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Dealing with Uncertainty: Selecting a Risk-Analysis Tool on the Basis of Project Characteristics and Phases

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DEALING WITH UNCERTAINTY:
SELECTING A RISK-ANALYSIS TOOL
ON THE BASIS OF PROJECT CHARACTERISTICS AND PHASES

by

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The final copy of this thesis has been examined by the signatories, and we Find that both the content and the form meet acceptable presentation standards Of scholarly work in the above mentioned discipline.

Abstract

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Dealing With Uncertainty: Selecting a Risk-Analysis Tool on the Basis of Project Characteristics and Phases

Thesis co-directed by Associate Professor Keith Molenaar and Assistant Professor Amy Javernick-Will

Risk and uncertainty are inherent components of projects and it is even truer in the construction industry which faces a higher exposure due to an always changing environment. To deal with this problem researchers and engineers came up with different methods to manage these risk factors in an iterative loop process called risk management. Even though each of the methods has its own intrinsic characteristics leading to both advantages and constraints, there is a void in the literature to select the most appropriate tool to manage risk on a project based upon its characteristics and the phase. From a survey sent out to construction companies, the current investigation establishes some trends on the usefulness of eight of the most used risk-analysis techniques subjected to the four project characteristics having the greatest impact on project performance (complexity, cost, schedule, scope) and the stage of the project development (broken down into five phases). Results are presented in a list format going, method by method, into the strengths, weaknesses, and best implementation situations. A limitation of this research is that this format is not user friendly for decision makers and building a model entering characteristics and phases as inputs and providing the most suitable risk technique as an output would be an interesting track to explore in future research.

Dedication

Je dédis cette thèse à ma famille qui m'a toujours supporté tout au long de mes études et plus généralement dans tout ce que j'ai pu entreprendre depuis l'enfance. Leur soutien et amour me sont précieux. Un grand merci à vous, maman, papa et Damien.

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- All the respondents of the questionnaires who take some of their personal time to help me make progresses in my investigation and without whom this research would not have been possible.

CONTENTS

List of Tables

List of Figures

CHAPTER I

INTRODUCTION

Background

Every time someone undertakes an action, there are uncertainties of outcome. The level of uncertainty depends on the action itself and on external factors related to the action. The construction industry has an inherent level of uncertainty not found in other industries (Dey et al., 2002). The temporary nature of projects, combined with the uniqueness of each project, can lead to uncertainties and risks that can create significant cost and schedule overruns. As a result, researchers and engineers have developed several methods and tools to identify and assess uncertainties on projects in order to manage the greatest risks.

Construction projects face differing levels of complexity, size, schedule, and scope. Despite these differences, decision makers frequently use the same methods and tools across situations: “Most contractors have developed a series of rules of thumb that they apply when dealing with risk. These rules generally rely on the contractor’s experience and judgment. Rarely do contractors quantify uncertainty and systematically assess the risks involved in a project" (Al-Bahar and Crandal, 1990). Following contingency theory (J. Woodward, 1958), it seems that the method chosen would be dependent on the nature of work at hand. Thus, methods would be best applied depending on project characteristics and phases. As Dey et al. (2002) stated: "There are several, or many, tools and techniques, which are applicable to risk analysis […]. The application is dependent on the contents and contexts of projects." However, there is a lack of published research to help guide a decision maker to select the most appropriate method/tool to assess risk for a particular project.

Research Problem Statement and Research Questions

For this research, the specific Problem Statement is *"How do project characteristics and phases influence the selection of risk-analysis methods and tools?"* To investigate this topic and benchmark the investigation, several intermediate questions need to be addressed:

- What are the existing methods and tools that exist to assess and analyze risks? What are their main advantages and disadvantages?
- What is the current state of practice in the construction industry for risk-analysis methods and tools?
- Which project characteristics point to the use of more rigorous risk-management processes?

- How useful specific risk-analysis methods and tools are depending on project characteristics and phases?
- How should decision makers select the most appropriate risk-analysis method or tool based upon the specificities of his/her project?

