turn, adopts the process in its ideal structure and, in the same time, offers different users the opportunity to customise the process to suit their needs under different circumstances.

11.4 The DSS

The devised DSS is a spreadsheet-based DSS built on Microsoft Excel package and composed of 10 worksheets. It has an introductory worksheet, five sheets for analysing five risk categories, one sheet summarising risk assessment, one sheet for analysing intangible benefits, one sheet for combining project risk and benefit assessments and, finally, one sheet including operation guidance. A copy of the DSS is provided on a CD at the back of the thesis. The introduction worksheet contains the developer contact details and illustrates the hierarchical structure of construction project risks and benefits. Five risk categories are considered namely; Financial risks, Technical and operational risks, Managerial and legal risks, Environmental and social risks, Health and safety and other risks. Every risk category has a separate worksheet as mentioned earlier. Concerning project benefits, they are categorised under two categories; tangible and intangible benefits. This research project focused on assessing intangible benefits and combining their assessments with project risk assessments. Hence, only intangible benefits will be analysed in a designated worksheet. Every worksheet is self-contained; it starts with a set of definitions of the required inputs and a set of potential risk/benefit factors to choose from. All the required operations or calculations are programmed as Excel functions to automatically generate instant results within the sheet. However, the risk analysis sheets are linked to each other through the summary one that aggregates the assessments together and eventually generates a project risk level. The results of this sheet are linked to the results of project benefits analysis through the decision making sheet which generates an evaluation score based on project risk and benefit levels.
11.4.1 Operating the DSS

Analysing project risks and benefits starts in the introductory worksheet where the analyst is asked to input the project initial cost. This figure is very important as risk impacts and benefit magnitudes are assessed as percentages of the project initial cost.

Figure 11-3: the introductory worksheet of the DSS

Having input the project initial cost, the analyst can move to analyse project risks. The analyst can start with any risk category or even start with analysing intangible benefits. There is no need to do the analysis in the same sequence of the worksheets.
Although analyst may choose different number of risks under different categories, the tool, in its current version, allows potential users to consider the top four risks under every category. This number was chosen as research participants mentioned that before tendering around 20-25 risks can be identified and analysed due to the limited amount of information. Hence, a complete analysis will generate its results based on the top 20-25 risks and the top four intangible benefits. Obviously, a more advanced version of the DSS should allow the user to specify the number of factors under every category and the categories to be considered in the analysis. However, this requires more time and advanced programming skills.

11.4.1.1 Risk assessment
Risk assessment is conducted in the same way for all risk categories, although the process is demonstrated through analysing project financial risks. The analyst starts risk assessment by identifying the top four financial risks. He or she can benefit from the available list of financial risks to draw his or her attention to what literature recommend as key financial risks. However, the analyst has a complete freedom of choosing the risks that best suit the case under analysis.

Having identified the top four risks, the analyst has to describe the risks by assigning importance weight to each of them and deciding on suitable values to the C, D, and F coefficients and estimating the likelihood of occurrence. The weights should be proportional figure between 0 and 1 and should sum up to unity. The tool will automatically calculate the value of probability of impact materialisation (P) based of the values C, D, and F. The proposed formula for calculating P is the weighted average of the values C, D, and F which are given equal weights. The likelihood of occurrence of any risk should be input as a proportional figure between 0 and 1.

It is worth noting that throughout the sheets, the input cells are the coloured and bordered ones. This was decided in order to help potential users differentiate between the input and the output cells.
The next step is assessing risk impact. The analyst is required to assess the impact of every risk on three project objectives: cost, duration and quality. Obviously, risk impact can be assessed on any project objective, however, in order to strike a balance between the level of detail and practicality, these objectives were considered as they are believed to be the key objectives of every construction project. Moreover, the names of the objectives can be easily changed. Hence, if the analyst wished to assess risk impact on three different objectives, he/she can amend the names of the objectives.

Financial Risks
When assessing risk you are required to provide a values to the following parameters:

1. Risk Weight: a number between 0 and 3 which reflects the importance of a risk factor. All the provided weights should sum up to 3. The default assumption is that they are equally important: $W = 0.25$
2. Likelihood of Occurrence: a number between 0 and 3 which reflects the probability that a risk factor may happen.
3. Coefficient of Project Features: a number between 0 and 1 which represents how the specifications, the environment and the unique nature of a construction project may help mitigate risk impact.
4. Risk Controllability: a number between 0 and 1 which reflects the experience of the management team, their familiarity with the risk and the extent to which the team is able to gain an advantage in dealing with the risk.
5. Dependency coefficient: an adjustment factor for adjusting the impact of each individual risk after considering the interacting risks.

Financial risks may involve risks such as:
- Delay in payments, cost and time overruns.
- Exchange rate fluctuations.
- Interest rate volatility.
- Inflation.
- Shortage of working capital.
- Failure to meet revenue targets.
- Collapse of contractors.
- Failure of suppliers to meet contracts (quality or quantity or timescale).
- Insufficient capital revenues.
- Fraud.
- Increased costs of revenue collection, etc.

### Figure 11.4: Risk identification, description and likelihood of occurrence assessment

<table>
<thead>
<tr>
<th>Risk Characteristics</th>
<th>Risk Weight</th>
<th>Likelihood of Occurrence</th>
<th>Coefficient of Project Features</th>
<th>Controllability</th>
<th>Dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk 1: Inflation</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>Risk 2: Payment delay</td>
<td>0.7</td>
<td>0.8</td>
<td>0.5</td>
<td>0.6</td>
<td>3</td>
</tr>
<tr>
<td>Risk 3: Cash flow</td>
<td>0.2</td>
<td>0.1</td>
<td>0.5</td>
<td>0.6</td>
<td>3</td>
</tr>
<tr>
<td>Risk 4: Cost overrun</td>
<td>0.3</td>
<td>0.8</td>
<td>1</td>
<td>0.8</td>
<td>3</td>
</tr>
</tbody>
</table>

Please assign values to each factor according to your experience.
2. Risk Impact Assessment

As a risk analyst, you are requested to assess the maximum possible impact of each risk factor on three assessment grades. The assessment grades are percentages of the initial cost of the construction project under analysis.

Risk impact is assessed on the three main objectives of a construction project: cost, duration and quality.

Please express your degrees of belief regarding the impact of each identified risk according to the percentages provided below. You can choose other percentages if you think they will be more suitable to the case you are dealing with. However, the grades must be the same for all risk categories which are going to be used when aggregating the assessments in order to generate an overall risk assessment on a project risk level.

The degrees of belief are proportioned figures between 0 and 1 represent the degrees of expectation that the impact could equalize the stated percentages of initial cost.

![Risk impact assessment table](image)

The analyst is asked firstly to choose suitable assessment grades, which are percentages of the project initial cost, and secondly to assign degrees of belief to every assessment grade for every risk.
Again, for practicality, the DSS, in its current version, asks the user to provide three assessment grades. Obviously, if the project is very strategic and requires a detailed risk analysis, the analyst may need to use more assessment grades. Such an analysis demands an advanced version of the DSS where the analyst can choose at the beginning the number of risks, assessment grades and project objectives.

The user can provide a complete assessment by assigning degrees of belief that sum up to unity. The assessment can be incomplete, however, due to lack of enough information. In some cases, the analyst provides no assessment at all in order to reflect that the risk has no impact at all on a specific objective. For instance, in the above figure, out of the four risks, only the last one has an impact on project quality. At this point, the tool will automatically multiply the degrees of belief by the value of $P$ and generate distributed assessments of risk levels on every project objective as illustrated in figure (11-6).

\[
\beta_{ij} = 1 - Li \times Pi
\]

Where:
- $\beta_{ij}$ is the degree of belief that the risk $R_i$ has no effect on the objective $O_j$.
- $Li$ the likelihood of occurrence of the risk $R_i$
- $Pi$ probability of impact materialization of the risk $R_i$

Figure 11-6: A distributed assessment of risk levels on project objectives
\( \beta_{ij} \) is the belief in the complement event of the event “a risk occurs and its impact materialises”. Hence it is calculated as the difference between unity and the product of the risk's likelihood of occurrence and probability of impact materialisation. Then, \( \beta_{ij} \) represents the belief in a risk not occurring and its impact not materialising.

In fact, the 0% assessment grade is created to solve a mathematical problem in differentiating between the ignorance, caused due to lack of information, and the effect of \( P_i \) and \( L_i \) as adjustment factors to the risk impact. Actually, the inclusion of the (0%) assessment grade is very important to maintain the exhaustiveness condition of the assessment grades. Moreover, it enriches risk analysis by associating it with the belief in the downside effect not materialising. As will be seen in the illustrative example, including the (0%) assessment grade and assigning belief degrees to it will be very helpful when assessment aggregation. It will enable the analyst to have an aggregated degree of belief that measures the belief in project risk effects not materialising. It can also be used to predict the degree of belief in risk effects materialising. These degrees of belief are very helpful for justifying any mitigation strategy of any decision to be made.

After assessing the identified risks individually, the obtained risk assessments can be aggregated. Assessment aggregation is done by the ER algorithm. The first aggregation will be conducted to find the financial risk level affecting every project objective. As can be seen from the figure below (Figure 11-7), the aggregated risk levels are also generated as distributed forms. The DSS also calculates the ignorance that is associated with assessing financial risk on every project objective. This ignorance is employed later for generating upper lower levels of the financial risk on every project objective. Clearly, these two limits can be averaged.
3.2. Aggregated risk assessment on every project objective:

According to the risk weights provided earlier, the aggregated assessment of this risk category on every project objective will be:

<table>
<thead>
<tr>
<th>Assessment Grades</th>
<th>Risk on Project Cost</th>
<th>Risk on Project Duration</th>
<th>Risk on Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Degrees of Belief</td>
<td>0.405</td>
<td>0.392</td>
<td>0.194</td>
</tr>
</tbody>
</table>

In the case of incomplete assessment there will be a degree of unassigned belief. The incomplete assessment is due to the ignorance and lack of information. The degree of unassigned belief, the ignorance, on every project objectives is the difference between the sum of aggregated degrees of belief on that objectives and the unity. Hence, the unassigned degrees of belief in this cases of the three project objectives are:

|                     | 0.01 | 0.46 | 0.17 |

For every project objective, the ignorance will allow you to differentiate between the best and worst scenarios of risk assessment. By assigning the ignorance to the minimum assessment grade one can assess the worst case scenario. This will yield the maximum risk assessment.

However, by assigning it to the minimum assessment grade we can assess the best case scenario where risk level is at its minimum value.

Obviously, these two boundaries of risk assessment can be averaged. The minimum, maximum and the average assessments on every project objective are illustrated below:

<table>
<thead>
<tr>
<th></th>
<th>Risk on Project Cost</th>
<th>Risk on Project Duration</th>
<th>Risk on Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum risk assessment:</td>
<td>0.896%</td>
<td>0.526%</td>
<td>0.722%</td>
</tr>
<tr>
<td>Maximum risk assessment:</td>
<td>0.926%</td>
<td>1.921%</td>
<td>1.269%</td>
</tr>
<tr>
<td>Average risk assessment:</td>
<td>0.908%</td>
<td>1.224%</td>
<td>1.021%</td>
</tr>
</tbody>
</table>
3.3. The Financial Risk Level on the Project as a whole:

Before getting the risk level on the project as a whole, please specify the weight of every objective. Similar to the risk weights, objective weight is a number between 0 and 1 and the sum of the three weights should be 1.

<table>
<thead>
<tr>
<th>Project Cost</th>
<th>Project Duration</th>
<th>Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Having assigned a weight to every objective, the risk level on the project as a whole will be:

Assessment of Financial Risk in the Project

<table>
<thead>
<tr>
<th>Assessment Gages:</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>(0)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of Belief:</td>
<td>0.266</td>
<td>0.102</td>
<td>0.015</td>
<td>0.477</td>
</tr>
</tbody>
</table>

Similar to the previous stage, the ignorance \(i\) is: 0.119

The maximum, minimum and average risk levels are illustrated below:

- Minimum financial risk level: £0.731
- Maximum financial risk level: £1.689
- Average financial risk level: £0.910

Hence, the equivalent sum to the average project financial risk level is: £234712.3

Further aggregation can be performed in order to calculate financial risk level on the whole project. In order to do that, the analyst is required to assign importance weights to the three objectives: cost, duration and quality. Obviously, the three weights should sum to unity.
The tool uses the importance weight for aggregating the distributed assessments of financial risk levels on project objectives: cost, duration and quality. As demonstrated in figure (11-8), the aggregation result takes a distributed form with the overall ignorance provided as well. The ignorance is again employed for generating upper and lower levels of project financial risk. These values are graphically depicted in order to help the user in preparing a risk assessment report.

The same analysis approach is followed for assessing the other risks in the remaining risk categories. In a designated sheet, illustrated in figure (11-9), the analysis results of the five risk categories are summarised. Risk analysts can aggregate these assessments in a similar way to the previous aggregations in order to generate project risk levels on every objective and on the project as a whole. Now, in order to aggregate the assessments of the five risk categories, the analyst should provide importance weights to every risk category. The aggregation generates an overall assessment of project risk level on every project objective.

As can be seen in figure (11-10), the aggregation results are in distributed forms. The aggregated ignorance levels are used for representing the degree of completeness in the provided analysis and generating upper, lower boundaries of the different risk levels.
# Risk Assessment Results:

## 1. Assessment Summary:

Having conducted a detailed risk assessment, this spreadsheet will summarize the assessment results of all risk categories on the three project objectives.

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>% of Project</th>
<th>% of Completion</th>
<th>% of Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Financial Risk</td>
<td>0.005</td>
<td>0.182</td>
<td>0.154</td>
</tr>
<tr>
<td>2. Technical &amp; Operational Risks</td>
<td>0.005</td>
<td>0.182</td>
<td>0.154</td>
</tr>
<tr>
<td>3. Managerial &amp; Legal Risks</td>
<td>0.005</td>
<td>0.182</td>
<td>0.154</td>
</tr>
<tr>
<td>4. Environmental &amp; Social Risks</td>
<td>0.005</td>
<td>0.182</td>
<td>0.154</td>
</tr>
<tr>
<td>5. Health, Safety &amp; Other Risks</td>
<td>0.005</td>
<td>0.182</td>
<td>0.154</td>
</tr>
</tbody>
</table>

## 2. Assessment Aggregation:

Besides the results summary, this spreadsheet contains an aggregation of all risk assessments in order to generate an assessment for project risk level on every objective and an overall project risk level. Each risk category has been associated with a weight in order to reflect its importance against the other categories.

The default assumption is that all risk categories are equally important, i.e., $W_i = 0.2$. *Weights can obviously be changed* according to your preference. However, they should always sum up to 1.

1. Financial Risk: $W_1 = 0.4$
2. Technical & Operational Risks: $W_2 = 0.2$
3. Managerial & Legal Risks: $W_3 = 0.1$
4. Environmental & Social Risks: $W_4 = 0.1$
5. Health, Safety & Other Risks: $W_5 = 0.1$
2.1 Assessment aggregation on a project objective level

According to the risk weights provided earlier, the aggregated assessment of project risk on every project objective will be:

![Risk aggregation table]

Similar to the previous risk assessments, the unassigned degree of belief (the ignorance) will allow you to differentiate between the best and worst scenarios of risk assessment.

By assigning this amount of belief to the maximum assessment grade one can assess the worst case scenario. This will yield the maximum risk assessment.

However, by assigning it to the minimum assessment grade we can assess the best case scenario where risk level is at its minimum value.

Obviously, these two boundaries of risk assessment can be averaged. The minimum, maximum and the average assessments on every project objective are illustrated below:

![Risk aggregation graphs]

Minimum risk assessment: 0.84 %

Maximum risk assessment: 0.98 %

Average risk assessment: 0.86 %
2.2 Aggregation risk assessment results on the project as a whole:

Before getting the risk level on the project as a whole, please specify the weight of every objective. Similarly to the risk weights, objective importance weight is a number between 0 and 1 and the sum of the three weights should be 1.

<table>
<thead>
<tr>
<th>Project Cost</th>
<th>Project Duration</th>
<th>Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.4</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Having assigned a weight to every objective, the risk level on the project as a whole will be:

<table>
<thead>
<tr>
<th>Risk Assessment on the Project as a whole (Project Risk Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment ranges:</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>0%</td>
</tr>
</tbody>
</table>

| Degrees of Belief | 0.254 | 0.083 | 0.028 | 0.537 |

Similar to the previous stage, the unassigned degree of belief, the ignorance, is:

0.118

Again, this unassigned degree of belief will be used to differentiate between the best and worst scenarios of project risk level. These levels are illustrated below together with the average one.

- Minimum project risk level: 0.05
- Minimum project risk level: 0.00
- Average project risk level: 0.01

Hence, the equivalent sum to the average Project Risk Level is: £13176.4
11.4.1.1 Illustrative Example:
This is a real project that was used as an application example for validating the DSS. The project was provided by Mr. S who was interviewed during the data collection stage and later participated in a validation case study. The specifications of the project are provided in table (11-1).

<table>
<thead>
<tr>
<th>Project type</th>
<th>Health sector (a care home facility)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>UK, North London</td>
</tr>
<tr>
<td>Client</td>
<td>Private client</td>
</tr>
<tr>
<td>Duration</td>
<td>Initially 110 weeks started May 2006. At the end, it took 150 weeks.</td>
</tr>
<tr>
<td>Initial estimated cost</td>
<td>£22.5 million. We won the contract with profit margin of 8%. Actually, all of this margin has gone eventually.</td>
</tr>
<tr>
<td>Actual cost</td>
<td>£27 million</td>
</tr>
<tr>
<td>Major problems</td>
<td>It was traditional contract. It is strange why it became a nightmare as we should have no risk because it is traditional contract. Actually, there was a problem in the design. The design was late and we continuously were late. The client had a contract with a design team who was always late and subsequently the client was always late in providing us with the design information. The contract people signed a contract with the client based on bills and quantities. We did not know how the client was able to produce bills and quantities without the design information.</td>
</tr>
<tr>
<td>The outcome</td>
<td>It was a nightmare project.</td>
</tr>
</tbody>
</table>

Table 11-1: Details of the case study’s project

Mr. S was asked to identify the major risks and to analyse them according to the proposed methodology. He decided that the major risks were financial ones and identified the top 4 ones as inflation, payment security, program overrun and subcontractors’ pricing. He estimated their likelihood of occurrence as 1, 0.1, 0.1 and 0.8 respectively. Mr. S also provided values to the F,C and D coefficients for every risk as displayed in table (11-2).

<table>
<thead>
<tr>
<th>Top Risks</th>
<th>Risk Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Project Features (F)</td>
</tr>
<tr>
<td>Inflation</td>
<td>1</td>
</tr>
<tr>
<td>Payment Security</td>
<td>1</td>
</tr>
<tr>
<td>Program overrun</td>
<td>0.5</td>
</tr>
<tr>
<td>Sub-contractor pricing</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 11-2: Risk Characteristics
Risk impact was assessed on project cost, duration and quality using three assessment grades; 1%, 2% and 4% of the project initial cost. Mr. S assigned his degrees of belief based on his experience in the industry and the project. Actually, he was not sure about the actual impact sizes of risk impact on the three objectives, for every risk, so he provided incomplete assessment as evident in table (11-3).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1%</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.7</td>
<td>0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Payment Security</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Program overrun</td>
<td>0.6</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Sub-contractor pricing</td>
<td>0.6</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 11-3: Risk impact assessments in distributed forms

Automatically, the tool calculates the value of probability of impact materialisation for every risk and multiplies it, and the likelihoods of occurrence, with the degrees of belief. The tool also calculates the degrees of belief that are to be assigned to the (0%) assessment grade of every risk as illustrated in table (11-4).

<table>
<thead>
<tr>
<th>Top Risks</th>
<th>Risk on Project Cost</th>
<th>Risk on Project Duration</th>
<th>Risk on Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.07</td>
<td>0.65</td>
<td>0.19</td>
</tr>
<tr>
<td>Payment Security</td>
<td>0.92</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Program overrun</td>
<td>0.93</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Sub-contractor pricing</td>
<td>0.25</td>
<td>0.45</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Table 11-4: Distributed forms of risk assessments on the three project objectives

The above table shows the individual risk assessments in distributed forms. These assessments can be aggregated after assigning importance weights. The importance weights of the four risks were decided as 0.2, 0.05, 0.25 and 0.5 correspondingly. Using the ER algorithm as an aggregation tool, the DSS provided the following results displayed in table (11-5).

<table>
<thead>
<tr>
<th>All risks</th>
<th>Risk on Project Cost</th>
<th>Risk on Project Duration</th>
<th>Risk on Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees-of-belief</td>
<td>0.405</td>
<td>0.382</td>
<td>0.154</td>
</tr>
<tr>
<td>Ignorance</td>
<td>0.01</td>
<td>0.46</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Table 11-5: Aggregated risk assessments on the three objectives in distributed forms
The above results show the aggregated degrees of belief and the aggregated degrees of ignorance on every project objective. As mentioned earlier, the ignorance is used to generate upper and lower risk assessment boundaries. For instance, the minimum and maximum risk assessments on project quality are calculated in the following way:

\[ \text{Min} - R - \text{ProjectQuality} = (0.17 + 0.26) \times 1 + 0.087 \times 2 + 0.043 \times 4 = 0.772\% \]
\[ \text{Max} - R - \text{ProjectQuality} = 0.26 \times 1 + 0.087 \times 2 + (0.18 + 0.0043) \times 4 = 1.269\% \]

The other boundaries can be calculated in the same way. These boundaries and their averages are summarised in table (11-6).

<table>
<thead>
<tr>
<th></th>
<th>Risk on Project Cost</th>
<th>Risk on Project Duration</th>
<th>Risk on Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum risk assessment:</td>
<td>0.98 %</td>
<td>0.526 %</td>
<td>0.772 %</td>
</tr>
<tr>
<td>Maximum risk assessment:</td>
<td>0.926 %</td>
<td>1.921 %</td>
<td>1.269 %</td>
</tr>
<tr>
<td>Average risk assessment:</td>
<td>0.908 %</td>
<td>1.224 %</td>
<td>1.021 %</td>
</tr>
</tbody>
</table>

**Table 11-6: Upper and lower boundaries and average values of risk assessments**

The aggregated degrees of belief assigned to the assessment grade (0%) are used to measure the belief in the expected risk effects not materialising. It can also be used to predict the degree of belief in risk effects materialising. This is treated as a complement event and the value is calculated as the remaining proportion to unity. Such kind of results, together with the upper, lower and average risk values are very rich and useful for informative decision making.

<table>
<thead>
<tr>
<th>Overall belief that there will be no effect on project objectives</th>
<th>Project Cost</th>
<th>Project Duration</th>
<th>Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.5%</td>
<td>51.4%</td>
<td>44.4%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overall belief in materialising the effect on project objectives</th>
<th>Project Cost</th>
<th>Project Duration</th>
<th>Project Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.5%</td>
<td>49.6%</td>
<td>55.6%</td>
<td></td>
</tr>
</tbody>
</table>

**Table 11-7: Aggregated degrees of belief in risk effect materialisation on every objective**

Another aggregation can be conducted in order to generate the project financial risk level. Mr. S provided importance weights to the three project objectives. He assigned project cost a weight of 0.5, project duration a weight of 0.3 and project quality a weight
of 0.2. Again, using the ER algorithm, the distributed assessments of financial risk levels on the three project objectives are aggregated together in order to generate the following distributed assessment of project financial risk:

<table>
<thead>
<tr>
<th>All risks</th>
<th>Project Financial Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees-of-belief</td>
<td>0%</td>
</tr>
<tr>
<td>Ignorance</td>
<td>0.477</td>
</tr>
</tbody>
</table>

| Ignorance | 0.119 |

Table 11-8: Project financial risk assessment in a distributed form

Similar to the previous aggregation, the aggregated degree of ignorance is utilised to provide upper and lower boundaries of the risk assessment. The aggregated degree of belief that is assigned to the (0%) assessment grade is utilised to represent the belief in the effect of financial risk materialising.

| Minimum risk level: | 0.731 % |
| Maximum risk level: | 1.089 % |
| Average risk level: | 0.910 % |

Table 11-9: The upper and lower and average values of project risk level

<table>
<thead>
<tr>
<th>Project Financial Risk Risk</th>
<th>Overall belief that there will be no effect on the project</th>
<th>Overall belief in materialising the effect on the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.7%</td>
<td>52.3%</td>
<td></td>
</tr>
</tbody>
</table>

Table 11-10: The aggregated degrees of belief in project risk effect materialisation

The above results are very useful for decision making and risk treatment. They show a detailed assessment of risk level supported with a degree of belief in the risk affecting the project. This might be very useful for budgeting and sharing project risks.

11.4.1.2 Intangible benefits assessment

Assessing project intangible benefits follows similar steps to assessing project risks, but requires fewer inputs. It starts with identifying the top four intangible benefits a
When assessing project intangible benefits, you are required to provide a values to the following parameters:

1. **Benefit weight**, a number between 0 and 1 which reflects the importance of a risk factor. *All the provided weights should sum up to 1.*

2. **Achievability**, a number between 0 and 1 which reflects the probability that you are able to achieve the benefit as it is perceived when tendering.

Intangible benefits can be *any perceived potential and indirect benefit* of the project. It may involve risks such as:

- Market dominance
- Compitition
- Company reputation
- Keeping the client
- Potential long-term benefits
- Keep the employees working
- Keep the plants and equipments in usage, etc.

### 1. Benefit Characteristics

Please specify the top 4 intangible benefits you think the project can offer:

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Benefit weight (w)</th>
<th>Achievability (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefit 1</td>
<td>A</td>
<td>0.6</td>
</tr>
<tr>
<td>Benefit 2</td>
<td>B</td>
<td>0.2</td>
</tr>
<tr>
<td>Benefit 3</td>
<td>C</td>
<td>0.1</td>
</tr>
<tr>
<td>Benefit 4</td>
<td>D</td>
<td>0.1</td>
</tr>
</tbody>
</table>

---

12 below.
Once this is done, the analyst moves towards assessing the magnitude of every intangible. Benefit magnitudes are assessed by means of monetary equivalents. The monetary equivalent is presented in a distributed form using assessment grades and degrees of belief. Similar to assessing risk impact, the analyst is, at first, asked to choose suitable assessment grades, percentages of the project initial cost, and then assign degrees of belief to every assessment grade, see figure (11-13).
Again, for practicality, the DSS ask the user to provide three assessment grades only. Obviously, more assessment grades can be used if needed. Assessing benefit magnitude requires less time than assessing risk impact as there is no need to consider project objectives. This is because there is no relation between a benefit magnitude and a project objective. Subsequently, the whole process will consume less time due to fewer aggregation steps. Having assessed the intangible benefit magnitudes, the tool multiplies the degrees of belief of every benefit with its achievability coefficient's value. The multiplication results in a set of adjusted assessments of benefit magnitudes as presented in figure (11-14).