Research Method

The researched is based on two surveys sent to construction companies implementing formal risk-management techniques. These questionnaires are designed to understand how and why companies use risk-analysis tools. The assessment of the usefulness of the analyzed risk-analysis methods is based on a triangulation of quantitative survey responses, qualitative survey responses, and published literature.

Results

We selected the eight most frequently used risk-analysis methods and the four project characteristics with the most significant impact on project performance from a review of the literature and the result of a survey. Then the usefulness of these methods based upon project phases and the selected project characteristics has been assessed in another questionnaire.

The results analyze the use of risk-analysis tools depending on project characteristics and phases as well as the benefits and limitations of each method. The methods have been reported more useful at the beginning of the project than the end with the exception of the construction phase which justifies the use of formal risk-analysis methods. The project characteristics that would influence the usefulness of a risk-analysis technique include: 1) complexity; 2) cost; 3) schedule, 4) scope.

The analysis draws trends concerning the appropriateness of each risk-identification and analysis method individually.

Conclusions

Literature and responses from industry representatives justify the initial intuition that the usefulness of different risk-analysis methods varies according to project phase and characteristics. The study presents the strengths and limitations of the eight most frequently used risk-identification and analysis tools and the project phases and characteristics that justify use of these methods.

Reader's Guide to the Thesis

Chapter 2 presents the context of the topic introducing risk and its potential consequences especially in the construction industry. The Chapter also emphasizes how managers deal with and manage risks and uncertainties on their projects. Finally Chapter 2 lists the different risk-analysis methods and tools that are found in the literature, describes each method and the threats and the opportunities of using them.

Chapter 3 addresses the methodology of the thesis. The process of the research is detailed based upon the CIFE horseshoe framework.

Chapter 4 explains the data collection and analysis.

Chapters 5 and 6 present the results of the research. Chapter 5 focuses on risk-analysis methods as a whole and Chapter 6 discusses each method. Trends on the effectiveness of the techniques based upon project characteristics and phases are established.

Chapter 7 summarizes the thesis, shows the limitations and barriers, and proposes possible leads for future research.

CHAPTER II

REVIEW OF THE LITERATURE

The construction industry is constantly affected by risk and its consequences: the records show "consistent and excessive overruns ranking 40-500% over the initial budgets" (Yeo, 1990). Sometimes risk leads to only minor ill effects, but it can also lead to project failure. To deal with uncertainties surrounding projects, managers established a loop process composed of several steps (Figure 1). In those steps, risk-analysis methods or tools are used. The literature abounds with description of such methods. Some are very different from others, some similar, but all have intrinsic characteristics that give them uniqueness.

A review of the literature was performed, the results presented in the following pages. The chapter first presents the context of risk in the construction industry before focusing on why and how risk management was developed. Then, the main methods and tools to deal with uncertainty are presented from a literature perspective, incorporating their strengths and weaknesses.