**Figure 11-14: The adjusted intangible benefit assessments**
Similar to the risk assessment case, a forth assessment grade, 0%, is added to account for the effect of the achievability confident. This inclusion will satisfy the exhaustiveness of the assessment grades. The degree of belief assigned to this assessment grade means that the benefit does not exist. They are generated by the following formula:

$$\beta'_{i} = 1 - A_{i}$$

Where:
- $\beta'_{i}$ is the degree of belief that the benefit $B_{i}$ does not exist
- $A_{i}$ the values of Achievability coefficient of the benefit $B_{i}$

The adjusted assessments of project intangible benefits can be aggregated in order to generate a project intangible benefit level. The ER algorithm is also used to aggregate the assessments. The results will be obtained in a distributed form and the aggregated ignorance can be used to generate upper and lower limits of project intangible benefit. These limits are averaged and graphically depicted as exhibited in the figure (11-15) below.
3.2. Aggregated assessment of intangible benefits

<table>
<thead>
<tr>
<th>Project Intangible Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>0.06</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>0.386</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>0.158</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>0.113</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>0.079</td>
</tr>
</tbody>
</table>

Due to the incomplete assessment; ignorance or lack of information, there is an unassigned degree of belief. The unassigned degree of belief, *the ignorance*, in this case is:

\[
\text{Ignorance: } 0.008
\]

Similar to the case of risk assessment, the unassigned degree of belief will be used to determine the upper and lower boundaries of the level of intangible benefit in the project.

3.3. Intangible benefit level:

By assigning the unassigned degree of belief to the best assessment grade we can get the maximum level of project intangible benefits. While, by assigning it to the worst assessment grade we can assess the minimum level of project intangible benefit.

The maximum and minimum levels can be used to generate an average assessment of the intangible benefits in the project.

The maximum, minimum and the average assessments of the project intangible benefits are:

- **Maximum Intangible Benefit**: 0.71 %
- **Minimum Intangible Benefit**: 0.51 %
- **Average Intangible Benefit**: 0.66 %

Hence, the equivalent sum to the average level of project **Intangible Benefits** is: £ 14895376.7
11.4.1.3 Project ranking

After calculating project risk level and project intangible benefit level, they can be used as evaluation criteria for comparing between different construction projects or different proposals of the same project. The DSS provides the user with a separate sheet, the “summary & decision making” worksheet, for combining project risk and benefit levels in such a way that makes it easy to rank alternatives. Figure (11-16) shows that two simple and easy to understand combination ways were suggested.

**Figure 11-16: Combining risk and benefit levels for ranking competing alternatives**
It is made very clear to the user that he or she has total freedom of using any other combination model for ranking competing alternatives. Moreover, it is up to the user to choose not to combine the two levels together and to use them individually, or together with other evaluation criteria, for comparing available alternatives.

11.5 DSS validation

As can be seen from the above figure, the DSS does not predict values or recommend actions. Its main duty is helping the decision maker in structuring the decision-making problem and doing the required calculations. It is an automated application of the proposed models and analysis approaches. The DSS operates in a different way from the existing tools and generates unique results which have no similar ones to compare with. For this reason, it is very difficult to validate the results or to test them against benchmark or historical records. Validation difficulty also comes from the fact that every assessor identifies different risks and benefits, provides different coefficient values or degrees of belief, and subsequently gets unique results. Furthermore, the same assessor, using the same risk and benefit factors, may reach different results when doing the analysis in different stages of the PLC. This is because the values assigned to the coefficients and the assigned degrees of belief might differ along the PLC.

For all of these reasons, validating the DSS took two steps. Firstly, the DSS was verified internally by checking the correctness of the included functions and testing the accuracy of the obtained results by comparing them to manually obtained results. The results were also checked against results generated by using the Intelligent Decision Systems (IDS) software which is developed to facilitate the ER approach as a general MCDM tool. Secondly, external validation was performed for evaluating the tool as a methodology rather than testing its results. The best way for validating a new methodology and a tool like DSS is indeed through a significant number of real case studies. However, this is often out of the control of researchers. Great efforts were put to arrange for as many case studies as possible. There were a number of cancellations with short notices. Eventually, the DSS was presented to four construction companies using a real project as a validation case. During the validation cases, the DSS, as a methodology, was compared to the existing tools or approaches used in these companies. The participants were asked to provide feedback about the DSS as a viable alternative to the existing ones. Hence, the focus was on observing the reaction of the practitioners towards the proposed methodology when using the tool, and getting
their feedback about it. Again, it was a validation of the whole framework of the DSS rather than testing the accuracy of its results as there was no benchmark of similar results to measure against.

In order to compensate for the relatively small number of case studies, a methodological validation was sought. I presented the analysis methodology and the DSS to experts in risk analysis and decision science in order to get their feedback as discussed in detail later in this chapter.

11.5.1 Validation criteria

The DSS was designed in alignment with reasons for not using DSSs and the features of a usable DSS obtained from the field work. These reasons and features were also used for validating the DSS. During the validation workshops, and after applying illustrative examples, a set of open-ended questions were discussed with the participants regarding the merits and the shortcomings of the DSS. In two cases, these questions followed a brief discussion about the difficulties faced when using their own approaches for risk assessment and decision making. The DSS was compared with two DSSs in use for a long time in these companies. Actually, these comparisons were vital for identifying the advantages of the DSS. When discussing the DSS and the analysis approach, the open-ended questions considered the following criteria:

- **Ease of use**: a question was asked to evaluate how easy to use the DSS for analysing real problems.
- **Complexity of analysis**: the level of complexity and detail in the whole process was discussed and whether this was an advantage or disadvantage.
- **Methodological clarity**: this point was investigated to check the clarity of the proposed decision making process.
- **Time consumption**: this issue is very important as lack of enough time to prepare a bid is a major problem in construction industry.
- **Quality and usefulness of the results**: the participants were asked to assess the quality of the generated results and their usefulness for aiding decision making.
- **Cost effectiveness**: participants were given free copies of the DSS so there was no cost for having it. Two of the companies have already got their own approaches and specialised staff which makes no financial difference for them to apply different tool if they decided to. The other two companies have their own approaches for assessing risk and making decisions without using such
tools. The issue of the cost effectiveness of the DSS was discussed with these companies as it will be demonstrated later.

Besides assessing the DSS against this set of criteria, participants were encouraged to discuss the shortcomings of the tool and to give suggestions for improvement.

### 11.5.2 Validation cases

As it was previously mentioned, four validation cases with four different construction companies were conducted. Three of them were interviewed and promised to share the research outcome with them, and one company participated in the mail questionnaire, through one of its executive managers. They expressed interest in examining the DSS. Table (11-11) provides some details about the validation cases.

<table>
<thead>
<tr>
<th>The case</th>
<th>Participants</th>
<th>Annual turnover</th>
<th>Company’s main projects</th>
<th>Date</th>
</tr>
</thead>
</table>
| A        | Mr K (Operations manager)  
MRS B (Risk and H&S manager)  
and 2 Quantity surveyors | £15 million | Residential, refurbishment and council projects. Mainly work with public sector | 23/11/2010 |
| B        | Mr S (Chief estimator, assistant to the financial director) | £4.3 billion | Residential, refurbishment and council projects. Mainly work with public sector | 02/02/2011 |
| C        | Mr D (Chief estimator) | £55 million | Residential, refurbishment and council projects. Mainly work with public sector | 16/02/2011 |
| D        | Mr P (Operations Director)  
Mr D (Head of PFI department) | £250 million | Housing, refurbishment and maintenance | 05/05/2011 |

*Table 11-11: The validation cases*

The participants were contacted before every meeting and provided with a copy of the DSS and a guiding manual. The aim was to get the utmost of the meetings and to use the time, which was agreed to be around 2 hours, wisely by focusing on evaluating the process and getting feedback about the DSS. Participants were asked to come prepared with real projects, from historical records or from their current projects, to use them as case studies. Unfortunately, only in Case (B) Mr. S prepared a real project to analyse. In case (A), the operational manager used a historical project, but without
giving detailed information about it, to provide inputs, together with the risk manager and two quantity surveyors, when trying the DSS. In validation case (C) and (D), the participants did not come with specific projects. For this reason, the analysis process was demonstrated through the inputs of case (B) as a real example without revealing any confidential information about the project. The participants were only informed about the project initial and actual cost and its initial and actual duration.

The discussions during the validation workshops were recorded and analysed. The transcriptions of the four workshops are available in Appendix (VI).

11.5.3 Analysing validation cases

11.5.3.1 Within-case analysis

11.5.3.1.1 Validation case (A)

The tool was presented to four members in the company: the operations manager Mr. K, the health, safety and risk manager Mrs B and two quantity surveyors working in the bidding department. After presenting the process of risk analysis and project evaluation using a historical project as a case study, the participants were asked to express their opinions about the tool and the analysis methodology. Mrs. B did like the tool and said that she understood the assessment methodology. Mr. K, however, expressed his concern about the extra cost for covering risks and the extra time and resource required to operate the tool. He said: “... as an operation manager, my duty is to take money off the project cost not to add any unnecessary costs in order to keep the business profitable”. He added that he needed more time to build trust in the tool before using it in practice. He argued that “…we may try it 40 times before we can really trust it to add any extra cost to the project. I think that we need time to build confidence in it.”

It was explained to Mr. K that he does not need to add extra cost to the project. Actually, the DSS calculate risk cost as a measure for comparison reason rather than a contingency sum to be added to the initial project cost. After this clarification he appreciated the logic behind the analysis methodology. One of the quantity surveyors raised the issue of the large number of required inputs especially when analysing complicated scenarios. Mrs. B mentioned the difficulty of finding right input values. However, she argued that it is a matter of time to get used to the tool which will have a more useful presence while the company is growing and the projects are becoming more complicated.
In general, the tool received a positive feedback from the participants who promised to try it and to build a history of usage in order to compare between the predicted and actual results.

11.5.3.1.2 Validation case (B)
Before demonstrating the DSS, Mr. S highlighted the key challenges they are facing when analysing project risk. He mentioned that the key problems were lack of enough time to thoroughly analyse the project, lack of enough information to come up with accurate estimates and market conditions, which did not allow high contingency sums. They were forced to estimate the contingency sum and then to negotiate it with the client in order to keep him satisfied. The analysis methodology was explained and the tool was presented with brief account of the theory and the calculations behind its interface. Mr. S was prepared for the workshop; he came with a construction project in mind to analyse. The specifications of the project were displayed previously in the illustrative example. Mr. S used the DSS for analysing the financial risks of this project. Actually, he was very interested in the assessment and evaluation approaches. According to him, “… the tool can be used when comparing between countries and projects in different countries. For instance, legal, health and safety, technical and operational risks are definitely country-specific. I think that a tool that can look at these risks will be quite a powerful tool.”

Mr. S gave very positive comments about the tool. He compared it with the approach used in his company and found it much better. He praised the level of detail in the analysis and argued that this was very useful as it forced the user to think of the risk and understand it within its surrounding environment. He argued that “… the tool is good because it gives a detailed level of the results and an averaged final figure… It is very useful to include the benefits in the analysis… Our risk register does not do that.” He found these results better than the type of results obtained from filling in the detailed risk register of his company without a thorough understanding of risk characteristics. He also liked the idea of focusing on the top 20 risks as they are quite enough in the tendering stage. He argued that in his company “… risk register is massive. It has about 200 items to be scored on likeliness, cost impact and program impact. Because it is massive people who are in charge of using it are simply filling in. It is so big and so frustrating.”

When discussing the limitations of the DSS and the development opportunities, Mr. S suggested including more information about the theory behind the tool in order to give
the user more confidence in what he or she is actually doing. He also suggested enhancing the analysis results with graphical illustration and keeping the tool as simple as possible so everyone can use it.

At the end of the workshop, Mr. S promised to share the tool with his colleagues who are interested in risk assessment. He promised to get back with any queries or suggestions. He also promised to share with me the results of any application of the tool in real projects. In fact, he got back after few days with a list of questions made by Mr. Kth B, the company’s insurance manager, who used the tool and needed some clarifications. The queries of Mr. Kth B were answered and some ambiguous points were explained. The questions of Mr. Kth B and the answers are available also in Appendix (VI).

11.5.3.1.3 Validation case (C)
Similar to the previous validation case, the workshop started with a general discussion about the practice of risk assessment and project evaluation in the company, the shortcomings of their practices and the difficulties they are facing. Mr. D mentioned that they are facing a problem when using their risk register for analysing project risk. People who are responsible for analysing risks are dealing with this task as a routine activity without a thorough analysis. He argued that “The people who are working on assessing risks usually do not understand the risks; they simply throw figures and values. The problem is that we do not know what the important risks to carefully look at. This is because we have huge number of risks in the risk register to be considered.”

This is the same difficulty that was mentioned by Mr. S. The problem of limited time for analysing project risk before tendering was also mentioned by Mr. D. He also talked about the limitation of their approach of neglecting independencies between risks which may accelerate project risk estimate and force them later to reduce it.

The DSS was later presented and the assessment methodology and the theory behind it were discussed. The inputs that were provided by Mr. S in the validation case (B) were used to demonstrate a real example of assessing project risk. Mr. D gave a very positive feedback about the tool. He found it more detailed than he expected and better than his company’s approach because of the detailed analysis it provided. According to him, the tool would be very useful especially in large projects. He welcomed the idea of using monetary equivalent as a measurement scale and appreciated the idea of incomplete assessment and the possibility of accommodating lack of information.
transparently. The use of ignorance for generating upper and lower risk levels was very much welcomed. He “liked the idea of monetary values as percentages of the initial cost for assessing risk... I think that the idea of calculating the ignorance and then using it in defining the boundaries is quite useful.” Mr. D realised the potential of the DSS as it was clear and easy to use by anyone. This was attributed to the deployment of Microsoft Excel package and the use of monetary equivalent as a measurement scale, which is easily understood by anyone. Regarding the limitations of the tool, he motioned the difficulty of justifying the values assigned to the different coefficients. He also highlighted the need for long time to get used to the tool and find the right values to be used. Finally, he suggested improving the tool by providing more guiding information and keeping the process as simple as possible.

11.5.3.1.4 Validation case (D)
The forth validation case was conducted in a construction company based in the area of greater Manchester with an annual turnover of around £250 million. One of the executive managers of the company participated in the mail survey and expressed his interest in further collaboration. Two managers participated in the validation workshop: Mr. P, the operations manager of the company, and Mr. D, the head of private financial initiative (PFI) department. Although the company is a well-known construction company, the workshop revealed that it had no structured approaches for risk analysis or project evaluation. The analysis methodology was demonstrated and the tool was displayed through an illustrative example, the project provided by Mr. S in the validation case (B). Again, the project was used without revealing any confidential information. Actually, the tool received different feedback from the two participants. Mr. P was not enthusiastic about the DSS at all. He found it too sophisticated for their business. He explained by saying that they used to work in projects they are experienced in so they did not need such a tool. They know their clients and they always aim to keep the process simple without any further complications. Hence, risk assessment and project evaluation are perceived as extra steps in the tendering process which require more resources. He argued that their top criteria are getting their money back and having the required resources to deliver the work. Hence, he argued that “If we find that there is an opportunity we will go for it without going through a process.” He further explained his point of view by saying: “… we always search for how to reduce the cost. I think that such an approach needs someone to work on. It will take around four hours and every hour will cost me 100 pounds. I do not think that we are ready to pay that sum of
money... We are a family owned construction company and we do not have half a man spare; this is how we make money." Mr. D, however, had a very different point of view. He praised the DSS and mentioned that before joining the company he worked with a bigger construction company where he used a sophisticated tool. He added that such a DSS would benefit bigger companies where very sophisticated projects are to bid for.

In fact, it was clear that Mr. D, who had a good experience in DSSs through working in a bigger company, had a positive attitude towards the DSS and the assessment methodology. He expressed his awareness of RM and uncertainty analysis theories and gave useful comments about the assessment process. Mr. P, nonetheless, had no experience in such tools and no interest in risk analysis. He admitted that he was very bad in probabilities. He apologised for being rude and negative about the process and explained that this was not personal but because he felt that the tool was not for him. He said: "The tool might be brilliant but I did not get it, so do not take my answers as offensive, simply because I am not familiar with probabilities or such kind of tools."

The difference in familiarity with risk analysis was reflected in the evaluation of the DSS against the evaluation criteria. The assessments provided by the two men were conflicting in almost every evaluation criteria. On the one hand, Mr. P found it difficult to use, not easy to understand, too sophisticated, very detailed, time consuming and not cost effective. According to him, it did not fit into his organisation as they followed a much simpler approach. However, he admitted that the tool was very useful and applicable in bigger companies. He elaborated: "...the tool is very useful when you have strategic projects so you can hold such meetings and workshops. For us, I think that it will cost us a lot of money to use it." Mr. P liked the idea of assessing risks and benefits simultaneously and found it very useful for comparing different projects. Mr. D, on the other hand, found the tool clear and structured, straightforward and easy to understand, with useful results and had great potential for bigger companies and those companies who wanted to grow and develop their businesses. He added that they also can benefit from it: "we may need such a tool in order to record our business and to capture the risks we are facing so we can use the recorded data in future bids."

These different attitudes may explain why practitioners are heavily relying on their experience for risk assessment and decision making especially in small construction companies. Moreover, they can explain why construction industry is still under developed technologically bearing in mind that the vast majority of construction companies are small or very small ones.
11.5.3.2 Cross-case analysis
In order to investigate the participants’ evaluation of the DSS against the evaluation criteria, an evaluation matrix is constructed to summarise the collected data in it. The matrix was very useful in analysing the data on a variable base across the four cases.

11.5.3.2.1 Ease of use
Apart from Mr. P who found the DSS complicated, all the participants found it straightforward and easy to use. They appreciated considering a fairly enough number of risks, 20 risks, when tendering as they usually suffer from limited time span to prepare a bid. Hence, ranking potential risks and focusing on the top 20 ones for a detailed analysis was quite practical and suitable as Mr. S and Mr. D felt. However, some of the participants argued that the required inputs needed thorough thinking and understanding of risks. This issue, actually, has a double-sided effect; it may stimulate thinking of risks and enhancing the ability of managing them, but in the same time it creates a difficulty in agreeing upon suitable values to the required inputs. The participants were informed that the number of inputs is directly related to the level of detail in the analysis, therefore, this issue is managed according to the analysis requirements.

11.5.3.2.2 Complexity of analysis
The complexity of analysis has attracted a general appreciation from the participant. They found the analysis quite detailed which is required according to Mr. S and Mr. D. They were satisfied with the different levels of aggregation the tool offered and the distributed and consolidated types of results it generated. They also agreed that the level of detail is more appreciated in large companies which face complicated and strategic projects. The participants, however, mentioned that they need time till they build confidence in the results of the DSS after agreeing on the right values to be used in the analysis. In fact, the participants were informed that they require some time till they build history of usage and decide on the right level of complexity and the right values required in different situations or projects. It is like tuning a guitar where the professional player is able to balance many factors in order to produce the right tune. Using the DSS will start as a learning process. This feature provides the users with flexibility and adaptability to different circumstances but in the same time makes validating the tool difficult.
11.5.3.2.3 Methodological clarity
Generally speaking, participants found the assessment methodology clear and transparent. They mentioned that it requires a few hours of tainting and then the can operate it smoothly. Mr. D was very satisfied with the clarity of the process. He mentioned that the results can be easily investigated. Hence, if unexpected results appeared, he can easily find why this happened. He found it very easy to change the inputs and see the direct effect on the results; it is very convenient to do sensitivity analysis. Mr. P, however, found it complicated; he liked to do business in the simplest possible way. He explained his attitude by saying that the more complicated the process is, the more expensive and resource demanding it becomes.

11.5.3.2.4 Time consumption
The analysis process was not believed to be time consuming. Most of the time is spent on thinking of the risks, understanding their surroundings and deciding on the input values. It seems that this feature was very much appreciated by Mr. S and Mr. D who argued that the beauty of the tool was to force people to think of risks when assessing them. Mr. D suggested that *“Group discussion would be needed to agree upon the final values of these parameters.”* Actually, the DSS consider a fairly small number of risks and benefits but requires a considerable number of inputs for each of them. Hence, conducting a detailed analysis may require a group decision making workshop for about two hours. However, in order to provide very quick results, every worksheet is designed to be self-contained. Hence, the users may decide to analyse specific risk categories in which may require less than 20 minutes.

11.5.3.2.5 Quality and usefulness of the results
The generated results were much appreciated. Specifically, the different levels of risk aggregation, the use of monetary terms to measure risk and benefit, the combination of risk and benefit, the distributed form of results that can be easily transformed into consolidated figure, the ability of providing incomplete assessments and the deployment of the aggregated ignorance for generating upper and lower assessment levels were believed to be very useful and unique results. Mr. S did support the idea of generating distributed results as he found it very informative. Moreover, he supported consolidating the distributed form of results as *“at the end you need to come up with a final figure to be used in the bid.”* Mr. D very much appreciated the concept of
ignorance and found it very useful as it is very common not to have enough information when tendering. He added that “this tool will be particularly useful in big projects.”

11.5.3.2.6 Main shortcomings and suggestions for improvement
The main shortcomings of the DSS that were mentioned by the participants are:

- The large number of required inputs: actually, detailed analysis has a downside of demanding a lot of inputs for every risk or benefit factor. It also requires other inputs for aggregating the individual assessments. It was explained to the participants that the large number of inputs is justified when analysing strategic and complicated projects.
- The difficulty in agreeing upon the right values of the required inputs. The participants concluded that they needed time to be able to input the right values and to build confidence in the DSS before using it in real cases.
- The difficulty of understanding the concept of degree of belief and differentiating it from the classical concept of probability. However, it was not a serious problem as the participants felt comfortable with the tool after explaining to them the concept of degrees of belief and conducting a real analysis task.

There were a number of improvement suggestions. Some of them were cosmetic, regarding the colours, graphics and the overall layout of the worksheets. Other suggestions were about including help information to help the users appreciate the meanings of the required inputs and the whole analysis methodology. A designated help and support worksheet was included to provide useful information about the theory behind the analysis methodology and help in providing suitable values to the required inputs.

11.5.4 Methodological validation
As mentioned earlier, in order to compensate for the relatively small number of case studies, a methodological validation was sought through consulting experts in risk analysis and decision making. For this purpose, a meeting was arranged with an academic member of the Management Science department at Strathclyde Business School who has developed a DSS for investment risk analysis while working with Accenture. During the meeting, the theory behind the tool was discussed and an
illustrative example was applied to try the tool. He did like the tool, the theory behind it, ignorance utilisation and the type of results generated. We also discussed the difficulty of validating such tools adequately. He argued that such tool can be validated through expert consultation, or inter-subject validation.

In order to get feedback from a wider range of expertise, the researcher participated in the OR 53 conference in Nottingham in September 2011. Three presentations were delivered in three different themes: Multi-Criteria Decision Making, Project Management, and OR in Construction Management. Two meetings were arranged with two scholars who have great experience in risk analysis and decision science and presented my contribution to them. The received feedback was promising and encouraging. Although there was no challenging questions or criticism that led to a major change in the DSS, they did not point towards any significant problem in the methodology or the tool. It is thought that these validation attempts add to the validity of the proposed methodology and the credibility of the DSS.

11.6 Summary and conclusions

In this chapter, the DSS components were demonstrated and an illustrative example was provided to exhibit the proposed analysis methodology. The chapter has also presented the results of the validation cases and highlighted the main benefits and shortcomings of the tool after applying real examples. It was concluded that the tool could provide a viable alternative to the existing tools used in two companies. Moreover, the other two companies, which do not use such tools, appreciated the usefulness of the tool especially if they decided to expand. Together with the previous research findings, the results of the validation cases help to conclude that the proposed models and methodologies have a genuine potential in enhancing the practice of risk assessment and project evaluation through structuring past experience and personal judgment and providing detailed analyses and rich results which are invaluable for informative decision making.
Chapter 12: Discussion of Research Results

12.1 Introduction

After presenting the research findings and analysing them in the previous two chapters, this chapter discusses the obtained results and the research findings in relation to research questions and the existing literature. It investigates the effectiveness of the research methodology in achieving the research objectives and addressing its questions. Moreover, this chapter evaluates the whole research project, figures out its strengths and weaknesses and checks the validity and reliability of its deliverables. Finally, it discusses the theoretical and practical implications of the research findings.

12.2 Research problem

This research project was carried out in order to achieve the following objectives:

- Investigating construction risk modelling and proposing an alternative model that can better capture the nature and characteristics of construction risk.
- Examining the effect of a size of the construction company on its practice of risk analysis and project evaluation
- Researching risk assessment tools and techniques and evaluating their usability in order to propose an alternative that structures the professional experience of construction practitioners.
- Reviewing the theory and practice of construction project evaluation and proposing an alternative framework.
- Building a decision support system (DSS) in order to facilitate the proposed risk model and assessment and evaluation methodologies.

An extensive review of the literature of risk modelling and assessment was conducted. The developments in risk modelling and assessment were documented and appraised. This was crucial for proposing a novel risk model that includes three parameters, besides the likelihood of occurrence and impact, for reflecting the effect of project features on risk impact, the ability of risk management team of managing the downside effect of the risk and the interdependencies between the risks. Risk cost was proposed as a measurement scale to assess risk impact on the different project objectives. Risk
impact is provided in a distributed form to enable expressing doubt and lack of information through allowing risk analysts to provide incomplete assessments. The assessment methodology structures the experience of construction professionals in a rather objective and rigorous approach. DST was employed innovatively for assessing project risk and the ER algorithm was used as an aggregation tool. The proposed risk assessment methodology provides a realistic picture of the project riskiness through assessing the co-existing benefits. A similar methodology for assessing project benefits and aggregating their assessments was proposed. The focus was on the intangible, non-financial, benefits as they used to be considered implicitly without following a transparent or structured approach. Project risk and benefit were dealt with as evaluation criteria for comparing between different construction projects or alternative proposals.

The attitudes of construction professionals regarding research propositions were surveyed through mail and on-line questionnaires and semi-structured interviews. The survey focused on the contractors’ side leaving the client side for a future research project. In general, the results showed clear agreement with the proposed approach. A spreadsheet-based DSS was devised to facilitate the proposed risk assessment and project evaluation approaches. Four validation case studies were conducted in four companies. The tool received very positive feedback and the participants appreciated its potential in practice. The participants were shown how risks and intangible benefits could be measured by monetary equivalents. This has positively changed their attitudes about the feasibility of measuring intangibles in monetary equivalents. The interviews and the validation cases were essential for supporting and explaining the findings of the questionnaires.

12.1 Discussion of research findings

12.1.1 Relationship to the research questions and the existing literature

12.1.1.1 Question 1
What other parameters can be included in the P-I risk model in order to better model risk and generate a more realistic risk assessment?

Literature review revealed different attempts to improve the P-I risk model (Han et al. 2008; Aven et al. 2007; Cagno et al. 2007; Dikmen et al. 2007b; Zhang 2007; Zeng et al. 2007; Cervone 2006; Jannadi and Almishari 2003). After evaluating these attempts and based on the safety analysis literature, a new risk model was proposed by extending
the P-I model to include a third dimension, probability of impact materialisation (P) that is defined by three parameters: Controllability (C), Dependability (D) and Project features (F). The inclusion of these parameters received clear agreement from the respondents to the questionnaires. Moreover, including these parameters in the risk model aligns with the actual practice of assessing construction risk as it was found during the interviews and the validation case studies. The new model provides a novel alternative that overcomes the limitations of the P-I model and builds upon the existing improvement attempts in literature. Furthermore, it creates a link between the RM and the safety analysis literature where similar models are used for modelling safety (Wang et al. 2004; Wang and Yang 2001; Yang et al. 2001; Wang et al. 1996; Wang et al. 1995). This may contribute to improving the theory of project risk analysis through expanding the conventional perception of safety management beyond the hazards and workers’ health and safety domains. In this regard, this research has presented the concept of “project safety level” that reflects the extent to which the project is safe in delivering its deliverables after considering the security measures put in place for managing project risks.

12.1.1.2 Question 2
To what extent risk cost is a feasible alternative for measuring risk impact on different project objectives?
Research findings prove that the idea of measuring risk impact in monetary terms is quite acceptable, simple, convenient and usable. It was perceived as a simple and practical method because of using a common language that everyone can understand in construction industry. This result actually comes in alignment with the literature that suggests similar benefits for using risk cost as an impact measurement scale (Chan and Au 2008; Sanchez 2005; Dey 2001; Williams 1995; Paek et al. 1993; Franke 1987). However, providing a monetary equivalent of risk impact on project quality was found rather difficult. Pricing extra cost or duration of a project is easier than pricing violating a specific quality measure. However, pricing risk impact on project quality is achievable with extra care and analysis. Appreciating the principle of pricing risk impact is thought to be attributed to the fact that providing contingency sum to cover unforeseen risks is very common practice in construction as literature suggests. Hence, pricing risk impact was not alien to practitioners.
The research builds on the existing literature and provides evidence for confirming the viability of using risk cost as a common measurement scale. In addition, this research provided an opportunity for actualising this suggestion through proposing an
assessment methodology and devising a simple and user-friendly DSS. It marks a step forward in the continuous endeavour for improving project risk analysis.

12.1.1.3 Question 3
Is it suitable to use a monetary equivalent as a common scale for assessing project risks and intangible benefits when evaluating different construction projects?

The idea of measuring intangible benefits using monetary equivalent did not get strong support from the respondents to the questionnaire. This result was explained through the interviews; the interviewees mentioned the difficulty of pricing intangible benefits. Actually, they felt it possible and suitable, but they did not know how to reach the right price. A similar attitude is already documented in the intangible valuation literature (Murphy and Simon 2002). Despite its difficulty, this research suggests that pricing intangibles is a viable, practical and understandable approach. This confirms the conclusions of Hunter et al. (2005) and Hofmann et al. (2005) that the most suitable way for valuing many different types of intangible capitals is using financial terms.

Regardless of the difficulty of pricing intangible benefits, using monetary equivalent as a common scale for measuring both risks and benefits was welcomed by all of the interviewees and the participants in the validation cases. According to them, pricing project risks and benefits was a straightforward and easy to understand method. This result provided a practical support and validity to the call for extending RM process to include both of risks and opportunities (Hillson 2002). Although such a comprehensive approach of analyzing project risks and opportunities seems to be very logical and useful, unfortunately the actual practice does differ. It was found that contractors usually go to projects with less risk and more profit; they do not usually make a trade-off between risks and potential rewards. This was an expected result from my experience and from the literature that records remarkable difference between the theory and practice of RM (Laryea and Hughes 2008; Lyons and Skitmore 2004; Uher and Toakley 1999; Akintoye and MacLeod 1997; Flanagan and Norman 1993; Thompson and Perry 1992).

Indeed, the proposed methodology of using a common scale for measuring risks and benefits did not largely attract the questionnaire’s respondents. However, it did appeal to the interviewees and the participants in the validation cases after applying real examples. The initial attitude of some of the interviewees has positively changed after applying real examples during the validation cases. Hence, judging the viability and the
practicality of the proposed methodology is difficult. It can be argued that it is feasible based on the results of the interviews and the validation cases. However, the questionnaire results show that this conclusion cannot be generalised statistically. Hence, this idea may attract more attention and acceptance if the DSS proved to be a useful and effective tool of balancing risk taking.

12.1.1.4 Question 4
Can past experience and personal judgment be structured and used objectively when assessing risk and evaluating construction projects?

The research confirmed the findings of previous research projects that past experience and personal judgment are the key element in analysing risk and making decisions (Dikmen et al. 2004; Lyons and Skitmore 2004; Wood and Ellis 2003; Uher and Toakley 1999; Baker et al. 1999a; Akintoye and MacLeod 1997; Shen 1997). Moreover, the questionnaire results show a great reliance on previous experience even in the presence of DSSs. Similar results were obtained from the interviewees. However, they emphasised that reliance on experience did not mean guessing or following gut feeling; it is using the available information.

The DSS was devised to assist the users in utilising available information from all sources, including practical experience, and using them in a transparent and auditable manner. The users can hold group discussions or workshops for discussing available information and cumulated experience in order to decide on the right inputs. The participants in the validation cases did like the tool and the theory behind it. They found the DSS useful for employing previous experiences and documenting them for future projects. This was believed as a learning activity where previous lessons and experiences can be used in current or future challenges. The proposed models, analysis methodology and DSS provide an effective tool for structuring the subjectivity element of risk analysis. This may contribute originally to the RM literature and respond to the call of understanding the actual practice of RM when designing any tool or DSS (Laryea and Hughes 2008).

12.1.1.5 Question 5
Do construction professionals complement their reliance on experience and personal judgment with special tools for aiding risk assessment and project evaluation?

The research results demonstrated that reliance on DSSs for aiding risk assessment and decision making is quite limited. This supports the results of previous researches
which indicate a limited usage of DSSs for aiding risk analysis in construction industry (Dikmen et al. 2004; Lyons and Skitmore 2004; Wood and Ellis 2003; Akintoye and MacLeod 1997). However, this research adds to the previous research findings another one; there is a heavy reliance on past experience and personal judgment even if DSSs are in use. This behaviour was attributed to the subjective nature of risk assessment and decision making in construction industry. Indeed, a lot of art and experience is required to analyse construction risk especially when negotiating risk allocation and risk allowance. This result, actually, confirms the finding of Laryea and Hughes (2008) that dealing with risk and pricing it is very subjective as risk estimate is adjusted by decision makers in order to suite their strategic objectives like winning a specific contract, beating competitors, keeping the workforce working or establishing a relationship with a specific client. In these circumstances, directors usually amend the contingency sums even if it is calculated based on a firm risk analysis. Hence, contingency sum may be better estimated on the basis of risks estimated risks rather than adding an arbitrarily sum. In fact, the same attitude was expressed when interviewing Mr. S.

It was found that the size of the company, the annual turnover, had a clear impact on the maturity level of practicing risk assessment and project evaluation. Big companies are more likely to have designated departments for RM and follow systematic approaches for RM and decision-making. This may suggest that DSSs are more likely to be used in big companies. The variance test revealed that small companies rely more on past experience and personal judgment for risk assessment and project evaluation than big companies. Similar results were obtained from the interviews. These results are logical and consistent with the literature. Big construction companies are more likely to bid for strategic and complex project which are more vulnerable to risks than small ones (Dey 2001). Hence, they are expected to demonstrate a high level of maturity in risk analysis and decision making. Small companies, however, may not follow formal approaches for risk assessment or decision making as they restrict their activities to specific types of projects and specific clients. Hence, their cumulative experiences may be enough for them to survive and avoid the impact of unexpected risks. This may lead to a conclusion that there is no pressing demand for DSSs to complement or support the experience of these companies. This was evident through the comments of the interviewees coming from small companies.

The participants in the validation cases acknowledged the merits and the usefulness of the proposed tool. However, they mentioned that they needed to try it for a long time till they build confidence in it after testing its results by comparing them to their
experience. Hence, the experience is the benchmark against which a new tool would be tested. Such an attitude demonstrates a great reliance on experience and a huge challenge against replacing it with more structured and objective approaches. This challenge was essentially evident during the validation case (D) that reflected very different attitudes of two professionals with dissimilar level of familiarity and experience in using DSSs.

Thus, the level of complexity of projects and familiarity with DSSs would determine the extent to which DSSs may complement and support personal experience in analysing risks and making decisions.

12.1.1.6 Question 6
What are the main reasons of the low take-up of DSSs for aiding risk assessment and decision making in construction industry?
The questionnaire included six reasons for not using DSSs and allowed the respondents to mention any other reason(s) that may prevent them from using such tools. The reasons were included after considering the relevant literature (Han et al. 2008; Laryea and Hughes 2008; Byrne 2005; Lyons and Skitmore 2004; McCowan and Mohamed 2002; Akintoye and MacLeod 1997; Diekmann 1992). However, the questionnaire covered other reasons and allowed the respondents to mention their own ones. In the mail survey, the six reasons were given similar importance with a slightly more importance placed on losing control over the process. There was, in fact, no dominant reason for not using DSSs for aiding risk analysis. This is a similar finding to the findings of Lyons and Skitmore (2004). According to the on-line survey results, the most frequently selected reason was a lack of awareness of how DSSs worked. The next most important two reasons were losing control over the decision-making process and lack of trust in DSSs. The respondents to the on-line survey mentioned other reasons like: the availability of such tools, the practicality, cost effectiveness and the limitations DSSs in reflecting human expertise. The interviews revealed similar reasons including cost effectiveness and the doubt of the tool’s benefits. These reasons confirm the findings of the previous attempts to understand the limited take-up of DSSs.

This research, however, provides additional reasons for not using DSSs. The company size was mentioned as reasons for not requiring sophisticated tools or DSSs. Small companies show more reliance on experience and less usage of DDSs than big companies. Another reason was elicited during the interviews. There is a general
attitude that a machine or a DSS cannot be used without human experience; they cannot replace human judgment. This is indeed a well-known issue in the history of DSS research and development. Mr. S argued that using DSSs generated a risk of making people rely heavily on them without perceiving the tool as an aid. In other words, using these tools will take the thinking element from the risk assessment or decision-making process. The interviews revealed that there was a general tendency of avoiding risk to survive in tough market conditions rather than thoroughly analyzing risks and balancing them with potential rewards. This negative attitude towards a calculated risk taking may be a major cause for not using DSSs in construction industry as the main focus of construction practitioners is packaging risk and transferring it to other parties or negotiating a contingency sums with the client to cover it. In summary, the research findings confirm the findings of previous researches and enrich them with other reasons that may explain the limited application of DSSs.

12.1.1.7 Question 7
What are the key features of a DSS that attract construction professionals to use it?
All the reasons that cause limited application of DSSs should be taken into consideration when developing a usable tool. Throughout the interviews and the validation cases there was a universal agreement that a tool should be as simple as possible. The interviewees and the participant argued that people in construction, especially in small companies, like to do business in a rather simple way. Moreover, they do not want DSSs to add to the complexity of the bidding process. This will incur extra cost and time, which is always limited during the bidding process. They have also raised the cost effectiveness of using DSSs and the need of having a tool that does not demand specialist people to operate. It is in some way or another referring back to the essence of simplicity in the DSS. The research findings enable summarising the features of a usable DSS by:

• being simple and easy to use
• being flexible and easy to customise
• providing quick analysis
• allowing users to express their own way of analysis
• utilising the practical experience of the user
• being clear and transparent in such a way that users appreciate the methodology and the theory behind the interactive interface;
These results actually confirms the validity of the calls in the literature for having similar qualities in any proposed DSS (Laryea and Hughes 2008; Baloi and Price 2003; Ward and Chapman 2003; Diekmann 1992).

### 12.1.2 Validity of the proposed models and methodologies

Validity can be defined as the correctness or credibility of a description, conclusion, explanation, interpretation, or any other sort of account (Maxwell 1996). It is a measure of correctness of any type of research findings or results. In this research, the proposed risk model, new assessment methodology and project evaluation framework need to be validated in order to be used with confidence in the devised DSS.

The proposed risk model is built using the same philosophy of the safety model as it was discussed in chapter 7. Moreover, the assessment methodology of both of risks and benefits uses the DST and the ER approach as a theoretical basis. These are well-established and verified theories for MCDM. Therefore, they are used in a rather innovative manner. Hence, the proposed models and methodologies are theoretically valid. The DSS was devised using the equations of the DST and the ER approach. The functions that are used in programming the cells of the Excel spreadsheets were scrutinised in order to ensure that the DSS is free from any syntactic errors introduced during the development stage. The generated results were tested to check their consistency across the different worksheets and against manually obtained results and against results generated by the Intelligent Decision Systems (IDS) software. A sensitivity analysis was also performed in order to test the variance in results according to different inputs. By doing that, the obtained results were found consistent and all of the functions in the DSS were verified.

### 12.1.3 Validity of the DSS

Validating the DSS goes beyond verifying the functions used for developing it. It involves validating the whole framework and ensuring that the system effectively supports decision making process. Ideally, DSS validation should assess the results and check their correctness against benchmarking results. The benchmarking results are usually the historical records of previous cases. DSS validation can be also conducted by involving a panel of experts who are able to judge the correctness of results and compare them against their predictions.
The devised DSS does not predict values or recommend actions. Its main duty is helping the decision maker in structuring a decision-making problem and doing the required calculations. It is an automated application of the developed analysis approaches. Moreover, the DSS operates in a rather different way from the existing tools, uses different assessment scales and, subsequently, generates unique results which may have no similar ones to be measured against. For this reason, it is quite difficult to validate the results objectively by testing them against benchmarking results. Hence, validating the DSS was conducted through inviting potential users to using it in real problems and asking them to evaluate the tool against a set of validation criteria. As it was discussed in the previous chapter, the tool has received a very positive feedback regarding all the validation criteria. However, the type of results it generated, risk levels, had no counterparts to measure. The DSS provided an estimate of project risk level, whereas the used case included a contingency sum. Hence, it was difficult to examine whether the risk levels on the different project objectives or on the project as a whole were correct. Validating the DSS has another difficulty which stems from the fact that every assessor identifies different risks and benefits, provides different inputs, has unique degrees of belief and, eventually, gets unique results. Moreover, the same assessor, using the same risk and benefit factors, may reach different results when doing the analysis in different stages of the PLC as he or she may provide different values to the required inputs or assign different degrees of belief to the assessment grades. Hence, for all of the above reasons, and in the absence of an objective validation mechanism, the DSS was validated as a methodology.

Although it may not be an ideal way of validating a DSS, it was the only available method of validation that can be accepted methodologically. Actually, a similar approach is used in observational research despite the criticisms raised against the validity of such an approach as observers are forced to rely mainly on their own perceptions (Adler and Adler 1994). However, the validity of the findings can be enhanced by using multiple observers to cross-check each of the findings and eliminate any inaccurate interpretations, following an analytical methodology by testing negative cases or presenting the findings with a high degree of internal coherence, plausibility, and correspondence to show authenticity (Adler and Adler 1994). Indeed, the DSS was observed by various observers; practitioners and experts. Their feedback and assessments were cross-checked. The results confirmed the findings of the interviews and the questionnaire, enriched them and enhanced the internal coherence of the research results and conclusions.
12.2 Research validation

The mixed-method approach was adopted and data was collected through questionnaires, interviews and case studies. The quantitative data was easy to manage and analyse using the SPSS statistical analysis package. An objective approach was followed for analysing the data and drawing conclusions from them. However, the qualitative data was more difficult to comprehend and to make use of.

In order to ensure the validity of the results of the qualitative analysis and the drawn conclusions, the approach of Maxwell (1996) was followed to deal with potential validity threats. All the interviews were tape recorded and then transcribed in detail in order to get a rich qualitative data. Later, the transcriptions were summarised using matrices in order to prevent any validity threat stemming from data description. There was a huge emphasis on transmitting the same attitudes and points of view of the interviewees in order to eliminate any possibility of interpretation threat to the validity of the findings. These two strategies were couples with utmost efforts to avoid any biased selection or interpretation to the collected data.

Great efforts were devoted for collating evidences and comparing and contrasting between the obtained results from the questionnaires, the interviews and the validation cases. Such a triangulation strategy was hoped to reduce the risk of any systematic error or bias. It was also deployed to increase the generality of the results, explanations and conclusions. Actually, the triangulation strategy was deployed as a treatment for potential validity threats and also as a validity-testing strategy. When conducting the interviews and during the validation cases, there was a systematic search for feedback from the interviewees and the participants regarding what was concluded from previous steps. This dynamic strategy for checking the validity of the conclusions, known as member checks, is believed to be the single most important way of validating the conclusions and ruling out the possibility of misinterpretation (Maxwell 1996).

Finally, it is worth emphasising that research validity is not a "context-independent property" of research methods or conclusions; it is relative to the research objectives and circumstances of the research (Maxwell 1992). It is thought that, within the limited time and resources to conduct this research, the adopted research methodology and the used methods were the best attainable options. However, the research has some limitations which are discussed in the next section. They can provide research findings and conclusions with a high level of validity.
12.3 Critical review of the research methodology

The research started by identifying a genuine gap in the literature of risk assessment and modelling in construction industry. A tentative proposal was proposed to fill in the gap and later improved after reviewing the relevant literature extensively. A pilot study was conducted to explore the reaction of construction people to the proposal and to benefit from their comments for further improvements. In order to check the feasibility, applicability and novelty of the proposal, a questionnaire was distributed, seven semi-structured interviews were conducted and a four validation case studies were arranged.

Due to limitation in time and resources, only 420 questionnaires were distributed. 96 valid responses were received through which two interviews and two validation cases were arranged. It could have been better if more construction professionals were reached. For this reason, the on-line questionnaire was administered. The result was getting 160 more responses and arranging for another two interviews. The respondents to the on-line questionnaire were from around the world which enriched the results generated from the mail questionnaire about the UK practice and enhanced their generalisability over the UK construction sector. However, it was difficult to calculate the response rate of the on-line questionnaire or to define the sampling frame as the on-line survey was open to everyone enrolled in the online communities through which the questionnaire was distributed.

Seven interviews were conducted, two face-to-face and five on phone. Both of the two interview types have advantages and disadvantages. However, it was the most convenient way to interview people due to their timetables, preferences and locations. It was very difficult, actually, to find more enthusiastic people to collaborate in the research effectively. It was planned to interview more people. However, some of them cancelled their appointments at very short notices. Moreover, it was inevitable to reschedule the interviews for a number of times with in two cases. Eventually, three arranged interviews and two validation cases were not conducted. People were always busy and the economic situation was not supportive during the data collection stage. The data collection and the research validation stages were very time consuming and demanding; they took around 16 months to be completed.

The proposed contribution could have been better tested and validated if more strategic and complex projects had been analysed. As it was mentioned in the previous chapter, not all of the people who participated in the validation cases came with real
projects to analyse as an example although I highly emphasised that the potential of the DSS could not be realised unless it was used to analyse complicated and strategic projects. A better validation could have been achieved if more companies had been engaged and more strategic project had been analysed.

12.4 Research implications

12.4.1 Theoretical implications

From a theoretical point of view, this study was, partly, exploratory and mainly confirmatory. Yet, the research was different from the traditional confirmatory research where hypotheses are tested by analysing collected data statistically. A deductive approach was followed through proposing an alternative to fill in an existing gap in literature. The key theoretical implications of this research project are:

- The proposed risk model is a vital alternative to the P-I model. It overcomes its limitations, provides a solid basis for a more realistic risk assessment and originally contributes to the literature of risk modelling and assessment.
- DST and the ER approach have a great potential in analysing construction and project risk; they deserve more attention from the researchers working in this area. Moreover, researchers may need to further explore their potential in tackling the subjectivity of decision making in construction management.
- The distributed assessments and the use of ignorance provide a feasible solution to the ongoing problem of lack of information and lack of consistency in the bidding stage. Indeed, they can be effectively employed for providing better project estimates in terms of cost, duration and contingency sum.
- The use of risk cost as a common scale for measuring risk impact on different project objectives proved to be a viable option. This confirms the validity of the calls in literature in this regard.
- Past experience and personal judgment can be structured and utilised in a transparent way. Researchers may follow similar approaches for handling the subjectivity of decision making in construction management.
- The research outcomes respond to the calls in literature for providing innovative, simple and usable approaches and DSSs for risk analysis and decision making.
12.4.2 Practical implications

This research project resulted in a DSS which assists construction professionals in risk assessment and project evaluation. The DSS encapsulates the theoretical contribution of the research. In fact, the tool has received positive feedback from the participants in the validation cases and the experts who examined it. From this premise, the main practical implications of this research include the following:

- Construction professionals can easily document their experience and, effectively and systematically, use it in future cases.
- The proposed risk model, assessment methodology and project evaluation framework can be used in any types of projects; they are not restricted to construction projects.
- The use of monetary equivalent would encourage people to use DSSs as it is a simple and straightforward way understood by everyone in construction.
- The DSS contributes to improving the practice of risk analysis and project evaluation; it emphasises the need for a thorough thinking of project risks and benefits and encourages group decision making to choose the right inputs and decide on the level of detail in the required analysis.

It is hoped that the outcomes of this research would contribute to improving the actual practice of risk analysis. Moreover, it is hoped that they would help raise the awareness of RM benefits and closing the gap between theory and practice of construction risk analysis and decision-making.

12.5 Summary

This chapter reviewed the research topic and discussed the obtained results and their relationships with the research questions and the literature. It also discussed the validation process and the validity of the proposed models, assessment methodologies, DSS and research findings. Moreover, the adopted research methodology was critically evaluated and its limitations, which might affect its effectiveness in answering the research questions, were acknowledged. Finally, the theoretical and practical implications of the research findings were explored. The next chapter will summarise the whole research project and outline the key findings, main conclusions, research contribution, research limitations and further research questions.
Chapter 13: Conclusions

13.1 Introduction

The overall aim of this research is researching construction risk modelling and assessment and project evaluation, and proposing a novel alternative that may solve the problem of low take-up of the available tools and DSSs. A comprehensive and critical literature review was conducted to document the development of risk modelling and assessment over the last half a century. Different risk models and assessment methodologies were reviewed and their merits and limitations were examined. A new risk model was proposed. The model includes, in addition to risk probability and impact, a third dimension, probability of impact materialisation, defined by three adjustment coefficients: controllability, dependency and project features. A new assessment methodology was also developed using monetary equivalent as a common scale for measuring risk impact on different project objectives. The DST and the ER algorithm were deployed to utilise the analyst past experience and to aggregate individual assessments. The assessments were provided in distributed forms to provide a panoramic view of risk, reflect possible lack of information, and enable analysts to provide incomplete assessments. The ER approach proved to be a powerful tool for representing ignorance and generating boundaries of the aggregated assessments. A decision making approach was developed to compare between different projects or alternatives based on their risk and benefit levels. A spreadsheet-based DSS was finally devised to utilise the new models and assessment methodologies and to assist construction professionals in evaluating construction projects. The fieldwork was conducted in order to test the feasibility, applicability and validity of the new proposals. Throughout the previous chapters, the research stages, the collected data, and the data analysis results were presented and discussed.

This chapter summarises the research findings and conclusions, exhibits the research contributions, discusses the research limitations and raises future research questions.

13.2 Summary of the key research findings and conclusions

The key findings and the main conclusions are summarised below. They are organised according to the research objectives.
• Investigating construction risk modelling and proposing an alternative model that better captures the nature and characteristics of risk.
  ▪ Despite its prevailing presence and due to its limitations, P-I risk model is subject to an ongoing development process (See section 3.3.1).
  ▪ A paradigm shift from “classicalism”; PT-based and simulation tools, towards “conceptualism”; analytical tools for analysing project risk can be noticed. However, this shift did not result in higher take-up by construction professionals (See section 3.4).
  ▪ A new risk model was proposed by extending the P-I model to include additional coefficients reflecting risk controllability, the features of the project and the dependency between risks (See section 7.2.3).
  ▪ The inclusion of the controllability, project features and dependency coefficients in the P-I risk model lines up with the actual practice of assessing construction risk (See section 10.2.1.2.1).
  ▪ The new risk model allows estimating a “project safety level” which reflects the extent to which the project is safe in delivering its deliverables bearing in mind its risks and the security measures in practice (See sections 7.3.1 and 7.3.1.1).

• Exploring risk assessment tools, techniques and theories and appraising their usability in the construction industry.
  ▪ PT, FST and the AHP have considerable limitations in analysing construction risk (See sections 4.2, 4.3 and 4.4).
  ▪ DST and the ER approach have got a great potential in project risk analysis and decision making. Nonetheless, they are still under utilised in these domains (See sections 6.2.4, 6.3.4, 6.3.4.1, 6.4 and 11.5.3.2.5)
  ▪ Contingency estimation is perceived as a risk management tool; assessing risk as a project attribute might not be the top priority when analysing construction project risk (See section 10.4).
  ▪ Despite their validity and theoretical soundness, the available tools and DSSs suffer from low take-up by construction professionals for various reasons (See sections 4.5, 5.5.1, 10.2.1.4, 10.3.2.5 and 12.1.1.6)

• Proposing an alternative risk assessment approach that utilises the experience systematically and encourages professionals to standardise their practices.
A new risk assessment methodology was proposed; it employs DST and the ER approach and uses risk cost as a measurement scale (See sections 7.4.1 and 7.4.2).

The proposed assessment methodology has received a promising feedback and appreciation (See sections 11.5.3.1 and 11.5.3.2).

Using risk cost as a risk impact measurement scale is quite acceptable, convenient and practical. However, practitioners found it a bit difficult to provide a monetary equivalent to risk impact on project quality (See section 10.2.1.2.2).

Reviewing the theory and practice of construction project evaluation and developing an alternative framework based on project risk and benefit levels.

Various tools and theories are available for project evaluation. Unfortunately, they are rarely used (See section 5.5 and 5.5.1).

A vast difference does exist between theory and practice; contractors mainly focus on project financial rewards and risks when evaluating between different alternatives (See section 10.2.1.3.1). They usually choose the projects that provide more profit and less risk; they rarely consider risk-reward trade-offs as they always need to maintain cash flows that keep their businesses running (See section 10.3.3.3).

The idea of measuring intangible benefits using monetary equivalent did not get strong support from the surveyed professionals (See section 10.2.1.3.2). It was understood that they found it difficult to provide sensible monetary equivalents to intangible benefits (See section 10.3.3.2).

The conservative attitude of the interviewees regarding pricing the intangibles changed positively after comprehending the project evaluation methodology and using the DSS (See section 11.5.3.1).

Investigating the effect of the size of construction companies on their practices of risk analysis and project evaluation.

Big companies tend to follow a more mature practice of risk assessment and project evaluation than small companies (See sections 10.2.2.3.6 and 10.2.2.3.7).

Past experience and personal judgment are key elements in making final decision regardless of the company’s size or the maturity level of its risk
analysis or decision making practice (See sections 10.2.1.2.3, 10.2.2.3.5, 10.3.2.4 and 10.3.3.4)

- Small companies tend to rely more on past experience and personal judgment for risk assessment and project evaluation than big companies (See section 10.2.2.3.5).
- Small construction companies may not be interested in assessing project risk level; their main concern is conducting a basic risk analysis and wrapping project risks by a contingency sum or passing them to subcontractors (See section 10.3.2.1)
- Big construction companies are more likely to use DSSs for aiding risk analysis and project evaluation than small ones (See section 10.2.2.3.5).

- **Building a DSS in order to utilise the proposed models and assessment methodologies.**
  
  - A spreadsheet-based DSS was devised for aiding risk analysis and project evaluation. It has received very good evaluation during the validation case studies (See sections 11.4.1.1, 11.4.1.2, 11.4.1.3, 11.5.3.1 and 11.5.3.2).
  
  - Compared to construction practitioners from outside the UK, the UK professionals showed less reliance on structured approaches or DSSs for evaluating construction projects (See section 10.2.2.3.3)
  
  - Practitioners maintain their reliance on past experience even when facing complicated situations; they do not necessarily use special tools or DSSs when facing complex projects. More importantly, there is a clear tendency to rely on past experience for making final decisions even if such tools are in use (See section 10.2.1.2.3).
  