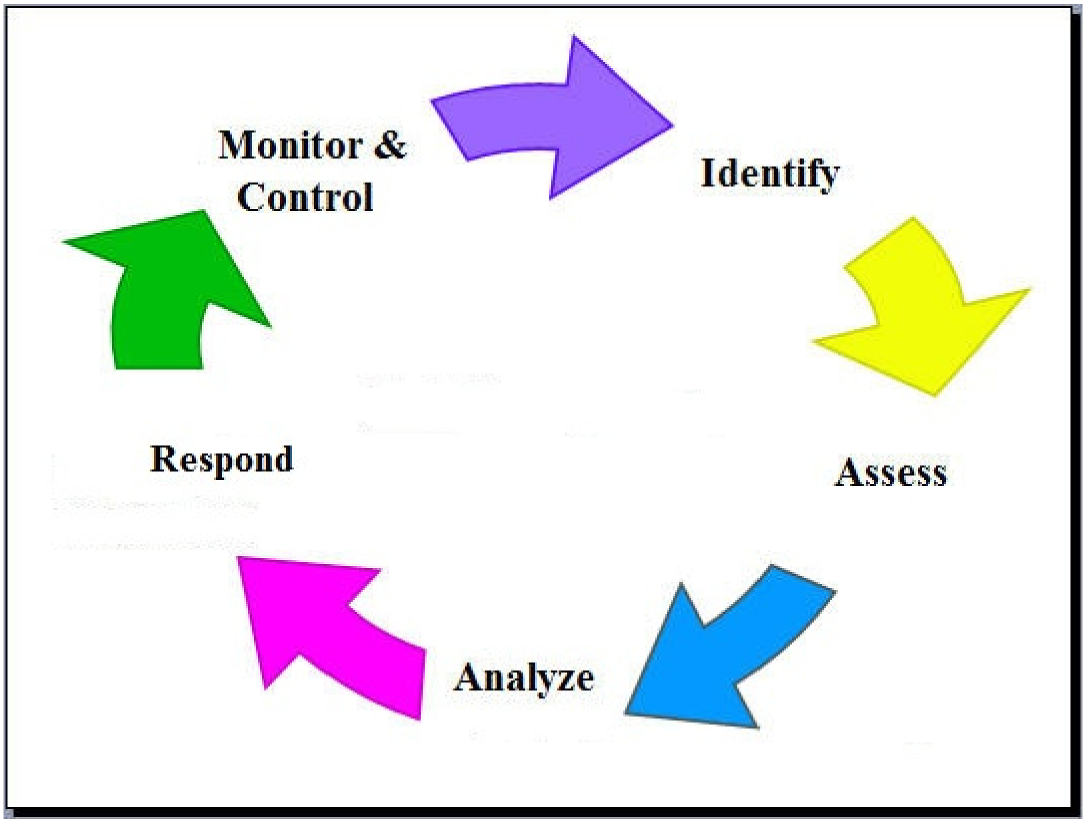


Figure 1 – The risk-management process

Context

Entering the world of uncertainty…

Most, even all, of the actions we undertake in our everyday lives involve uncertainties. If something is uncertain, it is "dependent on chance or unpredictable factors" (Cambridge University Press, 2010). Many external events influence any action and consequently its outcome. Being able to forecast the result of a future action requires precise anticipation of all the events that might be related to the action's progress, the way they will go as well as their consequence to or influence on the action.

Let us take a typical example to illustrate this point. When someone is heading to a meeting in his car, he never knows before leaving at what exact time he will arrive at his destination. Usually, he thinks about the average time he needs to take for his trip and adds some additional time (usually a few minutes) just in case something happens to him on his way (accident, engine trouble, traffic jam...). Even though we are aware that they might occur, such occurrences are totally unpredictable, since we do not know either their probability of occurrence or their impact (in terms of lost time). This example is also relevant concerning the additional time some people are willing to add to the trip to be on time. An unfortunate event can happen and delay the driver, but he has no idea whether the additional minutes will be enough to cover the lost time, and if he will still be able to arrive to his destination on time. The added time that we can also call "security time" may vary depending on the importance of the meeting (plane, interview, dinner…) and how determined the person is to be on-schedule. He is simply mitigating the potential risks he might encounter along his way by adding contingency to his schedule.

…of the construction industry

A favorable environment for risk

Every business has to face risks in order to maximize income; it is the basis of the industrialized economy. However, not all industries are equal in the ways in which they confront risky events and situations. Even in the same industry, two different projects can have variable risk exposures. Among all industries, construction is one of the most affected by risk and some consider that “the construction industry is exposed to more risk and uncertainty than are others” (Dey et al., 2002). The reasons for this higher exposure are well known.

First, by nature, construction activities involve risk: they are temporary, and work stations move quickly (Howell et al., 1988). Many construction techniques involve also the need for highly skilled workers. The greater the difficulty of the work for craftsmen, the greater the uncertainties in their activity (Akintoye and MacLeod 1997; Howell et al., 1988; Okmen and Oztas, 2004). Another obvious reason is that construction is an outside operation, so the work is subject to weather conditions (cold, heat, rain, snow) and the surrounding environment (traffic on a highway or proximity of a university, for instance). On the same note, soil conditions – a key element in a project – are changeable from site to site (Akintoye and MacLeod, 1997; Howell et al., 1988; Okmen and Oztas, 2004). Also, laborers are subject to exposure to serious injuries due to heavy components that are difficult to handle and more generally to all the hazardous conditions inherent in a construction site. Those safety issues are risks than can lead to major cost overruns (Howell et al., 1988).

Construction is one of the few industries in which the owner or client is directly involved in the process. All his possible changes in design during the project's various phases affect both budget and schedule and represent uncertainties (Akintoye and MacLeod, 1997; Howell et al., 1988). Finally, the political and economic environments play important roles in the construction process. Fluctuating prices of materials, inflation, and interest rates are examples of risks in those environments (Okmen and Oztas, 2004).

However, the probable main reason of a higher exposure to risk in the construction industry concerns design uncertainties. Every project is unique in design, and this lack of similarity prevents the creation of routine processes where risks are known and controlled (Okmen and Oztas 2004; Howell et al., 1988). Moreover, the risk level raised by design changes along the construction development process. The potential future design changes are more likely to happen early in design than towards the beginning of the construction works.

Even though all industries have to deal with some risks, the preceding examples show that the construction industry is seriously affected by risks which, if they are not properly addressed, may bring detrimental consequences. Christian and Mulholland (1999) have concluded that "approximately 80% of projects at the beginning of construction possessed a high level of uncertainty".

Examples best show what is at stake

Projects are judged by their ability to meet the budget, the schedule and/or specifications and expectations of quality (Guikema and Pate-Cornell 2002; Dey et al.

1993). Unpredictable events influence those three criteria either positively or negatively by increasing the budget or schedule (negative outcome) or shortening the duration or increasing the savings (positive outcome). However, historically, projects have tended to exceed their budgets and schedules rather than the opposite. The following are relevant examples of such overruns:

The first example concerns the Vancouver Olympic Village. A change in the financing source (different loan with higher interest rates) and other factors such as the omission of expenses from the original budget estimate led to an escalation of costs from $950 million (original budget) to $1.082 billion (real cost) (Gilbert, 2009).

The Hopkins Hospital is another example of a project exceeding budget and schedule. Situated in Baltimore, MD, the Hopkins Hospital is one of the largest health care construction projects. The completion of the construction was delayed by two years and exceeded the original budget by $252 million. A misevaluation of the price escalation is the main cause of the cost overruns: prices of steel and diesel fuel as well as wages increased drastically during the construction timeline. The market was busy, and it took more time for subcontractors to perform the jobs they had been assigned (Schultz, 2007).

The San Francisco-Oakland Bay Bridge main span is the most significant example. $80 million was estimated by the Department of Transportation in 1997 for the construction of a new, cable suspension bridge after the damages caused by the 1989 earthquake on the previous bridge. A bid almost 170 times higher was awarded 9 years later (Pollak, 2004). This high cost escalation was due to the Chinese demand for materials, of which concrete and steel were especially affected. On top of that, the design was uncertain and changed several times before construction began.

The reasons for the overruns are multiple and often unpredictable, though they are related to risk of potential events that could happen with predictable consequences. When non-properly addressed (which was obviously the case in the three examples and especially in the last), the damages can be significant, because so much money is involved. Not meeting the project objectives (in terms of cost, schedule and quality) often leads to project failure (Guikema and Imbeah, 2009).

Risk and Uncertainty

So far we can see that the discussion centers around the two terms, “uncertainty” and “risk”. It seems important to define those two terms at this point. In the literature their definitions are elusive and different from one author to another.