  - The key reasons for not using DSSs for risk analysis or decision making are:
    - lack of awareness of how DSSs work,
    - losing control over decision making processes,
    - lack of trust in such tools,
    - availability,
    - limitation in reflecting human expertise,
    - cost effectiveness (See section 10.2.1.4, 10.3.2.5 and 12.1.1.6)

- The most frequently required features of a desirable DSS are:
  - Simplicity and ease of use
  - conducting analysis quickly
- flexibility and ease of customisation to reflect the actual practice of the users
- utilising the practical experience of the users (See section 5.5.1, 10.3.3.5 and 12.1.1.7)

13.3 Generalisation of research findings and conclusions

The different data collection methods used in this research project and the different experiences and project types covered give the obtained results and the drawn conclusions a high level of generalisability, statistically, externally, and theoretically, internally. The two questionnaires have surveyed the attitudes of professionals who represented a wide spectrum of construction companies in and outside the UK. In addition to that, the interviews provided deep insights about the actual practice of risk assessment and project evaluation and helped in complementing and explaining the results of the questionnaires. Moreover, the validation cases further enriched the interviews’ findings and enhanced them with practical implications. In fact, one can appreciate a clear consistency between the obtained results from the different evidence sources in the vast majority of the investigated areas. This allows generalising the research findings with confidence to the UK construction contractors and, to some extent, beyond the UK boarders. Although a variance test has shown significant differences in a number of issues between the UK professionals and the people with experience from outside it, the results showed that the proposed approaches for risk modelling and assessment and project evaluation have generated more agreement from people with experience from outside the UK. This, actually, increases the confidence in generalising the research findings to the wider construction sector.

It is worth noting that the generalisability of research findings is dependent on their validity. The statistical analysis of the questionnaire data brought validity to the obtained results. Moreover, treating potential validity threats, as it was discussed in the previous chapter, supported the validity of the obtained results from the interviews. Furthermore, the quality of conclusions was enhanced through verifying them. They were constantly verified and checked during the interviews and the validation cases in order to develop an “inter-subjective consensus” according to the recommendation of Miles and Hubermann (1994).
13.4 Research contribution

The research contributed to the theory and the practice of construction management by the following points:

- A pioneering employment of DST and the ER approach in construction risk analysis and project evaluation
- A new risk model that overcomes the limitations of the P-I risk model and adds to the improvement attempts that exist in literature
- A viable way of tackling lack of information and utilising it effectively for more informative decision making through modelling ignorance explicitly and aggregating it
- A new risk assessment methodology that measures risk impact on different project objectives by means of monetary equivalents
- A new concept “Project Safety Level” which represents the size of project risk using the proposed risk model and assessment methodology. It expands the conventional project risk analysis by employing insights from the safety analysis domain and, thus, links the two bodies of knowledge together.
- A new model and assessment methodology for estimating project intangible benefits using monetary equivalents
- A novel approach for evaluating construction projects based on risk and intangible benefit levels
- A spreadsheet-based DSS facilitating the above contributions in a simple and easy-to-use tool aimed at construction contractors.

13.5 Research limitations

Although the research findings are validated and could be generalised, this research has its logical limitations. These limitations are summarised as follows:
The research findings were generated based on surveying construction contractors only. Hence, they are limited to this side and cannot be generalised straightaway to the client side. More research is required to investigate the feasibility of the research contributions and the validity of its findings from a client perspective.

The number of interviews and validation cases could have been bigger. The cancellation of three arranged interviews and two validation cases prevented from having a wider spectrum of professional points of view and constructive feedback.

The DSS needs to be tested in many different projects and companies over a long period of time in order to validate it objectively. The provided results need to be tested against actual ones after executing the analysed projects. Moreover, it needs time for the users to tune inputs to suite different projects or situations.

The participants mentioned that they needed time to get used to the assessment methodology and to build confidence in the DSS. This research was not able to investigate the accumulation of confidence in the tool.

Limited time and resources and lack of engaging partners, who are ready to spend time on trying the tool and giving access to more sophisticated data, were major barriers against examining the usefulness of the DSS in analysing complicated scenarios and testing the validity and practicality of the assessment methodology in these situations.

In light of the difficulty in validating the DSS using more case studies, additional simulation studies should have been arranged to encourage people, who are experienced in developing and/or using DSSs, to use the DSS and to get more feedback from a methodological and professional perspectives.

13.6 Further research questions

Having conducted the research and presented the main findings, conclusions and limitations, it is believed that this research project has opened a widow to address the following research questions:
1- To what extent the proposed models and assessment methodologies are valid, practical and useful from a construction client perspective?

It is of great importance to investigating the attitude of construction clients regarding the research questions in order to comprehend the actual practice of risk assessment and project evaluation in construction sector and to further validate the proposed models and methodologies from different angles.

2- How to better estimate a risk contingency sum?

The research results revealed that practitioners are more interested in estimating an accurate contingency sum than assessing a project risk level or comparing between different projects. It would be an original research project investigating the feasibility of the proposed analysis approach, or a customised version of it, for estimating contingency sums based on a list of pre-defined risks.

3- How to objectively validate the proposed DSS?

This may be achieved by applying longitudinal case studies in order to test the accuracy of the obtained results in different construction projects and organisations. The case studies enable comparing between the analysis results at the bidding stage and the actual risk and benefit levels after executing the projects.

4- To what extent the proposed risk model and assessment methodology can be used in projects outside the construction industry?

Obviously, the proposed risk model and assessment methodology are not restricted to construction projects. They are devised to better model and assess project risks, benefits and to compare between alternative projects accordingly. Hence, it is worth investigating the practicality and suitability of the proposed models and methodologies in other domains such as investment project appraisal, feasibility studies, policy making and sustainable and redevelopment projects.
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AIRMIC-ALARM-IRM (2002). Risk Management Standards AIRMIC, ALARM, IRM.

AIRMIC-ALARM-IRM (2010). A structured approach to Enterprise Risk Management (ERM) and the requirements of ISO 31000. AIRMIC, ALARM, IRM.


APM (2006). APM Body of Knowledge (APMBOK) 5th edn. 5 ed.: Association for Project Management


Sanchez, P. M. (Year). Neural-Risk Assessment System for Construction Projects. *In: Broadening perspectives, ASCE 183, 5-7 April 2005 San Diego, California*. ASCE.


Smets, P. (Year). Data fusion in the transferable belief model. *In: Proceedings of the third international conference on information fusion, 2000 Bruxelles, Belgium. 21-33


# APPENDICES

## 15.1 Appendix (I): Risk assessment and modelling literature review

<table>
<thead>
<tr>
<th>Date</th>
<th>Author/s</th>
<th>Journal</th>
<th>Tools and Techniques</th>
<th>Key Results &amp; Conclusions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>Chapman and Cooper</td>
<td>JORS</td>
<td>PERT, OR tools</td>
<td>This paper presented the “Risk Engineering” approach which integrates different OR tools to identify and measure uncertainty in Engineering Projects. Risk is modelled as probability of duration variation.</td>
<td>This paper is one of the earliest attempts to structure project risk systematically by dividing project into its components and identifying the risks that may affect each component. The paper mainly focused on combining risk events and producing joint probability distributions for activity duration and subsequently project duration.</td>
</tr>
<tr>
<td>1983</td>
<td>Diekmann</td>
<td>JCEM</td>
<td>MCS Probability Theory</td>
<td>The paper reviewed different approaches to provide probabilistic approaches for cost estimation.</td>
<td>Risk is modelled as variance in cost estimation.</td>
</tr>
<tr>
<td>1983</td>
<td>Barnes</td>
<td>IJPM</td>
<td>Probability Theory</td>
<td>Risk was modeled as Probability*Impact.</td>
<td>Risk impact was the variance in estimate regarding the cost or duration of a construction activity.</td>
</tr>
<tr>
<td>1985</td>
<td>Cooper et al.</td>
<td>IJPM</td>
<td>Mean-Variance, Probability Distribution</td>
<td>The paper aimed at providing an indication of the reliability of cost estimate and the adequacy of contingency allowance.</td>
<td>Risk is modelled as a variation distribution of base cost estimate. Risk Impact was assessed as a distribution of proportional variations on the base-cost estimate for the item. Risk assessments were combined into a total risk distribution, i.e. project cost risk.</td>
</tr>
<tr>
<td>1986</td>
<td>Beeston</td>
<td>CME</td>
<td>Probability Theory, Monte Carlo</td>
<td>The paper presented a method to combine risks in estimating</td>
<td>Risk was modelled as variance in estimate. MCS was used to provide</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Journal</th>
<th>Methodology</th>
<th>Summary</th>
<th>Comment</th>
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<tbody>
<tr>
<td>1987</td>
<td>Clark and Chapman</td>
<td>EJOR</td>
<td>Probability Theory</td>
<td>The paper presented the risk analysis methodology developed by Projects Department of BP’s Group Engineering and Technical to be used during the project appraisal. The computational methods in current use are based on the Common Interval and Memory (CIM) approach, which allows the direct enumeration of distribution combinations.</td>
<td>Risk was modelled as variance in activity cost or duration. It was represented as a distribution. Dependence between risks was presented by an explicit causal modelling structure with dependence percentages in order to generate a combined distribution for the dependent risks. Software was developed to facilitate the approach.</td>
</tr>
<tr>
<td>1987</td>
<td>Franke</td>
<td>IJPM</td>
<td>Literature review, Conceptual Argument</td>
<td>The author of this paper presented assessing risk impact in monetary terms. The aim was to quantify the different impacts of risk on different project objectives by using cost as common scale and uniform basis of assessment. Risk was modelled as probability and consequence.</td>
<td>It is one of the very few papers who highlighted the need for considering risk impact on different project objectives. However: The overall project risk was simply proposed as sum of the individual risk costs. This will raise a question about the interdependencies between risks and whether such adding up is exaggerating the actual project risk level.</td>
</tr>
<tr>
<td>1989</td>
<td>Kangari and Riggs</td>
<td>IEEETEM</td>
<td>FST</td>
<td>This paper has illustrated the use of FST as a risk assessment tool in the construction industry. There was an objective evaluation of the merits and the shortcomings of FST.</td>
<td>It is one of the most cited papers as it is one of the earliest attempts to use FST for handling the subjectivity in risk assessment in construction industry.</td>
</tr>
<tr>
<td>1990</td>
<td>Hull</td>
<td>IJPM</td>
<td>MCS, PERT, Probability Theory</td>
<td>The paper introduced different models used to assess proposal risk from cost and duration point of view.</td>
<td>Risk was modelled as probability of event and its consequence. However, the paper did not mention assessing proposal’s overall risk.</td>
</tr>
<tr>
<td>1990</td>
<td>Al-Bahar and</td>
<td>JCEM</td>
<td>Influence diagramming/</td>
<td>A methodology for construction risk</td>
<td>Risk was modelled as Probability and Impact</td>
</tr>
<tr>
<td>Year</td>
<td>Author 1</td>
<td>Author 2</td>
<td>Journal</td>
<td>Methodologies</td>
<td>Description</td>
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<tr>
<td>1990</td>
<td>Crandall</td>
<td></td>
<td>Monte Carlo</td>
<td>Management (CRMS) was introduced to help contractors analyze and manage the identified risks systematically.</td>
<td>The paper presented a new methodology for improving contingency estimation by identifying the key risk factors and structuring them as RBS. Then, according to the cost estimate distribution, a contingency is to be assigned for each risk factor. This is one of the earliest systematic methods for estimating contingency and assessing cost risk.</td>
</tr>
<tr>
<td>1990</td>
<td>Yeo</td>
<td></td>
<td>JME</td>
<td>PERT, Probability theory</td>
<td>The paper presented “contingency engineering” method for cost risk assessment and contingency estimation. Cost was represented as a normal distribution with most expected value and a contingency added to reduce the probability of cost overrun. The degree of dispersion of range estimates quantifies the estimator’s subjective risk assessment.</td>
</tr>
<tr>
<td>1991</td>
<td>Mustafa and Al-Bahar</td>
<td></td>
<td>IEEETEM</td>
<td>AHP</td>
<td>The researchers presented the suitability of AHP for assessing construction project risk during the bidding stage. Also, they deployed the hierarchy of AHP for getting the project risk level at the top of the Risk Breakdown Structure.</td>
</tr>
<tr>
<td>1992</td>
<td>Diekmann</td>
<td></td>
<td>IJPM</td>
<td>Influence diagramming, Monte Carlo Simulations, FST, Influence Diagramming.</td>
<td>The paper discussed the issue of applicability of risk methods and models. This paper also discussed the shortcomings of the risk analysis techniques which are based upon probability theory like MCS.</td>
</tr>
<tr>
<td>1992</td>
<td>Huseby and Skogen</td>
<td></td>
<td>IJPM</td>
<td>Influence diagram/Monte Carlo</td>
<td>The paper introduced a new risk model called <em>Dynamic risk model</em>. Influence diagramming was adopted to take into consideration the issue of dependency between risks. <em>DynRisk</em> is a software tool for</td>
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<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Journal</th>
<th>Methodology</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>Paek <em>et al.</em></td>
<td>JCEM</td>
<td>FST</td>
<td>This paper proposed a <strong>risk-pricing algorithm</strong> to assist contractors in deciding the bid price of a construction project using FST. The method consists of identifying risk elements and quantifying risk-associated consequences in monetary terms. This paper is one of the few attempts to try to price risk systematically. The researchers tried to price the positive and negative possible consequences in order to calculate the net price. However, <strong>there was a lack of clear methodology</strong> for pricing the overall impact.</td>
</tr>
<tr>
<td>1993</td>
<td>Tah <em>et al.</em></td>
<td>CSE</td>
<td>FST</td>
<td>FST was used to assess risk probability and impact using linguistic variables. <strong>The Fuzzy weighted mean was used to aggregate risk assessments.</strong> Risk was modelled as Probability and Impact</td>
</tr>
<tr>
<td>1994</td>
<td>Dey <em>et al.</em></td>
<td>IJPM</td>
<td>AHP, Probability Theory</td>
<td>AHP technique was used to comprehend objective and subjective assessments. <strong>Probability and impact model</strong> was adopted. Risk assessment was related to risk contingency using probability theory</td>
</tr>
<tr>
<td>1994</td>
<td>Riggs <em>et al.</em></td>
<td>COR</td>
<td>AHP, Utility Theory</td>
<td>This paper presented an approach for integrating technical, cost, and schedule risks as utility functions. (AHP) was used for eliciting utility functions representing the project manager’s relative preference for technical, cost, or schedule success. AHP also was used to assign probabilities to the decision tree. The alternative with the maximum utility was to be chosen. Technical (T), cost (C), and schedule (S) outcomes were treated as either succeeding or failing. The potential outcome of a project is ranging from complete success (TCS) to complete failure (T'C'S'). <strong>Utility was used as common scale</strong> for assessing the attractiveness of different scenarios with different levels of risk. The proposed model assessed the utilities in order to choose the alternative with the maximum utility.</td>
</tr>
<tr>
<td>1995</td>
<td>Williams</td>
<td>EJOR</td>
<td>Critical literature review.</td>
<td>There is lack of research for assessing the <strong>overall impact of Schedule and project duration risk</strong> is the most researched area.</td>
</tr>
<tr>
<td>Year</td>
<td>Author(s)</td>
<td>Journal/Conference</td>
<td>Methodology</td>
<td>Risk Assessment Details</td>
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<td>------</td>
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<tr>
<td>1995</td>
<td>Zhi</td>
<td>IJPM</td>
<td>AHP</td>
<td>AHP was used to assess the impact of risk factors and the weight, whereas the probability of occurrence was assessed via the direct judgment of the professionals after careful consideration. Risk probability assessment fell within [0-1].</td>
</tr>
<tr>
<td>1996</td>
<td>Williams</td>
<td>IJPM</td>
<td>Literature review, Conceptual argument</td>
<td>This paper discussed the limitation of modelling risk as multiplication of likelihood and impact. Such multiplication will produce an expected value of risk which is misleading and cannot be simply followed to prioritise project risks.</td>
</tr>
</tbody>
</table>
| 1996 | Wirba et al. | ECAM           | FST          | This article presented a risk management approach which identifies risks, checks for dependence amongst them, and assesses the likelihood of occurrence of each risk by using linguistic variables by using FST. Risk interdependencies were represented as interdependence tree. The interdependence coefficients were computed by using the fuzzy weighted mean method. | This paper is important and widely cited. However:  
- The fuzzy weighted mean method was only calculating the weighted average of the risks  
- The paper did not explain how to consider the interdependencies between risks at the same level of the hierarchy, not through different levels?  
- The researchers tried to use the aggregation rules of FST to consider interdependencies. |
<table>
<thead>
<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Journal</th>
<th>Methodology/Model</th>
<th>Summary</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Dawood</td>
<td>CME</td>
<td>Probability Theory, Monte Carlo, PERT</td>
<td>Risk impact was considered by estimating the cost of response strategy. However, this aggregation rule is one of the weaknesses of the FST.</td>
<td>Risk was dealt with as <strong>variation in activity duration</strong>. Risk management was used to provide an accurate estimate to the activity duration and then project duration.</td>
</tr>
<tr>
<td>1998</td>
<td>Tavares et al.</td>
<td>EJOR</td>
<td>Probability Theory, Random Distribution</td>
<td>The paper presented a methodology for estimating activity duration and project duration.</td>
<td>Project risk was the probability of not meeting the project objectives, i.e., time and cost. There is nothing to deal with the impact. The researchers did not consider the risk of the project quality success indicator claiming that the benefits tend to be more dependent on external factors rather than on the internal development of the project. Such claim may not be accepted easily.</td>
</tr>
<tr>
<td>1999</td>
<td>Mulholland and Christian</td>
<td>JCEM</td>
<td>Probability theory/PERT</td>
<td>The paper presented a systematic way to quantify uncertainty in construction schedules.</td>
<td>The main focus was the risk of duration overrun. Hence risk was dealt with as <strong>variation of activity and project duration</strong>.</td>
</tr>
<tr>
<td>1999</td>
<td>Ward</td>
<td>IJPM</td>
<td>Literature review, theoretical argument</td>
<td>The researcher illustrated the shortcomings of the Probability-Impact model and called for considering other information for a proper assessment of <strong>risk importance</strong> such as the nature of feasible responses, and the time available for responses. The researcher called</td>
<td>According to Ward (1999), <em>using a separate probability-impact grid for each type of impact was not appropriate</em>. Often such approaches use ‘numerical scoring’ for each impact and then add the three separate ratings together to give a single composite rating for each risk. He criticised this approach as the numerical values are</td>
</tr>
<tr>
<td>Year</td>
<td>Authors</td>
<td>Journal</td>
<td>Method</td>
<td>Summary</td>
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<tr>
<td>2000</td>
<td>Chapman and Ward</td>
<td>IJPM</td>
<td>Literature review, Theoretical argument</td>
<td>The researchers criticised the P-I grids for assessing risks claiming that it was over simplistic. They proposed their ‘minimalist’ approach. This approach identifies explicit ranges for both estimated impacts and the associated probabilities.</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Hastak and Shaked</td>
<td>JME</td>
<td>AHP</td>
<td>The aim of this paper was to present a risk assessment model for international construction projects (ICRAM). AHP was used to get the weighted significance of each risk factor. Risk was modelled as probability of the event and the associated severity.</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Tah and Carr</td>
<td>CME</td>
<td>FST</td>
<td>FST was presented as suitable tool for assessing risk probability and impact and also to quantify the</td>
<td></td>
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</table>

For considering the multiple impact of risk on project objectives in order to calculate the overall risk impact. He proposed his own approach of using a weighted sum of alphabetical ratings. Ratings and adding them together is not appropriate. I believe that his approach will be clearer. However it is not applicable as the risk rating will be, for instance, something like: 3A+2C+5D. Such assessment of risk could be hardly dealt with for further aggregation of assessments.

Risk is modelled as probability and impact. They argued that the P*I matrices generates unnecessary uncertainty by over-simplifying estimates of impact and associated probability.

This paper is very popular and is one of the most cited papers. Risks were subjectively assessed using a predetermined scale of 0–100, where 0 implies no risk and 100 implies maximum risk. The subjective risk assessment and the associated weight together provide the weighted RISK score. Risk assessments are aggregated by summing the weighted scores after considering the impact effect of the different aggregation levels.

The researchers tried to overcome the FST limitation in aggregating assessment by proposing their alternative. They admitted that it needed
### Interdependencies between Risk Factors and Risk and Consequence

They used the hierarchical risk breakdown structure (HRBS) to organise the risks.

### Further Investigation

They represented the total effect as a function of the E_max by using a modification factor, such that:

\[ E = \xi E_{\text{max}} \]

There is a concern about such way of aggregation. What if there is more than one predominant risk factor for instance?

### Literature Review

**2001** Baccarini and Archer

**IJPM Literature review**

This paper described the use of risk ranking methodology undertaken by the Department of Contract and Management Services (CAMS), a government agency in Western Australia.

The methodology is using **likelihood** and **consequence** risk model.

### Risk Scoring

Risk score is calculated for every risk factor considering likelihood and consequence on cost, time or quality. There is a concern about the over simplistic approach for calculating project risk. It is averaging the likelihoods and the impacts and then multiplying them to get the scores for risk on cost, time and quality. The final project risk is the highest of these scores which could be exaggeration.

### Decision Support System

**2001** Dey

**MD AHP, Decision Tree**

This paper provided a DSS for identifying the best strategy, project scenario, for managing construction project risk.

The **likelihood** of risk occurrence was calculated in AHP framework and **severity** was determined by guestimation. A decision tree was formulated for deriving expected monetary value (EMV) of each risk response strategy in each branch and finally selecting the best option through statistical analysis.

The final result of the approach was selecting the scenario with the lowest expected risk cost. The **time impact was represented in fiscal terms** so the total cost of any alternative can be derived. Within the decision tree, each scenario outcome was represented by the associated extra cost and extra duration. There was a lack of common scale to derive the total impact on cost, time and the rest of project objectives.
<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Journal</th>
<th>Methodology</th>
<th>Description</th>
<th>Findings/Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Xu and Tiong</td>
<td>CME</td>
<td>Stochastic Programming</td>
<td>A systematic approach using the stochastic programming concept on a spreadsheet program was presented to enable contractors to find the optimal pricing.</td>
<td>The main concern was assessing the risk in cost estimation and providing a tool for pricing. Risk was modelled as a cost variation.</td>
</tr>
<tr>
<td>2001</td>
<td>Tah and Carr</td>
<td>JCCE</td>
<td>FST</td>
<td>The researchers presented a fuzzy risk analysis model for assessing project risk rating. They used HRBS to structure different risk factors and their fuzzy aggregation tool to combine the assessments.</td>
<td>The model provided separate ratings of the total effect of project risks on project duration, cost, quality and safety. Hence, the model couldn’t compute the overall impact of project risk.</td>
</tr>
<tr>
<td>2002</td>
<td>Hillson</td>
<td>IJPM</td>
<td>Literature review, Conceptual argument</td>
<td>The aim was to improve risk handling by considering the co-existing opportunity systematically.</td>
<td>Assessment of both threat and opportunity can be conducted within a P-I model.</td>
</tr>
<tr>
<td>2002</td>
<td>Patterson and Neailey</td>
<td>IJPM</td>
<td>Literature review, Risk register</td>
<td>The authors developed software for assessing risk and project risk level. They call it Risk register data base.</td>
<td>Risk was modelled as Probability * Impact and project risk level was only the average of the risk scores.</td>
</tr>
<tr>
<td>2003</td>
<td>Baloi and Price</td>
<td>IJPM</td>
<td>Literature review, Conceptual argument</td>
<td>The researchers compared different theories for dealing with uncertainty in construction industry. They concluded that FST could be vital solution for assessing uncertainty in construction industry.</td>
<td>This paper focused on factors that may affect project cost and cause cost overrun. This paper is very important as it have provided a very important literature review and comparison between different theories to handle uncertainty.</td>
</tr>
<tr>
<td>2003</td>
<td>Jannadi and Almishari</td>
<td>JCEM</td>
<td>Literature review, Conceptual argument</td>
<td>This study has developed a risk assessor model (RAM) that determines risk scores for various construction activities. The model also provides an</td>
<td>The researchers provided a justification factor which is relating the risk level to the associated cost of correction actions.</td>
</tr>
<tr>
<td>Year</td>
<td>Authors</td>
<td>Journal</td>
<td>Method</td>
<td>Summary</td>
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<tr>
<td>2003</td>
<td>Nasir et al.</td>
<td>JCEM</td>
<td>Belief Networks, Monte Carlo</td>
<td>The article provided a schedule risk model to estimate the pessimistic and optimistic values of an activity duration based on project characteristics. The results of this article were limited to activity duration issues. Risk was modeled as variation in activity duration.</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Ward and Chapman</td>
<td>IJPM</td>
<td>Literature review, Theoretical</td>
<td>The researchers proposed using the term uncertainty, management instead of risk management. They argued that the word uncertainty implies potential opportunity, whereas risk used to be understood as threat.</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>Choi et al.</td>
<td>JCEM</td>
<td>FST</td>
<td>A fuzzy-based model was presented to consider uncertainty in both probabilistic estimates and subjective judgments based on the available amount of information. The model provided a tool for assessing risk in different project scenarios and computing the expected cost of each scenario. Risks are calculated by multiplying probability and expected cost.</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>Fan and Yu</td>
<td>JSS</td>
<td>BBN (Bayesian belief networks)</td>
<td>The researchers developed a BBN-based procedure using a feedback loop to predict potential risks, identify sources of risks, and advise dynamic resource adjustment. Risk was modelled as Probability and impact. However, risk impact was measured as damage cost. ( R = \text{Probability} \times \text{Damage cost} )</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>Oztas and Okmen</td>
<td>BAE</td>
<td>Monte Carlo</td>
<td>This study proposed schedule and cost risk analysis models and showed the</td>
<td>Risk was modelled as variation in cost or duration. MC simulation was used</td>
</tr>
<tr>
<td>Year</td>
<td>Author(s)</td>
<td>Journal</td>
<td>Technique</td>
<td>Applicability</td>
<td>Methodology Description</td>
</tr>
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<tr>
<td>2005</td>
<td>Molenaar</td>
<td>JCEM</td>
<td>Monte Carlo</td>
<td>to assess the ranges of activities durations and costs and hence accumulate the project duration and cost within ranges and confidence intervals.</td>
<td>The researchers used Monte Carlo simulation technique to consider the risks and uncertainties associated with project cost and duration.</td>
</tr>
<tr>
<td>2005</td>
<td>Shang <em>et al.</em></td>
<td>ECAM</td>
<td>FST</td>
<td>The papers presented methodology adopted to estimate project cost bearing in mind the different risk factors which may affect this estimate.</td>
<td>This paper presented a methodology developed by the Washington State Department of Transportation (WSDOT) for its Cost Estimating Validation Process. The methodology is based on identifying key risk factors affecting cost estimate and using Monte Carlo Simulations to <em>derive ranges of cost assessments not deterministic ones.</em></td>
</tr>
<tr>
<td>2006</td>
<td>Cervone</td>
<td>OCLC Systems &amp; Services</td>
<td>Literature review, Conceptual argument</td>
<td>Risk model was <em>Probability-impact</em> and the assessment is conducted by linguistic variables. The result is risk rating, linguistic or score.</td>
<td>Risk model was <em>Probability-impact</em> and the assessment is conducted by linguistic variables. The result is risk rating, linguistic or score. The output of the tool was a list of identified and ranked risks.</td>
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<td>Risk Discrimination was used to measure the impact of the risk on the project as a whole, rather than looking at each risk as an independent variable within the project. The use of discrimination factor accounts for the independence between risks.</td>
<td>This paper proposed a three dimensional risk model: ( \text{Risk} = \frac{(P*I)}{D} ) (D: \text{discrimination}) The three risk dimensions were assessed using linguistic variables</td>
</tr>
<tr>
<td>Year</td>
<td>Authors</td>
<td>Journal/Conference</td>
<td>MCDM Tool</td>
<td>Methodology/Approach</td>
<td>Key Points</td>
</tr>
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<tr>
<td>2006</td>
<td>Dikmen and Birgonul</td>
<td>CJCE</td>
<td>AHP</td>
<td>The paper proposed a methodology for risk and opportunity assessment of international construction projects and for ranking them using MCDM tool which considers risk and opportunity as project attributes. <strong>Risk was modelled by Probability and Impact.</strong> AHP value and weight was borrowed to stand for risk probability and impact. It is a very important paper as both risks and opportunities were simultaneously considered as project attributes for ranking purpose. Risk is determined by <strong>multiplying the relative impact with the relative probability of occurrence.</strong> However, there is question about the method for assessing project risk level by <strong>simply adding up the individual risks. This is exaggeration. The risk estimate in relative one as it is generated by AHP.</strong></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Poh and Tah</td>
<td>CME</td>
<td>Influence Networks</td>
<td>The paper developed an influence network that captures interdependencies among the parameters that determine the duration and cost of a construction task. <strong>This paper tried to provide methodology for combining cost and duration risks simultaneously. Risk was modelled as variation in activity cost and duration.</strong></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Thomas et al.</td>
<td>CME</td>
<td>FST, Fault tree, Delphi Method</td>
<td>Risk <strong>probability and impact</strong> assessment framework were performed based on fuzzy-fault tree and the Delphi method. The researchers tried to improve the fuzzy assessment by <strong>considering the opinion of different experts within a Delphi framework.</strong> The researchers called this way <strong>Fuzzy-Delphi method.</strong> The paper did not provide a framework for assessing risk level of a BOT project. Instead it provided a tool for assessing specific scenarios which may happen. Each risk impact was assessed as optimistic, most likely and pessimistic fuzzy assessments. The final impact assessment is the average of these three assessments.</td>
<td></td>
</tr>
</tbody>
</table>
| 2007 | Aven et al               | RESS               | Literature review, Conceptual argument | The authors argued that when comparing different project alternatives **manageability** of risk should be considered. Some risks are more manageable than others, meaning that the potential for reducing the risk is larger for some risks compared to others.
<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Journal</th>
<th>Methodology</th>
<th>Paper Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Cagno et al.</td>
<td>RM</td>
<td>Literature Review, Conceptual argument</td>
<td>The aim of this paper was to provide a multi-level and multi-dimensional model capable of identifying and analysing major risks in all work packages, project parties, organisational levels and PLC phases. The paper modelled risk as Probability-Impact function within a risk cube, RBS-WBS-OBS. Risk load was allocated to each project element by multiplying risk Probability and Impact. It is a very important paper. It is one of the few papers who dealt with assessing risk impact in monetary terms. <strong>Controllability</strong> was introduced as a ratio between the expected risk impact before and after applying mitigation actions to justify mitigation actions economically. Risk impact was assessed in monetary term as collective single figure without considering the different impacts on project objectives.</td>
</tr>
<tr>
<td>2007</td>
<td>Dikmen et al. a</td>
<td>AIC</td>
<td>CBR, Utility Theory</td>
<td>A Case based Reasoning was used to estimate international construction project mark-up. The researchers identified risk, opportunity and competition factors affecting mark-up. The overall utility of a project was identified as a function of risk, opportunity and competition utility. Although the model was able to compare different projects based on different criteria, it was unable to assess project risk as it is based on comparing the project criteria with previous data and hence to assess suitable risk contingency. Project risk was assessed by estimating correct contingency.</td>
</tr>
<tr>
<td>2007</td>
<td>Dikmen et al. b</td>
<td>IJPM</td>
<td>FST, Influence diagramming</td>
<td>This paper is to propose a fuzzy risk assessment methodology for international construction projects and develop a tool to implement the proposed methodology. FST was used as it was found more suitable to deal with subjectivity in risk assessment. The output of the assessment was a final cost overrun risk rating. Then the model could not assess project risk. It was just a rate calculated by using a scale of 1–10 which represents a low to high risk level. The researchers used the concept <strong>controllability</strong> or <strong>manageability</strong> to consider the firm experience and its ability in dealing with risk. <strong>They added Controllability as a factor affecting project risk level.</strong></td>
</tr>
<tr>
<td>Year</td>
<td>Authors</td>
<td>Journal</td>
<td>Technique(s)</td>
<td>Description</td>
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<tr>
<td>2007</td>
<td>Dikmen et al.</td>
<td>CJCE</td>
<td>ANP</td>
<td>The researchers used the ANP technique in order to consider the multi attributes affecting appraisal and selection decision. Risk was dealt with as major attribute and was assessed with the other three main attributes, Cost, Benefits and Opportunity.</td>
</tr>
<tr>
<td>2007</td>
<td>Hsueh et al.</td>
<td>AIC</td>
<td>AHP, Utility Theory</td>
<td>(AHP) and Utility Theory were used to develop a multi-criteria risk assessment model for construction pre-JVs stage and to integrate WWW and company databases. The overall expected utilities of projects were used for comparison.</td>
</tr>
<tr>
<td>2007</td>
<td>Zeng et al.</td>
<td>IJPM</td>
<td>AHP, FST</td>
<td>A new risk parameter, factor index (FI) is proposed standing for the nature of the inherent construction environment of a particular risk under investigation. Factor index reflected the relationships and the influences between the risk factors in the hierarchy.</td>
</tr>
<tr>
<td>2007</td>
<td>Zhang and Zou</td>
<td>JCEM</td>
<td>AHP, FST</td>
<td>A generic quantitative model proposed to assess the levels of risks in construction JV projects in China and to evaluate whether a JV was viable for project delivery. The fuzzy AHP based on expert judgment, the weight coefficients are acquired with the aid of the AHP techniques and the fuzzy evaluation matrixes of risk factors are founded through FST. Then the aggregation of weight coefficients and</td>
</tr>
<tr>
<td>Year</td>
<td>Author(s)</td>
<td>Journal</td>
<td>Methodology</td>
<td>Description</td>
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</tr>
<tr>
<td>2007</td>
<td>Zhang</td>
<td>IJPM</td>
<td>Literature review, Conceptual argument</td>
<td>The approach included three steps: setting up the hierarchy structure of risks, determining the weight vector by the AHP, and fuzzy assessment of risks. Fuzzy evaluation matrices produce the appraisal vector of risky conditions of the JV. This article illustrated the limitation of representing the relationship between risk event and risk consequence as statistical risk event-consequence link. The analysis of risks based on the link is incomplete, and neglects the mediating influence of project systems. The mediating influence can be characterised by project vulnerability. According to Zhang (2007), after a risk event occurs, a project system will have interactions with it. Project vulnerability takes into account more factors quite different from risk events, such as organizational malfunctions as the sources of project vulnerability. Project vulnerability has two distinct dimensions: the exposure of a project system to a risk event; and the capacity of a project system to cope with risk impacts.</td>
</tr>
</tbody>
</table>
risk factors affecting highway projects in China and building a risk model (R) that determine project risk level to prioritize different projects. AHP is used to assign weights to the factors and calculated to risk indices $R_1$ and $R_2$ for macro and micro levels. The project risk index is:  
$$ R = R_1 \times R_2 $$  
Risk index can be derived from the weighted effects of the risk factors in its group.

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Journal</th>
<th>Methodology</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Cioffi and Khamooshi</td>
<td>JORS</td>
<td>Probability Theory</td>
<td>The paper presented a method to estimate the total potential risk impact at a given certainty based on the impacts and probabilities.</td>
</tr>
<tr>
<td>2009</td>
<td>Khamooshi and Cioffi</td>
<td>IEEETEM</td>
<td>Probability Theory</td>
<td>The researchers presented a method to estimate the number of risks that can occur at any given confidence level after averaging the probabilities of the considered risks.</td>
</tr>
<tr>
<td>2009</td>
<td>Luu et al.</td>
<td>IJPM</td>
<td>BBN</td>
<td>This paper describes how Bayesian belief network (BBN) is applied to quantify the probability of construction project delays. The researchers argued that BBN showed good prediction rate and was accepted tool to deal with lack of historical records. The paper could not provide a tool for assessing risks which may cause delay in project. It could provide a tool to assess the possibility of delay taking place; for instance 60% will be a delay in executing project A.</td>
</tr>
<tr>
<td>2010</td>
<td>Fung et al</td>
<td>IJPM</td>
<td>Excel sheet,</td>
<td>The paper presented Risk was modelled as</td>
</tr>
</tbody>
</table>
Questionnaire a Risk Assessment Model (RAM), Excel worksheets, to assessing project risk from safety perspectives. The tool allows assessing risk levels in different stages of the project. The main focus was for accidents and injuries.

Frequency and Severity, \( R = F \times S \)

Severity (S) was defined as the sum of the normalised impacts of a risk: \( S = S_1 + S_2 + S_3 \) where \( S_1 \): extra time, \( S_2 \): extra cost and \( S_3 \): injury and disability.

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Methodology</th>
<th>Approach</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Mojtabadi et al.</td>
<td>SS</td>
<td>GTOPSIS</td>
<td>Risk is modelled as likelihood of occurrence and impact. The impact was broken down into three components impact of cost, impact on time and impact on HSE.</td>
</tr>
<tr>
<td>2011</td>
<td>Nieto-Morote and Ruz-Vila</td>
<td>IJPM</td>
<td>FST, AHP</td>
<td>Risk was modelled using three dimensions; Probability, Impact and Discrimination. The risk model of Cervone (2006) was adopted. ( R = (P \times I) / D )</td>
</tr>
</tbody>
</table>

The proposed methodology applied the GTOPSIS technique for collating assessments from different risk experts. The result was a list of key risks based on their scores. Likelihood and impact were assessed by means of scores representing linguistic variables.

The three risk dimensions were assessed using linguistic variables. To aggregate the assessments of different experts, the fuzzy arithmetic average was used. To aggregate risk scores to the top of the hierarchy, a fuzzy multiplication using arithmetic operations was deployed.
Dear Respondent,

In partial fulfilment of the requirements for obtaining my PHD Degree in business administration from Manchester Business School of the University of Manchester, I am conducting a survey on the practice of risk assessment and decision making before tendering in construction industry. It is targeted at practitioners in construction industry in order to investigate their practices in risk assessment and project evaluation from a contractor point of view.

The investigation will also cover the perception of decision makers about risk assessment and the importance and criticality of personal experience, intuition and gut feeling in making crucial decisions in the pre-tendering stage where limited information is available.

This survey is designed to take no more than 15 minutes of your valuable time. Your input is crucial for my research project and it will be highly regarded.

The information given by you will be treated confidentially. The information is going to be used for educational purposes only and only the researcher and his supervisory team will have access to it. This research project has been approved by the Manchester Business School Research Ethics Committee, Ethics Code: MBSPGR/M444

I would like to thank you in advance for your time and support. A pre-paid and addressed envelope is attached for your concern. Please use it to send me back your answers. I will be very grateful for your quick response.

Should you have any questions about completing the questionnaire, please do not hesitate to contact me at the contact details shown below.

Abdulmaten Taroun
PhD Candidate
Decision and Cognitive Science Research Centre
Manchester Business School
The University of Manchester
E-mail: abdulmaten.taroun@postgrad.mbs.ac.uk

Best regards,
Abdulmaten Taroun
Part one: Risk Assessment

Risk could be defined as any financial, legal, technical, environmental, social, etc., threat which may affect a construction project.

Please express your opinion concerning the following statements by ticking the right cells. For each statement you can choose one of seven available cells. The cells have scores ranging from **(1)**, which means total disagreement, till **(7)** which means full agreement.

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<tr>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Risks are different in terms of your ability to mitigate their impact when they occur.</td>
<td></td>
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<tr>
<td>1.2</td>
<td>Your ability to mitigate the impact of a specific risk is different from one project to another.</td>
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<tr>
<td>1.3</td>
<td>You discount a possible risk impact when other related and dependent risks have already been accounted for.</td>
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<tr>
<td>1.4</td>
<td>Risk impact can be measured as a monetary sum equivalent to the damage created when the risk happens termed as &quot;Risk cost&quot;.</td>
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<tr>
<td>1.5</td>
<td>&quot;Risk cost&quot; is a convenient and suitable way for assessing risk impact.</td>
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<tr>
<td>1.6</td>
<td>The idea of &quot;Risk cost&quot; for assessing risk impact is widely acceptable and well-established practice in construction industry.</td>
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<td>1.7</td>
<td>It is difficult to provide an equivalent monetary sum for all types of risk.</td>
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<tr>
<td>1.8</td>
<td>You can measure the impact of a specific risk on project duration in monetary terms.</td>
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<tr>
<td>1.9</td>
<td>You can measure the impact of a specific risk on project quality in monetary terms</td>
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<td>1.10</td>
<td>You identify the risks that may affect a project and measure their impacts separately.</td>
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<tr>
<td>1.11</td>
<td>You aggregate the impacts of the identified risks in order to generate a project risk level.</td>
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<tr>
<td>1.12</td>
<td>When preparing your bid, you approximate and allocate a contingency sum to account for possible risks.</td>
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<td></td>
</tr>
<tr>
<td>1.13</td>
<td>When estimating the contingency sum, you account for project risks collectively not independently.</td>
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</tr>
<tr>
<td>1.14</td>
<td>Your experience and gut feeling play a crucial role in assessing risk impact and the likelihood of its occurrence.</td>
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</tbody>
</table>
When facing complex and unique projects, you rely on your experience and intuition lessened for dealing with risk assessment.

When facing complex and unique projects, you use formal tools and software for assessing risk and project risk level.

Even if you are using decision support systems, your experience, gut feeling and intuition still play the key role in providing your final assessment.

### Part two: Project Appraisal, Evaluation and Selection

Please express your opinion concerning the following statements by ticking the right cells. Similar to the previous part, the cells have scores ranging from (1), which means total disagreement, till (7) which means full agreement.

| 2.1 | Intangible benefits of a project such as market share, and reputation can be measured by providing equivalent monetary sums. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2.2 | Equivalent monetary sum is a suitable way for assessing project intangible benefits. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2.3 | You discount your assessment of project benefits because they may not be always achievable as they are perceived before tendering. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2.4 | The method of measuring project intangible benefits in terms of monetary sums is widely acceptable and well-established practice in construction industry. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2.5 | The financial risk and the financial benefit of a project are always the main concern when comparing between projects and making commitment decisions. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2.6 | Using monetary terms for measuring both project risks and benefits is a common practice in order to compare between different projects or proposals and to rank them accordingly. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2.7 | You use special tools and decision support systems to support you in evaluating, ranking and choosing different projects. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2.8 | You relay mainly on your experience, intuition and gut feeling for comparing between different projects. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
If you do not often use decision support systems, that is because:

- They are complicated
- They contradict your intuition and experience
- You lose control over the decision making process
- You do not trust them
- You are not aware of how the system works
- You do not need them because you are experienced
- Others? Please specify

---

**Part three: Background & General information**

**3.1** Please indicate your level of education:
- Graduate
- Diploma
- Masters
- MBA
- PhD

**3.2** Please indicate your current position in your organisation:
- Project manager
- Department manager
- Executive manager
- Advisor

**3.3** What is the current annual turnover of your organisation?
- Less than 100 millions
- 100 – 500 millions
- 501 m – 1 Billion
- More than 1 Billion

**3.4** Please specify the length of your experience in construction industry:
- Less than 10 years
- 10 – 20 years
- 21 – 30 years
- more than 30 years

**3.5** What types of construction projects you are experienced in?
- Residential
- Industrial
- Commercial
- Property development
- Infrastructure
- Roads & Bridges
- Ground works
- Others? Please specify

**3.6** Is there a designated department or staff for risk management in your organisation?
- Yes
- No

**3.7** Are there any systematic approaches or formal protocols for evaluating projects/proposals and ranking them accordingly for supporting decision making?
- Yes
- No
If yes, please describe

---

**Note:**
If you are interested in applying the outcome of this research project, which is a decision support system for risk assessment and project evaluation, and having a free copy of it please tick this box □ and send me your contact details together with your answers. I will be grateful for your collaboration.

Best regards,
Abdulmaten Taroun

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**15.3 Appendix (III) Pilot study’s interview schedule**

Dear Sir/Madam,

This interview will last for around one and a half hour. You have the right to stop the interview at any time and you have the absolute freedom not to answer any question you. A tape recorder will be used to back-up my notes. All of the information you will provide me with today will be dealt with as top confidential information. Nobody, except the researcher and his supervisory team, will have access to it. The information you give today will be used for academic purposes only. Your name and your organisation’s name will be kept anonymous.

**General information about the interviewee**
- Name:
- Job title:
- Length of experience:
- Type of projects you are experienced in:

**Part one: Company information**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1.1</td>
<td>How long have your company been operating a construction business?</td>
</tr>
<tr>
<td>1.2</td>
<td>How many employees are recruited by the company?</td>
</tr>
<tr>
<td>1.3</td>
<td>What is the approximate annual turnover?</td>
</tr>
<tr>
<td>1.4</td>
<td>Is there any specific type of projects/clients you used to work with?</td>
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<tr>
<td>1.5</td>
<td>What is the geographical sphere of your business activities?</td>
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</table>

**Part two: Risk perception and analysis**

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>2.1</td>
<td>How can you describe the industry and the market conditions in which your company used to operate from a risk point of view?</td>
</tr>
<tr>
<td>2.2</td>
<td>Do you consider project risk as a main issue to be dealt with in the pre-tendering stage? If yes how?</td>
</tr>
<tr>
<td>2.3</td>
<td>How you define and perceive risk?</td>
</tr>
<tr>
<td>2.4</td>
<td>How do you identify and classify risks? Do you follow formal procedures? Please give examples?</td>
</tr>
<tr>
<td>2.5</td>
<td>To what extent you relay upon your past experience for identifying risks in different projects?</td>
</tr>
<tr>
<td>2.6</td>
<td>How do you define risk impact?</td>
</tr>
<tr>
<td>2.7</td>
<td>What is the most suitable way for you to appreciate the size of risk impact? Monetary term?</td>
</tr>
<tr>
<td>2.8</td>
<td>Do you consider risk impact on different project success criteria?</td>
</tr>
<tr>
<td>2.9</td>
<td>How do you perceive risk probability of occurrence? How do you measure it?</td>
</tr>
<tr>
<td>2.10</td>
<td>To what extent you relay upon your past experience and intuition for assessing risk impact and risk probability of occurrence?</td>
</tr>
<tr>
<td>2.11</td>
<td>How do you balance your risk taking? You know, not all identified risk will definitely occur and risk impact will not necessarily materialise in its maximum</td>
</tr>
</tbody>
</table>
2.12 Do you estimate a project risk level before tendering?
2.13 How do you assess project risk level?
2.14 How do you cover project risk when tendering?
2.15 How do you estimate project contingency?
2.15 Do you use any software to support you in assessing risk, project risk level or project contingency?
2.16 According to your responsibilities in the company, can you specify the most important risks to be considered before tendering?

Part three: Decision making policy

3.1 How do you make decisions usually?
3.2 Do you relay upon group or individual decision making processes?
3.3 How do you consider risk when making a decision?
3.4 How do you consider both of project benefits and risks when making any decision?
3.5 What are the main attributes of a construction project attributes you consider when making a decision to bid?
3.6 To what extent you depend upon your practical experience and intuition in making decisions? How do you do that?
3.7 Do you use any software or decision support systems when you are faced with complicated situation?
3.8 What are the qualities or the features you look for in a DSS if you want to use it for aiding risk analysis and decision making?
15.4 Appendix (IV) Interview Schedule

Dear Sir/Madam,

This interview will last for around one and a half hour. You have the right to stop the interview at any time and you have the absolute freedom not to answer any question you. A tape recorder will be used to back-up my notes. All of the information you will provide me with today will be dealt with as top confidential information. Nobody, except the researcher and his supervisory team, will have access to it. The information you give today will be used for academic purposes only. Your name and your organisation’s name will be kept anonymous.

General information about the interviewee
- Job title and main responsibilities:
- Length of experience:
- Type of projects you are experienced in:

Part one: Company information

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.1</td>
<td>What is the approximate annual turnover?</td>
</tr>
<tr>
<td>1.4</td>
<td>Is there any specific type of projects/clients you used to work with?</td>
</tr>
<tr>
<td>1.5</td>
<td>Is there a specific department or staff for risk management?</td>
</tr>
<tr>
<td>1.6</td>
<td>Are there any formal protocols for decision making in the organisation?</td>
</tr>
</tbody>
</table>

Part two: Risk Assessment

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Do you have an agreed-upon set of project success objectives? Do you identify the risks related to each objective?</td>
</tr>
<tr>
<td>2.2</td>
<td>How do you assess these risks?</td>
</tr>
<tr>
<td>2.3</td>
<td>Do you think that risk assessment is absolute? If not, to which issues is it related? How do you consider the relativity issue?</td>
</tr>
<tr>
<td>2.4</td>
<td>How do you assess risk likelihood?</td>
</tr>
<tr>
<td>2.5</td>
<td>How do you assess risk impact?</td>
</tr>
<tr>
<td>2.6</td>
<td>Do you appreciate the importance of risk? How do you consider risk importance?</td>
</tr>
<tr>
<td>2.7</td>
<td>Do you think that risks are different in terms of your ability of controlling their impact when they occur? How? Can you give examples?</td>
</tr>
<tr>
<td>2.8</td>
<td>Do you consider your ability of mitigating risk impact when assessing different risks? How?</td>
</tr>
<tr>
<td>2.9</td>
<td>Is your ability to deal with risk impact different from one project to another? How?</td>
</tr>
<tr>
<td>2.10</td>
<td>How do you reflect the different project specifications, characters and environment when you assess risk?</td>
</tr>
</tbody>
</table>
2.11 How can you embed the above mentions issues when assessing risk impact?
2.12 Do you assess a project risk level? Is it important for you to know it in this early stage? Why?
2.13 How do you determine project risk level?
2.14 When you produce a project risk level assessment, do you look at the identified risks as individuals or as a risky environment affecting the project?
2.15 How do you consider the interactions and dependencies between risks when assessing a risk or a project risk level?
2.16 To what extent you relay on your experience and personal judgment when assessing risks? How can you test the accuracy of your judgment?
2.17 Do you use any formal tools or software for assessing risk or project risk level? If yes, Please give example and if no please explain why.
2.18 Do you seek an expert advice? What type of analysis they may conduct for you?

Part three: Project appraisal, evaluation and selection

3.1 How do you compare between different projects? What attributes do you consider?
3.2 What do you regard as project benefits? Can you specify the most important intangible benefits?
3.3 How do you assess project benefits?
3.4 When assessing project benefits, to which extent are you confident that you will secure them? How do you consider the probability of not securing them fully in your assessment?
3.5 Do you assess a project attractiveness level?
3.6 How do you deal with intangible attributes?
3.7 Do you consider both of project risks and benefits when comparing different projects? If yes, how do you do this?
3.8 What scales do you use to assess different project attributes for appraisal and evaluation purposes?
3.9 Bearing in mind the risk and attractiveness levels of different projects, how can you rank them and choose the most preferred one(s) for you?
3.10 Do you use special tools or DSSs to support you in ranking and choosing from different projects?
3.11 Do you relay on your experience in this issue? How?
3.12 To which extent your experience plays a key role in your final decision?

Part four: Difficulties and Aspirations

4.1 What difficulties you used to face when conducting risk assessment or project evaluation?
| 4.2 | If you mainly relay on your experience, Why? |
| 4.3 | To what extent do you think that your experience and personal judgment play a key role in risk assessment and decision making even if you use DSSs? If you highly depend on your experience can you explain why? |
| 4.4 | If you use software or DSSs for these purposes, what are their main shortcomings or limitations? |
| 4.5 | What are the key attributes of a good DSS from your perspective? |
| 4.6 | What do you think of a DSS based on your personal judgment and personal experience? |
| 4.7 | Do you think that you can provide a monetary equivalent to the size of a risk impact or the size of a project intangible benefit? |

The last question, to which extent you think that what you have told me today can be generalised to other companies in construction industry?
15.5 Appendix (V) Transcripts of the semi-structured interviews

15.5.1 Pilot study interview

<table>
<thead>
<tr>
<th>Interviewees</th>
<th>Current position</th>
<th>Company’s annual turnover</th>
<th>Company’s main projects</th>
<th>Interview type</th>
<th>Interview date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr K</td>
<td>Operations Manager</td>
<td>£15 Millions</td>
<td>Residential, refurbishment and council projects. Mainly work with public sector</td>
<td>Discussion workshop.</td>
<td>10/03/2010</td>
</tr>
<tr>
<td>Mrs B</td>
<td>Risk and H&amp;S manager</td>
<td></td>
<td></td>
<td>It took around 2 hours.</td>
<td></td>
</tr>
<tr>
<td>Mrs S</td>
<td>Financial Manager</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mrs H</td>
<td>Contract &amp; bidding manager</td>
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</tbody>
</table>

Q1: Is there a designated department for risk assessment and management in this organisation?

B: That would be me to some extent. When we tender for a project I have to answer questions about risk assessment. If we are successful in winning the project then I have to provide initial risk assessment for the project. This will be mainly from health and safety risk point of view.

K: from financial point of view, I have to look at the project even before Bev looks at it. I look at it and think of it and decide whether or not to bid for the project. So we have some kind of risk assessment from this side.

Q2: Is there any procedures or protocols for making decisions in this organisation?

K: Yes. First of all we would look at where the tender is coming from. If the client is private company we may not take the project. If the client is a private person and the project has a big value we think of not taking it. So it is direct line and straightforward process. If the client is private person with significant figure so there is a high risk of not getting our money back so we would not bother to take it at all. Generally, there is a very high risk of not getting paid from a private person compared to local authorities.

Q3: You mentioned “Risk”. How can you describe construction industry from risk point of view?

K: immensely risky industry. There is high degree of risk from all aspects. Financially is major. There is at least five points where things can go wrong from finance point of view. There is also a risk in managing the actual work. There is risk involved in tendering the work; we have five people going through it. 20% chance of getting the tender means that there is risk in it. So, yah, risk is everywhere.

S: as a tender manager I think that there is high risk in tendering. To choose where to go and to decide to tender or not is really risky.

Q4: Can you please let me know how you define and perceive risk?

B: from health and safety point of view, risk is the hazard of accidents and injuries that may happen in site. The more people involved in the job, the more likely a risk is going to exist. Control measures are going to be taken; the work forces need to know what risk are there, site managers are required to manage risk in site with support of me. We continuously keep
monitoring risk management in site. Yesterday I went to the site to make sure that site managers are giving the work force the required training about risk and safety. K: For me, risk is a part of everything we do. Risk is perceived as a physical harm to one of our employees for instance. The major risk which may affect the company is a financial risk. I suppose other risks to our employees that might not necessarily are financial or physical harmful. For instance, stress miry. B: I think there is a risk for reputation. When you do anything right nobody will remember but when you do anything wrong then everybody will remember and this will affect the reputation of the company.

Q5: So, do you think that it is important before tendering to identify everything that can go wrong in the future and to be ready for it?
S: I think it is very important and this is actually a question which we keep asking before tendering for every item involved in the tender. We ask what we can do if this happened. H: From my point of view, we do not follow any procedure or model to do so. We do this based on experience, knowledge and group working. We depend on pooling everyone’s expertise to make the final decision. We do not have a specific way of doing it, do we?
K: No we do not have. We deal with every case based on its merits and accordingly we decide how to deal with it.

Q6: So, you do not identify and classify the risks that may affect a project before tendering?
K: Not in a formal manner. No, because generally when the tender come I look at it and assess in my mind whether there is a business opportunity there. I look at the client whether he is good. I suppose, in my mind I go through the project and think of what risk are involved and then decide whether or not to tender. So we do not have a specific session for risk assessment and everybody participate in it.

Q7: So, to what extent you relay upon your personal experience?
K: very high. I rely mainly on my experience to give me the results. All agreed.

Q8: How can you measure risk impact?
K: we would view.. What I would say on a scale from 1 to 5, erm.
B: I think it got to be a coalition of financial, physical, pain, gain and all things that decide whether or not to continue.

Q9: So, what do you think the most suitable way to measure the risk impact?
B: I would say, doing the same for describing health and safety; comparing the hazard to the value of the contract, the risk that the company is under, what we have to do in order to deal with it.

Q10: So, can we use monetary sums to measure the risk impact?
K: That would certainly be a way of doing that. I would personally do that because I would have enough knowledge about the product and to know myself whether it is financially sensible. If there was a private person asking us to do half a million job, I would initially look at it and think that if there is 30% chance that part of our money will not come in then our profit is taken away so there is no point doing the job. That is the end of the line. If it was a more established company, I would check out and do risk assessment about their finances and from that we can make a financial decision about working with them. So the risk assessment will be done for each part of the company, credit records for instance, and for each part of the job; obviously financial checks.
S: even before that, during the PQQ (Pre-Qualification Questionnaire) stage, you have got to ask how much it will cost to get through and then when you get the next stage you should ask
how much it will cost to get to the final tender. So, you should assess how much money you are going to spend to tender and then you may not get it at the end. So, it is a sensible way to measure the risk and to measure how much you need in core to cover it.

H: I think that we have different procedures and frameworks for tendering. Each of them will have different associated costs. I think that the idea of using financial terms to measure the risk is a sensible way.

Q11: Do you assess the impact of risk on the different success criteria of the project?
B: We monitor those items, cost, time and quality when we are in the process. So we monitor and assess these items throughout the project but not before we tender.
K: the only thing that makes us work on these issues is the project value. For instance, if the project is million plus in value then we spend some time thinking about these issue. If the figure is smaller than that we do not bother to do so.

Q12: So, the cost effectiveness, time and efforts, is essential for deciding whether or not to do such assessment?
K: That is right. I just want to mention that we do not have a specific team to do it. We do it individually.

Q13: How do you perceive or measure the probability of risk?
K: Just the experience. It might be not what you want to hear but actually this is how we do it. As i said earlier we first look at the client then the value of the project and whether or not we are able to do the job. This is usually what determines whether we will take the job or not. We look at whether the client is public or private. We look at the value. If the value is too much this may have an impact on our company. We look at the job itself. We assess whether we can do it or we have enough capacity of experience to do it.

Q14: Do you use something like: there is a chance of 60% this risk may happen?
K: No. We do not do something like that.
B: we do not use any model.
K: We do not have any specific way for generating such percentage. From my experience I look at it and say: ok, that is fine. Simply, i think of it like this: The client is public, the money is guaranteed, within our price range, we have regular financial payment and we can do the job and we have enough time so we go for it.

Q15: Can I understand that the financial risk of the project is the key?
K: It is the start of the process. If the project is not financially worth it, so there is no point to go for it.
B: but it is not the only factor. When we price a project we look at the profit. Sometimes we price it without actual profit in order to keep the client happy or to keep our staff working. Also, we do this competition reason and for keeping our clients. Initially, there is the financial but definitely there are other factors affecting the final decision.

Q16: So, how can you balance the risk taking?
B: we have to look where we are as a company.
K: It is a controlled risk. We are not really taking a risk that may affect our business. We are merely saying that we may work for wages rather than profit. So, we are not taking a risk that affects the financial stability of the company. We are just taking less financial profit.

Q17: But, in the same project how can you balance the risk and the reward or potential?
H: we have to see some benefit or prize at the end, whether at the end of it or at the end of another project attached to it. We have done something like that. We have done a small scheme which made us no profit or maybe small loss but it opened another door.
K: But we do not have a specific method for doing this or paper trial to monitor that.
H: we do not have a scoring system; we do not have a tick system. It is all mental experience and final decision making from key people.

Q18: How can you use your experience for comparing between projects with their pros and cons?
K: We manage it by first of all looking at the risks and seeing whether we can remove some of them. That might be through discussion with the client; changing the product, changing the design.
H: At the end of the day, key people would sit down and discuss it and the final decision is made.

Q19: If there is no scoring or any structured method, what if an independent body came to audit these decisions? How can these decisions be validated?
K: Actually, we do not do that. That would not happen at a decision making. We have ISO 9000 doing our management process but risk during tendering is not covered by that.

Q20: Do you assess project risk level?
K: every project has a risk level but we do not do it on paper. Every project is assessed but not written down.

Q21: How do you get this project risk level? Is it assessed based on the assessments of individual risks or it is looked at from a holistic point of view?
H: There would be sectioned criteria; financial, physical, etc to the appetite. We break down the risks into sub-categories.
K: I think it has to be very close to what we have decided as a level for deciding whether to go or not with the project. Then we can break it down and get people involved. But in the initial stages it would be: yes or no from the experience.
B: The initial risk factor to be looked at is the client. If the client is local authority then we would proceed. If there is another element of risk we would tender it. But if it is a domestic or private client, the discussion will take longer before we enter the pricing process.

Q22: But, how can you cover any potential risk?
S: there is always some kind of contingency to cover unforeseen risks for instance bad weather in the winter can cause delay in the project. This contingency is considered while pricing the project by the quantity surveyors. Then, when submitting the tender, K, I and the other managers would look at the bottom line figure and decide whether to accept it as it is or to reduce it if it is too high.
K: We might look for instance at the client and decide that there might be some delay in payment so we put extra percentage to cover this issue.
S: If there is always a health and safety risk down the road, we might add extra contingency to cover it as well.

Q23: Why do not you use any DSS?
K: There is no need for it. Our assessment is down to our experience. There is no need to try another method and change our method as it works accurately. It is quicker because the people who are making decisions they are making it quickly and accurately. Generally, there is no position where the risk is hidden. It is always obvious to us where the risk is.

Q24: Is it because of the size of the project or because you are experienced and your job is repetitive?
K: All of them I would say. There is a lot of repetition. Similar projects, not exactly the same but similar so we are experienced.
Q25: But if you are facing complicated situation, are you interested in using DSS?
K: We are always interested in trying anything that makes life easier. But to use a computer to make a decision which we used to make is something not..
S: The cost. The benefit of the DSS will not justify the cost of it..
K: The decision we made are based on relations. There are reasons. We know our clients and we have relation. These relations cannot be covered by a computer.

Q26: What I am trying to produce is a DSS not a decision making tool. So it will help you to structure your ideas and the problem you are facing. Are you interested in using something like that?
K: Well, I do not think that analysing risk in different way will change it. I know the risks we are facing and I know how to deal with them. So, I do not think that I need such tool. I do not think that I will use it.
S: What I think is, as our company grows such tool will bring benefit. But, for this particular moment of time, probably there is no benefit for us. But I think it is something we would need in the future.

Q27: Can you identify the major risks to be considered before tendering?
B: Health, safety and environment related risks. If we ignore these issues and something bad happened there will be massive fines to the company and our reputation will be damaged. And once our reputation is damaged it will be hard to the company to continue.
K: financial risks. If the company is at financial risk then the business will not continue. It is a major corner stone for any business. If the finance is affected then everything will go.
H: Finance definitely.

Thank you very much for your time.
Abdul
## 1. When you prepare a bid, do you have an agreed-upon set of project objectives? Do you identify the risks related to each objective? Can you specify the most important risks?

The job we do is generally not design and build. We generally do the job which has all its drawings and specifications. Risk assessment is done by the consultants so my job is to look through and see whether they have missed anything so I will add this risk to the risk assessment document. Then Bev will take the documents and based on the concerns of the consultants and myself she will prepare the final risk assessment and take actions to reduce and mitigate them.

## 2. How do you assess these risks?

I assess them from my experience. I look at the drawings, the location, how to use the location, what construction methods there are, etc. It is just a normal experience.

## 3. Do you think that your assessment is absolute or relative?

Yah, it is relative to many things. It might be relative to the speed of build, it might be relative to the location of the project, it might also be related to the product itself. If it is a new product which I have never done before, there is a risk that I might not understand the product properly so my assessment could be wrong. In this case, I ask external bodies to give me help in risk assessment.

## 4. How do you assess risk likelihood of occurrence?

Well, I do it by investigation and visiting the site in order to minimize the risk and reduce it to low level and hopefully eliminate it.

## 5. How can you assess the impact?

You can say that there is a chance of something happening but it would be difficult to know how much it will cost. We hope that it will not happen but I put a percentage of money extra in the contract in order to cover the risk just in case.

## 6. So, you assess risk in financial terms?

Absolutely!

## 7. Do you think that risks are similar or some of them are more important than the others?

Obviously, risks are different. Some risks may have impact on our work forces but have no financial impact on the company. Other risks, like buying specific product, may have no impact of the employees but they have terminal impact on the company and the business.

## 8. How do you reflect the importance issue in your assessment?

Well, you would assess each of them based on their merits. We weight each risk or scenario based on its own merits.
9. **How do you reflect your experience and controllability when you conduct risk assessment?**
   It is a scenario where you use your experience and seek advice. For instance, if there is a chance of 10% risk in a specific part of the project so I will add extra 10% to its price in order to cover it. So you assess the risk percentagewise. It is not something I do on a daily basis but I think this is the method I would use.

10. **Having identified the major risks in your project, do you accumulate their assessments?**
    No I do not do it. I do not go that way. I would not look at the whole project risk. I would look at the risk to job for myself and from there I would say that this risk is covered by our experience and if not I would go for external consultancy to help. I would not think that at this stage I would do a complete risk assessment on project cost, time and profitability on a scheme from start to finish. I am not sure whether that would help us. It must be warped in some way or another to come up with the final figure.

11. **So you mainly use your experience instead of this structured way of assessing risk?**
    Not necessarily. I mainly try to package the risk and reduce it as much as I can by passing it to our sub-contractors.

12. **Do you appreciate that there are interdependencies between the identified risks?**
    Yes mitigating some of them would indirectly affect the other risks.

13. **It seems that you relay mainly on your experience. How can you test the accuracy of it?**
    Yes, I would say that 75% of risk assessment is done by me based on my experience. The only way for testing it is the experience. Over time it proved to be working. Because it is working it means that it is right.

14. **Do you think that because of the size of the company this way is enough and you do not need to justify further by providing analysis document?**
    Yah, yah, you are absolutely right. I have long experience in construction industry and I tend not to write everything down. I do everything solely through my mind and I do not write down everything which I think something bad. I think that here in this company they do not like this way but this is how I do it.

15. **Maybe because you are senior and partner in this company you can do it in this way.**
    If not I think you need to do such assessment in clearer way.
    Yah, yah, you are absolutely right.

16. **Why don’t you use formal tools for risk assessment?**
    Actually we do all the things you are talking about but not in a formal and well-documented way.

17. **What attributes you may consider when comparing different projects?**
    First of all it is the client. We need to do financial risk assessment on the client. We also look at the project specification and whether we can do the job and we have the resources. We also look at cost, availability of men, profitability, location and experience.

18. **What about the reputation?**
    Well, we have built our reputation and we definitely think of enhancing it. But if it comes that the project which will enhance our reputation with a possibility of not getting paid,
getting paid would definitely go first. So, there is no point of having good reputation if the business is no more running. The ability of the client to pay is a key.

19. It is obvious that financial risk and financial issues are your main concern. What are the other attributes you look for in a project?
   Keeping the employed people at work; this gives me the opportunity to train them as we go along. If the job is in certain field this may enhance our reputation.

20. How can you assess these intangible benefits and combine their assessment with the intangible ones?
   It is difficult to do that and it is difficult to put a final cost on that. This is because it is very small parts and I am not sure how much they are as a percentage. In theory they add a percentage to the profitability of the project but I am not sure about the exact percentage.

21. So, you think that these intangibles could be measured in financial terms.
   Yes. Yes we can but I am not sure how to provide an exact figure.

22. How do you assess your confidence level when assessing the benefits of a project?
   How do you assess the achievability of project benefits?
   Well, I suppose that history would say that 70 – 80% of the times I was right. If you look historically at pricing a job assessing risk and providing final figure and then comparing with the actual outcome you find that 85% of the times I was right. So, yes I consider the achievability factor and for this reason I raise the cost in order to cover that this might be.

23. Similar to risk assessment, do you accomplish benefit assessment and come up with attractiveness level of a project or you simply use your experience to decide?
   Obviously, experience has a lot to do with this issue. If we have four projects on the table, everybody has a view about them. But from my experience, because I know the client and because I know the work stream I have better overview to give the final say about which is the best just simply because I have been doing the same job for over 20 years now.

24. How can you combine both risks and benefits in comparing different projects?
   I do not know. You would have to set us specific tasks and tick lines to go through, give scores to every job and go through to the another job. You should have a strict formula for risk and to apply it for each job. It is not something I do but I am sure that it is possible.

25. Do you use DSS for evaluating projects and ranking them?
   No, I mainly depend on my experience.

26. What are the main difficulties you used to face when conducting risk assessment or project evaluation?
   The major difficulty would be a product or area outside my field of excellence. It would be only on a short term till I find somebody with experience. The other problem is a job which I want to do but with a company which I do not know and I do not have trust in. So, I need the job and I can do it but I do not know the client and whether he is willing to pay or not. Also I think there is a difficulty is combining the assessments of risk and benefit in a justifiable way. It is difficult but I try to make it easier by knowing what the job is, who the client is, where the location is, and what time of the year. All of these facts will help me.

27. To what extent your experience plays the key role even if you have a DSS?
   Even if you have the very best software and it has been trialed and tested there will be experience to be added to the end of it. It is human nature. You always try to beat the machine. Nobody would say it is natural to say that. But, only after years of using a machine and trying it you will be building trust in it. In the early stages you try to believe the machine and understand it. The more you use it and the more good results you get the less input you put yourself.
Obviously, if a machine says that you should go with a project and I do not think that we should go so I will stick to my experience. I need to check the tool and trust it before I use it.

28. But, what if the tool say that you should add 12% to cover the project risk and you think 10% is enough, what do you do in this case?
   I would initially stick with the 10% because I think that some risks like financial risk could be fixed while going along. So if the machine says 12% and I think 10% I would work hard on this and this and this to bring the risk down. So, if there is 10000 pounds extra which make me lose the job then I will go for the lower, i.e. the 10%.
   I think that the worry would be if I said 5% and the machine said 30%. This is a big problem because one of us is seriously wrong and if I want to add 30% to the job we are never going to work.

29. So, you are balancing between taking risk and not losing the job; positive risk taking?
   Yes, positive risk taking is what we are doing here when a project comes in. If the money people say one pound I may say 90 pence because I know that I can make these things positively happen even though he said that was the best. We do that weekly.

30. What do you think of using financial terms for measuring risk and benefits?
   I think that it is an easy and straightforward way of looking at things. So you are measuring risk in extra man-hour and the cost of that so much per month, so much per year. It is similar to what we used to do. Many times we use man-hour to bring things down to its basic level. It is a common language understandable by everyone. At the end of the day you put your price in man-hour and then start negotiation with the client and we agree upon any extra work. It is done that way in the UK. Not easy but it is an understandable way for all parties.

Thank you very much for your time.
Abdul
### 15.5.3 Interview (2)

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Current position</th>
<th>Company’s annual turnover</th>
<th>Company’s main projects</th>
<th>Interview type</th>
<th>Interview date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrs B</td>
<td>Risk, Health and Safety Manager</td>
<td>£15 Millions</td>
<td>Residential, refurbishment and council projects. Mainly work with public sector</td>
<td>Fact-to-face. It took around 1.5 hours.</td>
<td>21/04/2010</td>
</tr>
</tbody>
</table>

1. **Characteristics:**
   My role in the company is health, safety, environment and quality manager. I am also working in the human resources and training department. I have been in the health and safety management domain for over 20 years and I have been working in this company over the last four years.

   The company is growing rapidly. We made massive jump in the last two years. The firm doubled in size and I think that by this time next year the firm will double in size again. The company turnovers are doing the same. Last year we expected to do 8 millions we did ten. This year we were expecting 10 millions, we made 12 millions as turnover.

2. **When you prepare a bid, do you have an agreed-upon set of project objectives? Do you identify the risks related to each objective?**
   In the early stages of the project, you are generally trying to get a feeling about the site you are going to work in. Then, you can answer these questions of health and safety accordingly. In the second stage; if we have been offered the work, we can be given the corporate construction information which is a detailed description and a breakdown of the job to different stages, phases and packages. Part of this information package, there will be a list of what are the perceived risks by the designers. Then as a part of the construction phase chart I will conduct an initial risk assessment. I do it in two parts. Firstly, I go out and look at the site and examine its characteristics and the surrounding sites. This will help to use the suitable control measures to manage the risks.

3. **Do you categorize the identified risks according to their effect of project objectives?**
   I provide the company with guidance to the risks which will cost more. I am not really involved in saying that we should not do the job because the risk is too high. I just give guidance to the managers about the risks and risk management in the project and they make decisions.

4. **How do you assess these risks?**
   I follow the Health and Safety standard. There are five steps to be followed. I identify the hazard, the risk level, the people who are going to be affected, propose control measures to be put in place and then I evaluate how these control measures are going to reduce the risk. In many cases we can reduce the risk significantly. But in some cases we are unable to reduce the high risk level into lower level because of the nature if the work.

5. **How can you assess the unforeseen risks during the construction stage while you are bidding?**
   There is nobody perfect and there are no two construction projects alike. You can account for every possible risk but when the actual work start you may face totally unexpected problems in the site. The majority of things are foreseeable but there are always unforeseeable things. What you should do is when you are bidding you should add a bit of extra money to account for the unforeseeable risks.
6. **How can you estimate this extra bit of money?**
   Well, I use the past records and experience. I have got the accident record over the last five years. I look at the type of accidents and how much has cost us. And, I consider that we are getting more experienced in controlling the risks so the records tell us that the risks are costing us less on time. Things are different now from when I started. The accidents are less and cost is less. When I started working with this company there was no risk and safety control measures so there were many accidents.

7. **Do you think that the risk assessment if absolute or relative?**
   No, risk assessment is not absolute. The big job has always more risk that the small job. In big projects there are more people involved, more people may have accident and more equipments and plants in the site.

8. **How can you assess risk likelihood and impact?**
   As I said earlier, I go to the site, look at what the designers perceive as risk, have my own thoughts and use my background experience. I can then determine some idea about what could go wrong and what the impact could be. I can use my training and background to estimate how much the impact of the accidents. As part of my training, I had been in courts many times. I listened to the cases and the claims by the injured people. I know the penalties which may occur if there was a breach to the health and safety regulations and law. From such experience I can estimate the impact of risk.

9. **So, you estimate the likelihood of risk and estimate its impact in financial terms?**
   Yah, absolutely.

10. **Do you think that risks are similar or some of them are more important than the others?**
    There are many simple risks which you can deal with them easily. But, for instance, if someone falls down from scaffolding he will get killed. Such serious risk needs you to sit down and think more carefully of taking appropriate control measures.

11. **Do you think that risks are different in terms of your ability of managing them?**
    The same risk in different project requires different way of dealing with it. This is simply because we gain experience of dealing with the risk from one project to another. This is actually what we are doing. We are getting the risk lower and lower. This is a learning curve for everybody.

12. **But how can you consider your experience when assessing risk?**
    Well, if the risk is a risk which I have dealt with before and I have experience in it, it will take less time for me to work on it and find the suitable control measures.

13. **Do you discount its potential impact because you have good experience in dealing with it?**
    Yes I do.

14. **Do you aggregate the individual risk assessments in order to come up with project risk level?**
    I do similar thing when putting the construction phase plan together. I have a number of spreadsheets. Each has the hazards, where these hazards are coming from, who is at risk, the risk rating; low medium, high very high (I use a numbering system for rating risk), the control measures which put in place, how the control measures are reducing risk (also I use numbering system for this evaluation) and finally I have a specific domain to show whether the risk is properly control or not.
15. But, how can you transfer this structured way of managing risk into project risk level or percentage for contingency?
   Again, I do not get involved in the decision of how much it would cost apart from some specific cases, accidents, when I talk with the managing director about the cost of specific risks. The decision makers in the company would use the guidance and the risk assessment I provide in order to decide how much they have to add to cover the risks. I am involved in identifying the hazards and they have to decide the monetary figures to cover those hazards.

16. Do you think that risks are independent or related to each others?
   Sometimes when you are putting control measures for specific risk you are actually creating new risk. For instance, scaffolding is a control measure to protect people who are working on the roof. It is in the same time an attraction to children which is another risk. So we have to fence the scaffold in order to prevent the children from climbing it. So, yes risks are inter-related and not independent.

17. To which extent you depend on your experience for risk assessment?
   I depend on my professional judgment quite a lot. I have more than 20 years experience in health and safety management domain.

18. Do you use formal tools for risk assessment?
   No I do not use formal tools. As I said, I depend mainly on my experience and professional judgment. I use what I have learnt over years. I have done a lot of training and I use standard and guidance for risk management.

19. What attributes you may consider when comparing different projects?
   Obviously, we have got to look at the resources and decide whether we can coop with the required resources. We choose the one which we can best coop with. We look at the project which would bring us most profit. I think that these are the two major things we look at; resources and profit margins.

20. What about long term strategy; reputation, market share, future alliance?
   We do have long-term partnerships with housing associations. We have got a very very good reputation. Most of the job we get is coming from a word of mouth. We are well known for delivering very good product at a reasonable price. Now we are getting some jobs without tendering for. We have built our reputation and definitely we do not to damage our reputation by a serious accident on site.

21. How can you assess these intangible benefits and combine their assessment with the tangible ones?
   I do not think that we have a philosophy for doing such combination. I think that the managing director decides what he think will be the best for the company. It is not always money. He may give a go for a project which brings us less money but because the client is a regular client and he want to keep this client. He would rather to do this instead of working with a new client who may not see again. The managing director would always look at different projects and choose the ones which would bring more benefit to the company.

22. How do you assess the achievability of project benefits?
   Well, I do not think that you can do. In every project there are lots of unforeseen accidents. You cannot be sure about what may happen. You would never ever get a project without unforeseen. We try to get as much information as possible.
23. Do you think that financial terms, as a common scale, could be used to combine risk and benefit as multi-criteria for comparing different projects?
   Possibly, yes. This methodology seems to have benefit. What we need is, actually, a simple way of doing things which help us make decisions fairly quickly.

24. Do you use DSS for evaluating projects and ranking them?
   No.

25. Why?
   I look specifically at health and safety so I am not involved in such decisions. Actually, I give them feedback about risk, health and safety which can help in decision making.

26. What are the main difficulties you face when doing risk assessment or project evaluation?
   The main problem is time. As I said, the company is growing rapidly and we are getting busier and busier. I think that the company would grab the software you are going to produce if it can save time for decision making.

27. What features you are looking for in the DSS?
   It has to be simple and easy to use. I would like it to save my time when rating the risks. Anything can make my life easier would be welcomed. The problem with the score rating is that if you are a professional safety officer and you had training you would understand it. If I went to the managing director and showed him a figure, risk score, he would not understand what I am talking about. The software has got to be simple and understandable by everybody.
   The problem with health and safety is that there is lots of math in it. The older people are not fond of math. They need something simple, you put some information and quickly it comes up with a figure.

28. To what extent you think that what I have proposed today would be appreciated by other companies?
   I think that most people in this country rate risk in similar way. Not always numbers. Sometimes they identify low, medium, high, very high risks. But, the majority of companies use numeric scores. If we can link these numeric scores to some sort of rating system for the cost, I think that this would work.

29. To what extent you think that people depend on their experience for risk assessment and decision making?
   I think that this happens a lot. The problem in the smaller companies is that they do not have people like me because they cannot afford to take somebody on. So, I think that if you have some sort of program to help them they would jump to it.

Thank you very much for your time.
Abdul
15.5.4 Interview (3)

<table>
<thead>
<tr>
<th>Interviewee</th>
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<th>Company’s main projects</th>
<th>Interview type</th>
<th>Interview date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr MK</td>
<td>Project manager</td>
<td>£1 Billion</td>
<td>Residential, Property development, and Construction services</td>
<td>On phone</td>
<td>09/06/2010</td>
</tr>
</tbody>
</table>

1. When you prepare a bid, do you have an agreed-upon set of project objectives? Do you identify the risks related to each objective? Can you specify the most important risks?
   Yes. Every time we receive a job to tender for and we decide to tender for, a tender case would be created and a team is assigned to prepare for tendering. As part of tender submission and before we submit our tender, a number of sign off procedure has to go. As part of the tender document, a risk impact assessment document is included.

2. How do you conduct this impact assessment?
   We identify the risks and assess their impact in terms of likelihood and impact size. Then we take measures in order to manage the risk and to keep the risk level low in order to make sure that the tender can proceed. For instance, we have to satisfy ourselves with the measures taken to avoid risks or reduce their impact before we submit our tender to the client. Hence, the process starts with identifying risk then assessing its likelihood and impact and then managing it.

3. But, how do you assess risk likelihood and impact?
   Obviously, we use a scale from 1 – 5. If the risk may have huge impact then we assess the impact as 5. If we don’t have control measures to reduce the likelihood of risk, so the likelihood is still high then we assess likelihood as 3 for instance. Now when multiply these two scores we get 15 which is high and more than the cut-off of 10. So, it is a numerical scale for assessing risk but there is a narrative behind it. The decision to proceed with tendering is based on numerical data.

4. How can transfer risk scores into your bid which contain cost and duration?
   What we do is: from our experience we try to manage the risk and reduce it to the minimum. We also allocate financial allowance to account for any residual risks.

5. So, you transfer the scores into financial allowance?
   No we do not do that. We cannot simply say that if there is a residual risk score of 15 then the allowance should be this amount of money. There is no mathematical link between risk score into financial allowance. It all depends on the specification of the project and the actual situation we are facing. It will all be down to the project manager and managing director to decide the allowance.

6. Can I understand that it depends on the specific nature of the project, the managerial capability of the managing team and their experience? So the same score could mean different allowance in different project.
   Absolutely! You are absolutely right. There is no way of simply taking the risk score and say this is 10,000 or 15,000 pounds.
7. Do you appreciate that some risks are more important and crucial than the others? How do you deal with the importance issue?
   Yes we do. We use sort of weight to reflect the importance issue.

8. Do you generate a project risk level?
   No we do not do that. We identify and assess risks individually and then we submit the bid. Once we get the project we have a bid settlement meeting. In this meeting, every identified residual risk remaining in the bid will be transferred to the operational stage. Every month there will be a report with a page for the risks and opportunities. The residual risks are automatically added to this page. So we do not pool the risks together and generate a project risk level. We have the bid settlement meeting with the commercial manager, technical director and managing director. If they are happy with the control measures taken to mitigate the risks then we proceed with the tender.

9. To which extent you depend on your experience when conducting risk assessment?
   At the bid stage, the risk schedule is produced. You identify risk, assess risk likelihood and severity, and produce the risk schedule. That risk schedule is reviewed by an extended team. Once agreed by the extended team, the risk schedule is presented to the bid manager, technical manager, commercial manager and managing director who will finally sign it off. So as you see my judgment will introduce the process but there is host of individuals signing on it. So it is not an individual work it is a team work. Your initial risk assessment will be reviewed by at least five or six very senior managers before the managing director, who sign the bid off to be presented to the client, and will go through three processes which are signing, reviewing and the bid settlement meeting.

10. Do you seek expert advice when facing complicated situations or you simply do it yourself?
    Yes, we seek consultancy from consultants during the bidding stage if needed.

11. Why don’t you use DSS?
    I cannot answer on behalf of the whole organization as I am not that senior in management to know why. Really I do not know. I can answer to this question individually and from my own point of view. I think that risk assessment is probably conducted by understanding all factors and consequences and measures. I think that the machine cannot structure all of this knowledge. You cannot rely on a computer for identifying key risks or factors affecting the process. You can only feed the machine with the information you have and the inputs you gathered.

12. So, you think that the DSS cannot replace the decision maker, it can only help in calculation
    Yes, absolutely. You cannot rely on a computer to identify key risks to any project.

13. What attributes you may consider when comparing different projects?
    It is mainly the profit plan of the project and the project which has the best return to the business. If we have more than one project to bid for the other issue to be considered is the client. If we think that there is a client whom we need to keep and to build long relation with, we would agree to work for him even if the project would make less return. However, if there is more than one client; two clients for instance, we would look at the project which makes us more profit unless the project can make us increase our capability for doing it.

14. Do you follow formal protocols or use formal tools for comparing different projects?
I cannot answer this question because it is down to the bid manager and the managing director. I do not know really how they make these decisions. But, definitely there are management procedures to make such decisions.

15. How can you assess the intangible benefits and combine their assessment with the tangible ones?
   Again, I am really not in a position which allows me to provide answer to this question.

16. What are the main difficulties you used to face when conducting risk assessment or project evaluation?
   Actually, the absence of co-ordinate project design information is a huge challenge for us. When you do not have structured and detailed information you do not know exactly what you are bidding or what may happen. This will create a lot of risks because you are making assumptions. The second major difficulty is getting the correct number of people and the right people on the bid.

17. So, because of the lack of information you make assumptions; you depend on your experience and gut feeling in making critical decisions.
   No we do not use gut feeling. We try to use the available information and make assumptions based on our experience for making decisions.

Thank you very much for your time.
Abdul
1. **Characteristics:**
   I have more than 25 years of experience in construction project management. I am currently working as a contract administrator in XXXXX (£5.7 Billions, 35000 employees). My answers today will be based on a project I am working one which has an overall value of 850 million pounds sterling. Currently, the project is in a stage where we have already spent 55 million out of its overall value.

2. **When you prepare a bid, do you have an agreed-upon set of project objectives? Do you identify the risks related to each objective?**
   Yes. The main risk we have is the negotiation of the financial terms of the contract. There was negotiation concerning the commercial aspect and the cost of mobilization and accommodation of the staff and the people on site. The second aspect was having sufficient resources to accommodate the staff who are working on site. The other risk was the project cost. We tried to consider all aspect that can change the initial project cost. So the main risks we used to deal with were the financial risk of the project and the risks related to the resources which are required to allow the contractors to deliver what is expected from them because the contract was engineering and construction. The contractors were responsible to construct the engineering resources which are provided to them.

3. **Having identified these risks, which are mainly financial ones, how do you assess them?**
   When the main contractor was selected based on the commercial aspect, we had already assessed what the cost of the work was likely to be. We look at the contractor previous work and make judgment about the possible project cost. The contractor has provided an estimated cost to the project which was in alignment with what we have thought of. For this reason we have selected him. So, the risk was assessed as a variation of project cost and this was based on the costs of previous projects the contractor has delivered.

4. **How can you assess risk likelihood and impact before tendering?**
   Usually we conduct what we call an investment appraisal. The client initially has an idea in his mind and we work for him as a consultant. We help him to transfer his ideas into real project. Usually, the client does not know exactly what his project will exactly be. We provide him with this investment appraisal coupled with risk assessment. Because we are experienced contractors, we use our experience and knowledge to say to the contractor: from our experience and previous work, for this particular site we think that these are the main risks you may face. We provide the client with number of options. Each of them has an estimated cost coupled with different set of possible risks. So, we try to understand the site and then, based on our experience and knowledge, we provide the client with set of options.

5. **Can I understand that you use your previous knowledge and experience to identify risk and price it?**
Yes. What we do is we identify the set of risks associated with every option and then use a spreadsheet to calculate the cost of each risk. We provide a monetary sum to represent each identified risk because from our past experience in similar projects we are able to assess how much each risk can cost us. Usually, when we sign a contract with the client we agree upon a date of project completion. This date considers the risks which has been identified and can cause delay. We also agree upon penalties for exceeding this date. For this reason we are able to transfer the delay caused by a risk into monetary terms based on the contract we signed with the client.

6. From your experience, do you think that the identified risks happen independently or there is kind of interrelation between them? How do you deal with such interrelation?
Actually, the identified risks may have such interrelation but it depends upon the sequence of the work and the method of construction. If a risk happened and if we think that it may cause delay in the date of completion we ask the contractor to deal with this delay and to try to recover the missed days. We ask him to provide us with a recovery plan.

7. So, in the tendering stage you may think of solutions for such interrelations? How do you do that? Do you discount their individual impact cost?
As I mentioned previously, before we tender we have full engagement with the client and we have a whole schedule of possible risks based on our experience with previous projects. We discuss with the client the possible risks that can happen in this project before we sign a contract with him and agree upon a completion date based on our experience in similar projects. So, when we come to the client we definitely know before we tender what are the impact of the identified risks, how to resolve it and what cost is likely to be based on our previous experience. Sometimes you have to estimate these costs. By in large, you try to assess the costs of the relevant risks that you may encounter and pass them to the client.

8. What attributes you may consider when comparing different projects?
People generally put a commercial team and assess the cost of the tender. Obviously it also depends on who is the client. If the client is a client who you are interested in working with you would look at the tender carefully and if you are an experienced contractor you would put a fair price. Then you provide detailed schedule and specifications. Usually we have a meeting with the client and we ask for clarification about all the risks which we lack information about. The issues which we do not have enough information about force us to make assumptions in order to estimate the cost of it. So we first price the project and the risk as accurate as possible then we discuss with the client the unclear aspects of the project and finally we make assumptions. Based on the assumptions, a figure is generated as a contingency to cover the risks.

9. Away from the commercial benefits, how can you assess the intangible benefits and combine their assessment with the intangible ones?
Logically, you go to the project that generate more profit for your company bearing in mind, obviously, that your company is capable of doing the job. In terms of intangible benefits, these benefits are considered when tendering and we try to make the client realize his commercial objectives.

10. Do you think that the intangible benefits could be measured in terms of percentage of the commercial benefit?
I think you can do this because it is similar to portfolio modelling when you consider different projects and you have to account for these intangibles. So I think, yes it would probably be suitable way.

11. Do you think that we can use a common scale, financial terms for instance, for combining the assessments of both project risk and benefit in order to compare different projects?
I think that it may be difficult because contractors usually go to the projects which have less risk and make the most profit. Every contractor would like to deliver his work as soon as possible in order to maintain his cash flow. For project risk assessment, it mainly depends on knowing the contract and the risks which are involved in it. We try to deliver different options with different risk assessments and then go to the one which is the most profitable.

12. So, contractors do not tend to make trade-offs between extra risk and extra potential reward?
Yes they do not make such trade-off as you always need to maintain your cash flow in order to keep your business running. I am very aware of portfolio analysis theory and I know that companies may need to be more positive about risk but in practice reality is very different. In practice, contractor would try to avoid risk. If there is a risk which will reduce his profit he would go to negotiate the price with the client in order to cover it.

13. Can I understand that neither the client nor the contractor would take risk assuming that there is a chance of transferring it into opportunity? They only try to pass it to the other party or to re-negotiate the price.
Yah, you are absolutely right. The more risk the contractor thinks he may take the more he goes to the client to negotiate the price or to make sure that the risks are insured.

14. Do you use DSS for evaluating projects, ranking them and hopefully choosing the best of them?
In my whole career I used once MontCarlo in one project only. That was on a project in the railway industry. I think that in construction industry people do not tend to use software for risk assessment. They might use it during the tendering stage. But they follow more practical approach when the construction work starts. Finally, risk management used to be based on how knowledgeable they are about risk and how the contract has mentioned how to mitigate risk and how to consider the time and cost caused by risk. Also it deals with insuring that the contractor is being paid fairly to cover the risks he is responsible for. Equally, the contractor is required to monitor and manage risk day by day to ensure that the client is charged to the minimum. So, during the planning stage you can certainly use lots of software packages, like MontCarlo, to work out the risk. During the construction stage the only possible way to managing the risk is a practical approach. You may also use some sort of software to back up the practical approach.

15. To which extent you depend on the experience when using software?
Practical experience plays a key role in feeding the software with the required inputs. Any software will only be used based on the information you put to it. That information is based on experience. You may get that information from the sub-contractors’ experience but this depends on how long they have been doing the job. I think that the supply chain of the contractor would be the key source for providing such information. Based on the construction supply chain and the feedback of the sub-contractors, the contractor would be able to give accurate estimates and inputs. So it is not guessing; it is based on how the supply chain is functioning. This can determine when the key resources are going to be available and when the completion date is going to be. I think that understanding the
cranes and the plants in the site and knowing when the materials are going to be delivered is much more important than using software.

16. From you long experience, to what extent you think that what you have told me about the practice of risk assessment and project evaluation could be generalized over the construction industry in the UK?
To be honest with you, I am not aware of how things are done in the industry. I can only tell you about what I have done myself. From my experience and from what I have done. I think that the most important thing is to understand the project and the involved risks in it and trying to link this understanding to the project cost and duration. The other important issue is the type of contract. For instance, if the contract is a guaranteed maximum price then the concerns will definitely be different.

I think that the most important three issues to be always considered are the project cost, duration and the type of contract.

Thank you very much for your time.
Abdul
15.5.6 Interview (5)

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Mr S</td>
<td>Chief estimator, assistant to the Financial Director</td>
<td>£4.3 Billions</td>
<td>All types of engineering and construction projects</td>
<td>On phone, it took around 1.5 hours</td>
<td>17/08/2010</td>
</tr>
</tbody>
</table>

1. **Characteristics:**
   I joined this company in 2002 and it was my first entrance to the construction industry. I worked as a quantity surveyor for around 5 years and then moved to cost planning. Currently I work as an assistant to the company's financial director. I have been in my current role for two months. We work on around half a dozen sectors of construction projects. We are about 4500 monthly paid staff globally and probably around 15000 weekly paid employees.

2. **When you prepare a bid, do you have an agreed-upon set of project objectives? Do you identify the risks related to each objective?**
   We are quite selective for the projects we bid for. There is the project turnover for instance. Also there is the company decision to move away or towards a specific sector for instance, the residential projects. Over the last four years we relayed heavily upon them and they composed big proportion of our portfolio. Now there is a decision in the company to move away from the residential sector as it is obviously declining while other sectors are booming. There is always high conscious decision about what type of projects to bid for. We are a group of companies and we have our contracting arm which does the job of contracting as a major contractor. We have also different construction divisions so we look for projects which maximize the group benefits as a whole; the projects that maximize the expertise and return of every individual group company. So it is not just a contracting business.

3. **So, what about risk? Do you identify the risks? Have you got a structured way for dealing with risk?**
   Yah, we have a standard risk register. Let me go back one step. We have a process with certain gateway sign offs. So for example, if we have to obtain permission to bid for a project, we have to pass through certain steps before we proceed and present it for higher approval. Within this process one of the documents is a risk register. It starts with a generic risk register in the first week of the bid, ideally, and then it gets updated once more information about the project becomes available.

4. **But, within this risk register how do you assess risk?**
   It is very very subjective. It is mainly based on experience. Within risk register, there is a section for risk identification. We identify all risks and potential causes. There is also a section for mitigation, insurance or simply not taking it. Then scores are given after these measures are taken. For instance, risk could be assessed as red. After taking the mitigation measures it can be transformed into gray because a green score has been given to the mitigation measures. Risk register is not only about identifying risks. It is also about identifying methods for risk management and then assigning the risks to individuals who are in better position to deal with it.

5. **So, I can understand that you depend mainly on your experience.**
   Yah, at the beginning of the bid, a generic risk list is provided about what probably may happen and what risks can affect and what mitigation measures could be taken. Obviously,
only a part of the risk register could be filled. As project go through, those risks which were dropped may be realized or may go ahead without them.

6. From the identified list, do you appreciate that some risks are more important and crucial than the others? How do you deal with the importance issue?
I think we use a sort of weight when dealing with risk severity and likeliness of happening. We weight them in monetary values. The larger the risk in monetary value terms, the higher the need for mitigation.

7. Do you appreciate that risks are different in terms of your ability to mitigate them? How do you reflect that?
Again, we treat them in monetary values. Obviously, if you give a project to half a dozen of project leaders and commercial managers you will end up with half a dozen of different risk assessments. This is the bit which we struggle with and personally I find this annoying. In such activity, most people will be on the side of caution and then you may see some bias. If people want to win the project and if they see it for whatever reason as a must win, then the marks are filled in less rigorously and more optimistically so we have biases in risk assessment.

8. So, when you have such biased assessments, how do you harmonize between them and generate a final assessment?
More likely the moderator is going to do so. Through the monitoring stage which is a key stage, the moderator will try to align these assessments. But I am not sure whether the moderator align them specifically or.. I am not sure.

9. Do you provide an assessment of a project risk level?
Yes we do. At the last stage of the process before we tender, the project goes to internal tender settlement. Generally, people will be looking at our competitors in order to set our price. We will try to give our best price for the client and so contingency to risk, design and development will be the first thing to go. Typically, our risk will be low and this depends on the market especially at the moment. We do not think that a client would be ready to see a figure of more than 3% as a contingency for risk and development.

10. So, if a project has more than 3% as a contingency it will be considered as not desirable for tendering..
Well, no it is not the case because after the project has reached this stage we are almost signed up for tendering. It is unlikely at the end of this process and after spending time for tendering. What is more likely to do is probably to highlight areas where we need to manage the risk more through mitigating it more or change the way of thinking of it. We may think of changing the way of delivery.

11. But, how do you generate this figure?
We started to use Monte Carlo which actually adds another level of subjectivity. I do not think that it is right to simply add risks up assuming that all of them will happen at their maximum values. This is why we use Monte Carlo analysis. What I personally view is: if your risk is bigger in size than your contingency margin then you should be prepared to lose money.
The way we run the risk profile is that we have a number generated by Monte Carlo or whatever method. We have this number which we think a likely figure and then it is due to a business decision to come to that 3%. Then it is that difference which represent the inherent risk which is not covered by the contingency sum and as long as people are aware of this difference and comfortable with it.
12. Do you deal with the identified risks as individual risks or as a risky environment affecting the project?
   No, I do not think so. We do not simply add all risks in the risk register. This will give you only the maximum value which is not probably what actually happen. You may have a risk expense of million pounds in your risk register when it is probably more likely to be a fraction of that if you deal with it in different way and this is where the Monte-Carlo analysis comes in. Now if you add this one million pound risk to the rest of the risks in the risk register you will be assuming that all the risks are going to occur at their worst expense and this is why I think it is not right to add them up.

13. So, the maximum possible scenario should not always happen and you may need to consider other factors to mitigate their expenses
   Well, if all the identified risks in the risk register happened at their highest values, you have been either: a) mega unlucky or b) simply it just happened.

14. From your experience, how much the actual expense for project risk would be compared to the contingency sum you allocated in the tender?
   Actually I am not sure about that. I think it tends to exceed our contingency and we probably spend more than our contingency. It is a pessimistic view I suppose. I mean you generally spend the majority of it if no more than it. That comes down to the tendering where you are possibly force to put in a number which is acceptable externally. Again I am not aware that we did any research about the difference between the number we generate and the actual risk expenses. I am not sure that we did an exercise like that.

15. You mentioned earlier that risk assessment is very subjective. To what extent you rely on your experience when conducting a risk assessment?
   Actually a large reliance..

16. To which extent this reliance is affected by the project size or complexity? Do you use DSS for risk assessment?
   Any tool is useful. It would help I think. At the end of the day it is an aid. The main reliance is on experience but the problem with it is that it is very subjective.

17. What attributes you may consider when comparing different projects?
   The highest level is sector. What sector we are looking at or constraint in and then.. I am not sure that I am the best person to answer as I mainly involve after the opportunity has been identified. I work within a team who look at the projects which are coming up and then decide which ones to bid for. So, from the top of my head I would say: who the competitor was? what our chances of success would be? whether we are strong in that area. Again it is also very subjective. For instance, health care and education, we consider ourselves very strong in those areas. Hence, if we are bidding for railway project we are fairly good but we are not sure about how likely to win the project. This is sort of self decisions coming through.

18. How can you assess the intangible benefits and combine their assessment with the tangible ones? Can you, similar to risk assessment, use monetary terms to assess them?
   I am not sure how can you do that..

19. For instance, extra percentage to the project NPV?
I suspect that, probably, the percentages that could be applied to such thing would be quite low; probably less than 1%. When we talk about 50 million pounds or 100 million pound project this 1% will be equal to half a million or one million. I am not sure how would we put such figure.
I think that it would probably be applied. For instance, for specific projects or clients we might price more. Also the type of procurement system would affect this.

20. Do you think that using financial terms as a common scale to measure project risk and intangible benefits could be a usable method for comparing different projects?
Yah.. I think this depends on the level of information available to blog into that risk and benefit assessment. Yah.. it seems a good idea but it needs enough information along the way to assess risk and benefit.

21. Some projects have high risk level but also big potential and the others may be less risky but with less potential, do you think that this way could be a good idea to make a multi-criteria decision?
Yah.. It is kind if trade-off.. Yah I think so..

22. From you experience, do you conduct such multi-criteria consideration?
Actually, in our risk register we do not combine the potential or benefit assessment.. Again, it depends on the information available.. We usually conduct risk assessment to the projects which has been already identified to bid for… But, yah.. I think you are right. We may need to combine risk and benefit assessment together.. We can have an extended risk and opportunity matrix..

23. What are the main difficulties you used to face when conducting risk assessment or project evaluation?
Well, probably the main difficulty is how to manage such activity and the lack of consistency, may be lack of information. The problem of managing such activity and the lack of consistency become greater especially when you are preparing for a project so you need to make a decision.. A decision of investment.. Investing money time and resource. Based on that you may end up with not what you think about.

24. What are the attributes of a DSS which make you not encouraged to use it?
I think, probably, the biggest problem would be that the people are only filling in information and not perceiving it as an aid. My main concern is that it will take the thinking around a problem. So there is a problem that the people would focus on the numbers and the monetary values instead of thinking about what the actual risk is and understanding the risk. Because, the most important is determining the mitigation strategy and what the mitigation is. You have to understand what the risk is in order to plan how to mitigate it. That would be my only concern I think.

25. From your experience, to what extent you think that what you have told me about the practice of risk assessment and project evaluation could be generalized over the construction industry in the UK?
I did not work in similar company so I am not so sure. But definitely, I would be interested to know whether they do this thing differently of maybe better. We always look for benchmarking ourselves against the best. I would assume that in general they depend on their subjectivity and they face similar difficulties.

Thank you very much for your time.
Abdul
1. Characteristics:
My company is a small construction company with around 100 employees and 25 millions as annual turnover. We mainly work on refurbishment projects; residential, commercial and education. We work with both public and private clients.

2. When you prepare a bid, do you have an agreed-upon set of project objectives? Do you identify the risks related to each objective? Can you specify the most important risks?
Typically, when we want to tender for a project we evaluate whether we have the skill set to complete the project effectively. The first objective is to conclude whether or not we are able to build the project and to ensure that the people on board have the technical experience to deliver the project and to meet the technical challenge. We will consider whether the client has a clear objectives and meet commercial constraint i.e., he can pay you. Also there is work consideration; whether the architect, the engineers and the quantity surveying people can be depended upon to design the project efficiently and cost effectively and whether these people can be relayed upon to administer the building contract with fairness.

3. But after you take these concerns into consideration, do you identify the risks related to each of them? How do you deal with risk issue?
As a major contractor, what we used to do was to package the project, i.e. divide the project into sub-contract packages and to pass the risks through to the sub-contractors and to organize the packages between these people who are capable of managing the risk on our behalf.

4. So, you do not use to assess risk by yourself?
Well, as a major contractor our main concern is to de-risk the project, i.e. to pass the risks into our subcontractors. That is, actually, how always has been in the UK.

5. But, from your experience, how do you assess risk if you are required to do so?
This can be done by analyzing the project and all the parties involved in it. For instance, if the project is a new built then the majority of the risks will be in the ground. If the project is a refurbishment project then the risk is likely to be between the retained structure and the retained fabric.

6. Do you consider risk likelihood and impact when you conduct a risk assessment?
No actually. As a major contractor our duty is to manage the risk by transferring it to the sub-contractors who are working in direct connecting with these risks. For instance, the technical risks are transferred to the sub-contractors who are in better position to managing them.

7. But, what about the residual risks, how do you assess them?
This is done by recognizing all the risks related to a project. After identifying them, security measures are required to put in place. We want to make sure the project managers,
surveyors and supervisory teams are familiar with the various areas of risk embedded in the project.

8. In managing risk, to what extent do you depend on your experience and personal judgment?
   Construction is a risky business. As a major contractor once you identify the risks you need to manage your people who are managing the risk. Experience will exactly be essential for managing risk.

9. Do you use and formal tools or DSS for risk assessment?
   We have a standard assessment form for evaluating projects. We are not that sophisticated in order to need such tools.

10. Can you please let me know why?
    I think it is because of the size. We are a small company. I do not think that construction industry in the UK is so sophisticated. Basically, there is two main concerns which are time and cost. Most construction contractors are concern about them. We always work to manage these two items in such a way that these two major issues are under control.

11. Having mentioned that, do you think that using financial sums to represent the amount of risk a project may hold could be a suitable way for assessing risk?
    I think that it is the easiest management tool to manage the financial aspect of the project. Obviously, you need to analyze each section of the project financially and then identify the related risks and assess them by the financial exposure. You can also identify the risk by calculating the time. You can use programs such as Microsoft Project. You calculate the exposure in terms of time and then you can equate that to cost by seeing the cost of delay according to the contract.

12. What attributes may you consider when comparing different projects?
    We consider the attributes which lead into success. Competition issue is important, i.e. how many competitors are tendering for the project. We also look at the client we are going to do business with. We also look at the consultant we are going to work with.

13. What are the project benefits that can attract you?
    Actually, the project should be cheap for us. Our estimation department should find the project suitable. Also the tendering process is an important issue whether it is one stage or two stages tendering process. With the single stage tender the opportunity to win the contract is much better.

14. How do you assess the intangible benefits?
    The tangible benefits are always the most important. The intangibles are also considered such as a new client, a new market or a new type of project. We set a team to look at how much would be the investment. We need to know how much the income would be in order to win the first opportunity.

15. To what extent do you depend on the experience for evaluating projects? Do you use any DSS to help in this matter?
    Experience is the main mean for evaluating projects. We do not need a DSS as we tend to do things as simple as possible. Again it is a matter of the size of the company. The bigger the company the more sophisticated tools are required and the more risk to be taken on board.

16. What are the main difficulties you used to face when conducting risk assessment or project evaluation?
    Basically, how much information the people were able to gather for you. Along the time, you will receive a call for a chief estimator or a quantity surveyor telling you that they have
a project coming out to tender and they give you very basic information, i.e., new build or refurbishment, geographical location and approximate value and they are unable to give you a technical appraisal. The key problem is the limitation of information.

17. What are the attributes of a DSS which may encourage you to use it?
   It has to be a simple one page system; make it as simple as possible.

18. From you long experience, to what extent you think that what you have told me today could be generalized over similar construction companies in the UK?
   I would say that 99 out of a 100 company operate in the same way.

Thank you very much for your time.
Abdul
1. **Characteristics:**
   I am currently working as a chief estimator responsible for designing and pricing ground works. As part of my responsibilities, I carry out risk assessment for contractual and process stuff and also reviewing the way by which risk assessment is conducted during design.

2. **When you prepare a bid, do you have an agreed-upon set of project objectives? Do you identify the risks related to each objective? Can you specify the most important risks?**
   The assessment is concerned with the ground conditions, the relationship with the client, the type of work involved particularly any up normal risks associated with the site. On that basis an initial grade is given to this inquiry and whether the project is to be considered for tendering in the instance and then the next stage is reached. At this stage the chief estimator and the designer will conduct a detailed risk assessment once all information is available. The final judgment will then be made in terms of: a. what we can do and what we cannot do, b. any up normal risks associated with the works and how are we going to mitigate them and protect ourselves and the others. This will feed into both contractual, i.e. how fast we can do the work on site and financial consideration in terms of how much should we allow for the risk policy and any other protective measures for instance considering any potential injuries.
   “A very structured and detailed gateway approach from identifying risks, assessing them and reviewing them during execution stage”.

3. **But, do you classify the identified risks and assess their impact on different project objectives?**
   During tendering, risk assessment is conducted for different categories of risks, ground conditions, site conditions, contractual and commercial, client etc., using a spreadsheet where grades are associated to each risk item from low to exceptional after identifying the risks which may affect them. Now any item graded with exceptional risk will automatically require further risk assessment. So there are protective measures that any high risk will be picked up in very early stage. Also, there are measures to be taken in order to reduce any high risk. These risks are also tracked and protective measures should always be taken during the execution stage in order to mitigate risk.

4. **Do you consider risk likelihood and impact when you conduct a risk assessment?**
   Yes. The detailed risk assessment will have a risk matrix which provides grades for both impact and likelihood. On this basis we build an assessment of that particular risk. Again, this process will help to decide whether to tender or not. If the risk is high and present then this will prevent us from tendering.

5. **When you do the assessment, do you appreciate that some risks are more important and crucial than the others? How do you deal with the importance issue?**
   I think that weighing in some kind of grading will reflect that. So risk grading will reflect that.
6. From your experience, do you think that risks are different in terms of your ability of controlling and mitigating their impact?
   Yes. There are risks which we used to deal with so we have more control on them than other risks which we do not have experience in dealing with. And, the environment will have impact, if the project environment changes then our ability of controlling risk will change.

7. How do you reflect this controllability when you conduct risk assessment?
   Part of that comes down to the client we are working for. Obviously, different contractors have different abilities in controlling risks. Some contractors are more experienced. They take security measures which can better control risk than a local contractor who is not very experienced.

8. Do you consider project features when you conduct risk assessment?
   Obviously, some projects have better environments than other ones. Hence, we might reduce our risk assessments accordingly. However, this depends on our relationship with the sub-contractors who are working on sites. We usually provide them with some measures to reduce potential risk impacts. According to our control on the site and our responsibilities we can consider a reduction in risk assessment.

9. Do you provide an assessment for a project risk level? How do you provide such assessment?
   Yes, we provide an overall assessment for the project as a whole. Weights will be assigned to the up-normal risks which we think that they will have big impact of the risk grade of the project.

10. Do you deal with the identified risks as individual risks or as a risky environment affecting the project?
    We divide the project work into sub-sectors and smaller chunks to which we assess all the potential risks which may affect them. We usually divide the work into 12 different sectors and we assess risks affecting each of these chunks. Then, these assessments are accomplished to generate an overall assessment to the whole project.

11. Do you appreciate that there are interdependencies between the identified risks?
    How do you reflect this issue when you conduct an assessment to each of them?
    It is a very good point. It is usually difficult to consider the relationships between risks. There is either a direct or indirect relationship between risks. Actually, when providing risk assessment, it is mainly based on the appreciation of the risk analyst and his appreciation to the relationships between different risks and how they are inter-related. It is really depending on the person who is doing the risk assessment and how he sees what may affect his assessment.

12. So, it is very subjective
    Yes, yes. I think that it is very important that the person who is responsible for providing risk assessment should not only be aware of what sort of risk may happen, what are the potential consequences, but how risks can be mitigated and what measures are to be implanted. Sometimes, you identify a particular issue and do something about it to mitigate it as much as you can but you end-up creating problems in other areas of the project.

13. So, you relay a lot on your experience when conducting risk assessment
    Actually, a lot of experience is used to be honest. It is because when you want to take measures you will look at what you have done previously and whether there were problems. Other source of experience comes from the feedback we get from site like how the contract is set up and whether the measures taken in the office are suitable and whether they are achievable in site. For instance, it is easy to sit in the office looking at the drawings and then come up with a risk assessment and a protection measures. But in reality that can be completely unsuitable in site. Hence, you should ask for someone's experience even if a person who is working in site and maybe have a conversation with.
14. How can you judge the accuracy of the experience which is used for providing a risk assessment?
Currently, we certainly encourage feedback from the site and from the supervisors’ level on the ground. They are given extra role during the early stages and the attend meetings for mitigating risks during the tendering stage. Obviously, that may not predict all what will actually be found in the site. Currently, we are encouraging more feedback from the site. We encourage more effective participation from people working in the site so they can say for instance: you have identified A, B and C but you missed D and E. So there will be a continuous feed back in order to consider any unforeseen risks due to the amount of information we have been given during the tendering stage.

15. Do you use DSS for risk assessment? What features you may look for if you want to use?
We use such tool. It is a spreadsheet which is used to provide risk grade.

16. What attributes you may consider when comparing different projects?
Actually, in the early stages we have three stages for evaluating a project: In the first stage, we evaluate who is the client we are going to work for. Obviously we will do a risk assessment to assess the supply chain of required services and how likely we can secure the work with the key client. In the second stage, we look at the work in terms of value, Expected value, and in terms of technique, how difficult is to carry out the required work. Some projects are scored higher because very few companies in the country can do the specified work in them. Finally, risk category such as, but not only, how difficult the site is and how limited the information we have.

A score is given for each of these categories and then an over-all score is produced based on these scores. Based on the over-all score, the higher the better, a decision can be made whether or not to tender for that specific project.

17. How can you assess the intangible benefits and combine their assessment with the tangible ones?
In some respects, the grade which is given to the client in the first instance used to reflect that. We consider the market we used to tender for so we make sure that we keep present and respond to our clients to show them that we are able to deliver all their requirements. Sometimes, we may not be very competitive to win a contract in a market in which we are not present. So, assessing the client contains all these concerns. As a company, sometimes we may go for a project which does not have commercial benefits but we need to keep our connection with the client especially those clients who are difficult to keep a connection with. We also reflect in the client score the case of difficult project which we think that they are difficult from the client point of view to communicate with so we score them high in order to build our reputation.

This all feeds to sort of business development. For us as a company we acknowledge where we are and where we want to be. So, sometimes we speak to the client about what we can do and what we are willing to offer.

18. But do you scale these intangibles or provide some sort of equivalent sums?
Actually, it is difficult to do that. At the end, it depends on the preference of the company board and how the board sees the company working and where it is heading. Personally, I do not think that there is an easy way for assessing these intangibles or scoring them.

19. How do you assess your confidence level when assessing the benefits of a project?
How do you assess the achievability of project benefits?
Actually, it is difficult to provide such assessment. For instance, the actual risk can only be measured at the end of the project by comparing the actual with the planned.
20. Do you think that we can use a common scale, financial terms for instance, for assessing both risk and benefit?
I think that would be a very good idea and nothing else can offer a way for comparing several projects in terms of both risk and benefits. We, actually, are carrying out something like that. Yes, I think that something like that would be very useful.

21. So, do you think that pricing risk and converting intangible benefits into financial terms could be something feasible?
I am actually not sure that this can be done for converting intangible benefits into financial values. I think that using grades and scores could be better and can be consistent with the company's preference as I mentioned earlier. I think that providing such values could sometimes be very expensive so nobody would like to do that.

I think that combining the assessment of intangible benefits with the identified risks will take us to another level of assessment. Usually, the intangible benefits are assessed by the board of directors for strategic consideration which is different from the detailed risk assessment which is conducted on lower level.

22. Do you use DSS for evaluating projects, ranking them and hopefully choosing the best of them?
Actually, the initial scoring system which is conducted manually combined with the detailed risk assessment conducted by the spreadsheet is enough for us and we do not need any further tools.

23. To which extent you depend on the experience for evaluating projects and assessing the benefits?
We actually depend a lot on experience which may be based on evidence coming from previous work with the client or mainly on the experience and knowledge of the individual who is conducting the assessment. Again, the assessment of three areas of concern, the client, the work and the risk, and the scores which are given to each of them will be wholly or partially down to the experience of the assessor.

24. What are the main difficulties you used to face when conducting risk assessment or project evaluation?
The main difficulty is the amount of information given to us in order to conduct a risk assessment. Quite often in the early stages of the project we are given bills and quantities just to price a certain work without any information about the site where the work is going to be or even the ground conditions or how we will be working. At that stage, we can do risk assessment but because of that amount of limited information there is no point to do that. So the major problem is the lack of enough information to make a sensible decision about the risk.

25. What are the attributes of a DSS which may encourage you to use it? What are your concerns about any DSS or tool you have examined?
The main issue internally is the time required to complete the task. At the end we need an effective tool which can conduct assessment for the majority of project within 15 – 20 minutes or so. Obviously, for complicated projects it may take more that that but for generic risk assessment it should be very quick and simple.
Given the wide range of project we are working with in terms of vale and risk, the risk assessment tool could be a simple spreadsheet. The tool should be applicable to all types of projects and usable in every case.

26. From you long experience, to what extent you think that what you have told me about the practice of risk assessment and project evaluation could be generalized over the construction industry in the UK?
I think that certainly the major contractors are in sort of similar level in terms of how assessment is carried out. In terms of risk in site, I would not necessarily say that they are pretty good in controlling these risks in sites based on my experience but certainly the actual process is there.

We work with large number of sub-contractors. I found that the perception of risk does differ and the potential risk in site is much higher when small contractors are in site while it is much less when we are working with big contractors. We are trying to improve that.

Thank you very much for your time.
Abdul
15.6 Appendix (VI) Transcripts of interviews during testing case studies

15.6.1 Application case (A)

<table>
<thead>
<tr>
<th>Participants</th>
<th>Company’s annual turnover</th>
<th>Company’s main projects</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr K (Operations manager)</td>
<td></td>
<td>Residential, refurbishment and council projects. Mainly work with public sector</td>
<td>23/11/2010</td>
</tr>
<tr>
<td>Mrs B (Risk and H&amp;S manager)</td>
<td>£15 million</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Quantity surveyors</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

The tool was presented to four members in the company; the operations manager, the health, safety and risk manager and two quantity surveyors.

What is your general feeling about what you have seen today?

**Mrs B:** I liked the program, understand it. This is because I worked with you from the beginning. We would like to try it in order to see whether it works for us but my initial thought is that it is good.

**Mr K:** As an operation manager, my duty is to take money off the project cost not to add any unnecessary costs or to make the process more complicated in order to keep the business profitable. I think that we need to use this tool maybe 40 times before we can really trust it to add any extra cost to the project. I think that we need time to build confidence in it.

Mr K wanted to say that he is not ready to add costs to the project in order to cover the risks. Instead, his main focus is to reduce the cost. The researcher explained that he does not need to add extra cost to the project. Actually, the DSS calculate risk cost as a measure for comparison reason rather than a contingency sum to be added to the initial project cost. After this clarification he appreciated the proposed methodology for assessing risk. He appreciated the methodology after this clarification.

**QSs** raised the issue of high figures for assessment grades.

The researcher explained that the assessment grades are the same for all risks. Hence, we can play with them and reduce them if the risk level is low. Adapting the assessment grades to suit the case is essential. After trying the tool for many times and appreciating the different types of projects you become comfortable with using suitable assessment grades. According to the size of the project and the type of it you will decide suitable assessment grades and then assign different degrees of belief to suit different situations.

**DSS feedback:**
After illustrating the proposed assessment methodology and after showing how to use the DSS by applying an illustrative example, the interviewee has expressed the following comments regarding the methodology and the DSS:

<table>
<thead>
<tr>
<th>Ease of use</th>
<th><strong>Mrs. B:</strong> I liked the tool. It is easy to use. This is because I had risk assessment training.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity of analysis</td>
<td><strong>QS:</strong> The large number of inputs we have to input before we get the final figure is an issue.</td>
</tr>
</tbody>
</table>

I explained that the level of detail required by the board will affect the number of inputs required. I explained that the belief can be allocated totally to one grade for instance.
<table>
<thead>
<tr>
<th>Methodological clarity</th>
<th>Mrs. B: It is clear I think.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time consumption</td>
<td>Mrs. B: I do not how much time it will take to input all the figures. I think that we have to give it a go and then we can have a better idea.</td>
</tr>
<tr>
<td>Quality and usefulness of the results</td>
<td>Mrs. B: Eventually, the tool will be very useful for us I think.</td>
</tr>
</tbody>
</table>
| Main shortcomings      | Mrs. B: I think that the main difficulty is the figures we have to put in. If we are unable to put the right figure I do not think that the tool will give us the right figure for us.  
I think that it is the issue of getting used to the tool. The more we use it the more people are getting used to it and the more they are accurate the figure they are putting in. Eventually, the tool will be very useful for us I think. |
15.6.2 Application case (B)

<table>
<thead>
<tr>
<th>Participants</th>
<th>Company’s annual turnover</th>
<th>Company’s main projects</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr S (Chief estimator, assistant to the financial director)</td>
<td>£4.3 billion</td>
<td>Residential, refurbishment and council projects. Mainly work with public sector</td>
<td>02/02/2011</td>
</tr>
</tbody>
</table>

What do you think of what you have seen today?
Regarding comparing projects and decision making, I think that the tool can be used when comparing between countries and projects in different countries. For instance, legal risk is definitely a country-specific, health and safety is country-specific, technical and operational risks are country-specific. I think that a tool that can look at these risks will be quite a powerful tool.
When we bid for small projects for instance a 30, 40, or 50 million pounds project, we do not have enough time to conduct a detailed analyse the bid. The major risk is the lack of enough information.
When I was working in the cost planning department, there was what we call it market acceptance of contingency level. The market is prepared to accept a maximum level of contingency sum, for instance 5% of the estimated cost when the lack of enough information would suggest 10 to 15% of the estimated cost as a contingency allowance. However, it is not possible for the client to have such figure in the tender. Hence, we use Monte Carlo to show the gap between the contingency that we can show externally to the client and the potential risk that we have to carry. So the Monte Carlo will show us the probability that the actual risk will be less that the contingency level we agreed with the client.

DSS feedback:
After illustrating the proposed assessment methodology and after showing how to use the DSS by applying an illustrative example, the interviewee has expressed the following comments regarding the methodology and the DSS:

<table>
<thead>
<tr>
<th>Ease of use</th>
<th>I think that it is quite easy to use.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I think that there are 4 major risks under every risk category. Usually, we have so many items and I am wondering whether 4 is enough when we go in details in the project. In total there are 20 major risks which are considered. I think that they are quite enough to be considered in analysing risk when tendering.</td>
</tr>
<tr>
<td>Complexity of analysis</td>
<td>It is detailed but you need such complexity. It is easy to use and gives you different levels of risks.</td>
</tr>
<tr>
<td>Methodological clarity</td>
<td>Yes I think that it is clear. Your explanation was brilliant. I am not sure how the other people will find it but think, for me it was very clear.</td>
</tr>
<tr>
<td>Time consumption</td>
<td>I think that it does not take a lot of time to fill in and use the tool. I think it needs time to think of the risks. I think that it is good because it makes people think of the risks.</td>
</tr>
<tr>
<td>Quality of results</td>
<td>It is good to see the detailed result. However, the detailed result is not enough as you need to average it and come up with final figure to be used in the bid. The tool is good because it gives a detailed level of the results and an averaged final figure.</td>
</tr>
<tr>
<td>Usefulness of results</td>
<td>It is different from what we are currently using. Mainly it is more detailed. We used to weighing exercise and severity * likelihood. We use Monte Carlo but it does not take into consideration the dependency between risks. But we use it because we can not simply add all the risks in the risk register (in their maximum values) assuming that all risks will definitely happen. It is unrealistic to assume that and it will only generate the worst case scenario in its maximum value. I think that the only benefit of risk register is to show the maximum possible risk. Regarding the risk register, it does not consider the benefits. It is considering the risks and it is massive. Because it is massive people who are in charge of using it are simply filling in. It is so big and so frustrating. Its about 200 items to be scored on likelihood, cost impact and program impact. This is pre-mitigation scoring. Another scoring is to be conducted after mitigation.</td>
</tr>
<tr>
<td>Main shortcomings</td>
<td>I think that it would be better if you can include more help information in the tool to give the user more ideas about the methodology. Few sentences will help to explain the process and the methodology, I know that some people would like to know what they are using even if they do not know the mathematics behind. Just to explain why we are doing specific action.</td>
</tr>
<tr>
<td>Suggestions for improvement</td>
<td>Just keep the process as simple and clear as possible and include more help information.</td>
</tr>
</tbody>
</table>

Answers to the queries made by Mr Kth B, the Insurance manager of the company:

1. **How is the dependency figure applied?** Risks may be inter-dependant within a category but may not be inter-dependant with all other risks in that category.

Dependency coefficient is actually playing the role of discounting factor. It will reduce the maximum possible impact due to the consideration of the co-existing risks. The idea is, simply, a set of risk factors will not behave independently; they will create a risky environment where the impact of this environment may be less than the sum of individual impacts of the identified risks. Hence, mitigating one of them may directly or indirectly mitigate the other dependent ones. According to the existing risks within the risk category under analysis, the dependency factor for every single risk is assigned after studying and thinking thoroughly of the other risks in the category in order to choose the right value for it.

2. **Likewise some risks are positively linked i.e. the occurrence of one risk may increase the likelihood of another. It is not clear how these interdependencies are captured in the DSS.**

Definitely, some risks may stimulate the occurrence of other risks or increase the severity of their impact. The analyst is asked to think thoroughly in the risks he/she is going to consider during analysis and then choose suitable likelihoods and assessment grades. Assessment grades are meant to represent the size of the impact. When the impact of one risk is going to be increased by another risk, the analyst should use bigger percentages of project initial cost as assessment grades and then allocate most or maybe all of his belief to the maximum assessment grade when assessing the risk which impact will increase due to the existence of other risk. However, the unaffected risks can be assessed by assigning most or all the belief to the smallest percentage; the minimum assessment grade. Hence, assessment
grades and the amount of belief assigned to each of them when assessing risk impact can be used to control and account for the case where the dependency between risks plays a negative role instead of positive one which is accounted for via the dependency factor.

3. The concept of the degrees of belief is difficult to understand and interpret. Further clarification on this point would be of benefit.

As explained in the guidance and in the DSS, belief degree is a proportional figure between 0 and 1 represents the degrees of expectation or confidence that the impact could equalise the stated assessment grades which are percentages of initial cost. It can be thought of as a probability mass assigned to an event which is the size of impact equals a specific amount. Hence, the total belief, 100%, will be divided between the three assessment grades in order to reflect the probability of occurrence of every possible size of impact, i.e., possible percentage of the project initial cost.

4. Some of the degrees of belief outputs on the summary pages would be more appreciable if they were converted into a monetary form or a percentage range in the same way as the project risk level and the assessment of project intangible benefits.

Actually, they are presented in their shape because they are going to be aggregated further in order to generate the project risk level. So, the project risk level is converted into monetary sum after all the risks have been aggregated.

5. It would be very useful if the results were transferred from a numerically tabulated form into a more visual graphic form.

The newer version of the DSS contains graphs and guiding information which I hope will make it a more user-friendly tool.
15.6.3 Application case (C)

<table>
<thead>
<tr>
<th>Participants</th>
<th>Company’s annual turnover</th>
<th>Company’s main projects</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr D (Chief estimator)</td>
<td>£65 million</td>
<td>Residential, refurbishment and council projects. Mainly work with public sector</td>
<td>16/02/2011</td>
</tr>
</tbody>
</table>

The current practice:
Currently we use a risk register for assessing risk. We have a problem in our approach. It is dealt with as a routine activity to be conducted and prepared in order to be included in the tender. The people who are working on assessing risks usually do not understand the risks and they simply throw figures and values. The problem is that we do not know what the important risks to carefully look at are because we have huge number of risks in the risk register to be considered. The problem in our approach is that it is very isolated in terms of how risk is assessed. It is very difficult to get useful and usable results out of it.

- You are dealing with risk assessment by providing scores (low, medium, high, etc.) How can you relate the risk score to the monetary sum which reflect the risk impact?
  No, we do not have such formula which relates risk level into monetary terms. It depends on the situation and the surrounding environment. The same risk may cost you different amount of money in different situations or projects.

- When you want to compare between different projects, how can you combine the identified risks together?
  We usually average the risk scores and come up with a figure which represents project risk.

- Usually, how many important risks do you consider when tendering?
  Approximately we would look at 20 – 25 important risks.

- Do you come up with a figure to represent the project risk?
  Yes, usually each individual risk will be assigned with a sum of money. All of the sums will be them added together to generate a total sum. We provide an estimate for the risk allowance in its best and worst cases and then we may average them. This figure will be included in the tender. Obviously, this is not as good as the project estimate but it shows that this issue has been looked after and considered in the tender.

- Do you estimate the monetary sum when assessing risk or the cost estimator does it?
  For the technical risk we estimate the required sum to cover the risk and then we would provide such information to the cost estimator. For the technical risk we can conduct a very detailed analysis of how much the risk would cost. For other risk we might not be able to do such analysis and here is where the experience would be crucial to reasonably estimate how much the risk would cost.

- Approximately, how much the sum would be?
  Usually, it would not be more than 10% of the estimated cost.

- What is your concern about the methodology you are adopting now?
  It gives us a very generic rating for a project based on based on so many risks. In terms of comparing projects, it does not take into consideration the independencies between all the factors that may affect the risk estimate. This will escalate risk estimate very quickly so we need to reduce it later.
DSS feedback:
After illustrating the proposed assessment methodology and after showing how to use the DSS by applying an illustrative example, the interviewee has expressed the following comments regarding the methodology and the DSS:

“It is very good. I said that we have an issue with the existing process we have. It takes a lengthy process to analyse major projects (unable to identify the major factors). I think that this tool will be particularly useful especially in big projects.”

<table>
<thead>
<tr>
<th>Ease of use</th>
<th>In general it is easy. However, the percentages which are needed to assess the parameters need to be thought of. You know, there are a lot of percentages to be specified and it is not straightforward to understand the meaning of these percentages and then provide the right figure.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity of analysis</td>
<td>The tool definitely has better hand and it has more detailed type of analysis than the one we have got at the moment. Our approach does not provide such detailed approach of analysis. The results it gives are not only scores. So there is a balance between the complexity of analysis and the required detailed results.</td>
</tr>
<tr>
<td>Methodological clarity</td>
<td>I think it is a clear methodology. Although I am not very familiar with risk calculation methodology but I find it an easy and obvious approach. When you come to the result, if you find a surprising result you can easily get back and see where is it coming from and you can easily check the values that might have caused such results. So it is not that complicated and you can see a clear route.</td>
</tr>
<tr>
<td>Time consumption</td>
<td>I do not think that it is time consuming. I think the time focus will be on analysing the important risks and deciding on the values of the parameters. Group discussion would be needed to agree upon the final values of these parameters.</td>
</tr>
<tr>
<td>Quality of results</td>
<td>I think that the results are quite useful in terms of comparing projects. I quite liked the idea of monetary values as percentages of the initial cost for assessing risk.</td>
</tr>
<tr>
<td>Usability of the DSS</td>
<td>I think it is usable. I am actually interested in seeing what values it can generate and then comparing these values to what we have. I think it definitely worth trying and I am quite happy to use it in real projects and see how it works. I think that it needs to be used for a lot of times until you get the correct values for the probabilities and the other parameters.</td>
</tr>
<tr>
<td>Usefulness of the results</td>
<td>I think that the idea of keeping room for ignorance and then calculating the overall ignorance from here and there is quite useful. In the early stages of the PLC we usually lack enough information so I think that the idea of calculating the ignorance and then using it in defining the boundaries is quite useful.</td>
</tr>
<tr>
<td>Main shortcomings</td>
<td>I think that the only difficulty is justifying the values which are going to be used. I think we should justify commercially what risk to be considered and what values to be assigned to these risks. I think that in order to use this tool, there must be a clear guidance of what values to be used in assessing risks in different situations.</td>
</tr>
</tbody>
</table>
Suggestions for
improvement

Honestly, I found the tool much more detailed than I expected.
I will be interested in seeing how user friendly it will be. I think that it is
not complicated but I do not know whether people find it easy to use
Excel. I think that making things as simple as possible is always useful
for using the tool in real business.

General feed
back

I liked the idea behind it and I am interested in seeing it in real
application.

352


15.6.4 Application case (D)

<table>
<thead>
<tr>
<th>Participants</th>
<th>Company’s annual turnover</th>
<th>Company’s main projects</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr P (Operations Director)</td>
<td>£250 million</td>
<td>Housing, refurbishment and maintenance</td>
<td>05/05/2011</td>
</tr>
<tr>
<td>Mr D (Head of PFI department)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What is your general feeling about what you have seen today?

**P:** I think that it is far too sophisticated for our business. I have not seen such tool before. We are interested mainly in assessing contingencies, payment contingency for instance. For this reason, we always search for how to reduce the process. I think that such approach will add to the tendering process. This needs someone to work on it. It will take around four hours and every hour will cost me 100 pounds. I do not think that we are ready to pay that sum of money.

We usually tender for projects where we are experienced in. We have our clients and we focus on the projects that we know what contingency level may contain. If we face a project where we are not experienced in we will not spend time in analysing it, we will simply walk away from it. We focus on areas where we have build expertise in. We have nine businesses in different areas and we always make decisions which will affect the whole businesses. Hence, we have our criteria when assessing any opportunity that can benefit the whole businesses. If we find that there is an opportunity we will go for it without going through a process. Getting our money from any project is the major criteria we look at as it is the only criteria that keep us in business. Have we got enough recourses is another important issue to look at when we see an opportunity. Having seen how we do business, your approach is very sophisticated way for us. We like to keep things as simple as possible and we always like to bring things to the basics. The more complicated the things are the more resources you need to spend on it.

I think that such tool cannot be used directly in our case. I think it needs somebody to work with us for 12 to 18 month and to focus on our strategic goals and tailor it to suit our own case and make predictions towards the future. It needs to be customised and altered to take into consideration our way of doing business and then after 12 or 18 month we can test the predictions of such tool and to which extent it benefited our business. We are a family owned construction company and we do not have half a man spare and this is how we make money. So I would think of developing such tool in terms of 18 months of extra cost and what benefit can I get from it.

**D:** Before I join this company I used to work in a much bigger company and we used to use such sophisticated tools. I think that such tool would benefit bigger companies where very sophisticated projects are to be tendered for. I remember that we worked as sub-contractor to a company which was responsible for delivering a power plant. I know that very complicated tools have been used to analyse risks before tendering.

DSS feedback:

After illustrating the proposed assessment methodology and after showing how to use the DSS by applying an illustrative example, the interviewee has expressed the following comments regarding the methodology and the DSS:

<table>
<thead>
<tr>
<th>Ease of use</th>
<th><strong>P:</strong> I think that it is quite complicated.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D:</strong></td>
<td>I think that the tool looks straightforward. What you need to do is</td>
</tr>
</tbody>
</table>
really to know what to input. Unless you know from your historical experience what inputs should be used it would be very difficult to be used. I think that unless you record your historical data it will be difficult to update it and use it in this tool for decision making process.

I think that the usage of such historical data is present in the Construction Engineering companies who are more sophisticated than us and they use such tools.

**Methodological clarity**

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</thead>
<tbody>
<tr>
<td><strong>P:</strong></td>
<td>Not for me. I think that it is quite complicated.</td>
</tr>
<tr>
<td><strong>D:</strong></td>
<td>I think it is not complicated. It needs half a day to play with it and familiarize yourself with the tool.</td>
</tr>
<tr>
<td><strong>P:</strong></td>
<td>I quite liked the idea of quantifying the benefits together with the risks. I think that the idea of bringing the two opposites together and assessing them is quite useful, I liked that. I have not seen it before.</td>
</tr>
</tbody>
</table>

**Time consumption**

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<table>
<thead>
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</thead>
<tbody>
<tr>
<td><strong>P:</strong></td>
<td>In general it will take some time to identify the key risks and them thinking of them in order to assess them. I am wondering whether spending this time will bring any benefit.</td>
</tr>
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</table>

**Quality of the results**

<p>| | |</p>
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<tbody>
<tr>
<td><strong>P:</strong></td>
<td>I always struggled with probabilities and I do not know whether anyone would be interested in knowing that this cost would be this with 60% or 50% probability. I think that my answer is personal.</td>
</tr>
<tr>
<td><strong>D:</strong></td>
<td>I think that the results are quite useful. They are similar to the three points' estimation methodology. They are similar to Monte Carlo results where you have results and confidence levels in them. I think that the average is quite useful because at the end of the day we need a figure to be used.</td>
</tr>
<tr>
<td><strong>P:</strong></td>
<td>I feel that these percentages are like guess work, guess to get the right percentages. I do not think that this is what we want. I think that what we want is something that brings us money. The tool might be brilliant but I did not get it so do not take my answer as offensive simply because I am not familiar with probabilities or such kind of tools so I did not get it. Also, I think that the percentages and the figures are personal and subjective. Every one going to use the tool will generate different set of percentages and figures.</td>
</tr>
<tr>
<td><strong>D:</strong></td>
<td>Yeh, but I think that this tool is used when different people sit together and think of the percentages to be assigned. If you remember the power plant project we worked in as a sub-contractor, I think we spent months and months attending meetings and workshops for identifying and assessing potential risks during the design stage.</td>
</tr>
<tr>
<td><strong>P:</strong></td>
<td>I think that such tool can be useful and very applicable when you have strategic projects so you can hold such meetings and workshops. For us, I think that it will cost us a lot of money to use it.</td>
</tr>
</tbody>
</table>

**Main shortcomings**

<p>| | |</p>
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<tbody>
<tr>
<td><strong>P:</strong></td>
<td>I do not think that there are any shortcomings. There is a lot of data there and I think that a lot of effort was spent to produce the tool. The only thing is that it does not fit in our organisation as it is. I think that we need something much simpler.</td>
</tr>
<tr>
<td><strong>D:</strong></td>
<td>I think that we may need such tool in order to record our business and to capture the risks we are facing so we can use the recorded data in future bids.</td>
</tr>
</tbody>
</table>