For Al-Bahar and Crandall (1990), uncertainty represents the probability of occurrence of an event so that a certain event has no uncertainty. However others (Okmen and Oztas 2004; International Standard ISO 2009) refer to uncertainty as new situations for which there is a lack of historical data that prevents decision makers from having “information related to, understanding or knowledge of an event, its consequence, or likelihood”. The AACE International’s Risk Management Dictionary (2000) takes a different approach to defining uncertainty as all the events that could happen during a project leading to risks (whether with positive or negative consequences). This definition relates to the definition of risk.

Though the AACE gives multiple definitions of risk, arguing that it can represent all uncertainties, only the downside uncertainty (threats), or the total effect of uncertainty (threats minus opportunities), most authors refer to risk as a probability. For Christian and Mulholland (1999) and Hartono et al. (2003) it is “the probability that an adverse event occurs during a stated period of time”. This definition relates risk only to its negative consequences, while others define risk as an uncertain event (with its probability of occurrence) which can affect the project objectives favorably or adversely (Al-Bahar and Crandall, 1990; Ashley et al. 2006).

All those definitions refer to the same idea, though some are broader than others. For the sake of remaining consistent within the thesis, it is necessary to establish working definitions of those two essential terms. The Project Management Body Of Knowledge (PMBOK, 2000) offers a definition of risk that is widely accepted within the construction industry: “an uncertain event or condition that, if it occurs, has a positive or negative effect on a project’s objectives”. Uncertainty is the same as risk, but the probabilities of occurrence are unknown. Risk is an *unknown known* while uncertainty refers to an *unknown unknown*.

In this thesis, we adopt the following definitions which reach a consensus between the previous. Uncertainty refers to event with an unknown parameter: occurrence, impact, possible outcomes, etc. Risk is an uncertain event which can have a positive or negative effect on the project objectives.

Risk is not Calamity

Dealing with Risk and Uncertainty

Goal

Uncertainties and risks can lead to cost and schedule overruns (as shown earlier in the examples) or even to project failure. Aware of the possible financial losses that can affect a project and a company if risks are not properly addressed, since the early 90s construction managers and researchers have tried to create a way to control uncertainty. The ultimate goal of this is the ability to choose to accept or decline an invitation to tender, but also to manage risky situations in ongoing projects in a structured manner usually called risk management (Okmen and Oztas, 2004).

The 4 Main Responses

After risks are identified, the company can accept, avoid, mitigate, or transfer the risks (Ashley et al., 2006). Acceptance is the simplest method – not changing anything in the construction process; the risk is understood, and, if it happens, the managers are ready to deal with it. Avoidance is the opposite: managers want to remove the risk often because they judge that it could have too serious an impact on the project outcome. Mitigation is in between the first two: managers cannot afford not to do anything (because the impact could be too harmful to the project's objectives) but are willing to accept it up to a given threshold. Mitigation refers essentially to a decrease in the probability of occurrence of a risky event.

Transference “transfers the financial impact of risk by contracting out some aspect of the work” (Ashley et al., 2006). This can be done by sub-contracting an activity and thus transferring the risk to the sub-contractor or by contracting insurance on the specific activity.

Contingency

In implementing one of the four responses the most common method is to allocate a contingency amount, which consists of an amount that will counteract the eventual unforeseen circumstance. For the same risk, the amount will be different depending on the response method selected. The major concern is allocation of the proper amount. Indeed, if too large a contingency fund is allocated in an invitation to tender, the proposal could be economically unattractive. On the other hand, if the contingency is not examined carefully enough, and the allocated amount is too small, the project may fail to face potential risky events and expose itself to overruns. The contingency has to be realistic both to avoid overruns due to potential unaddressed risks and to remain attractive in the bidding.

The most frequently used technique of contingency allocation is called “classes of estimates”. It consists of adding an amount to the financial estimate of a project based upon the phases of the project from feasibility to final cost analysis. Indeed, there are different types of risk depending on the stage of the project (Mak and Picken, 2000). In addition, the impact of an individual risk decreases during the course of the project’s development. As the project progresses, some former uncertainties become “less uncertain” (i.e. their probability of occurrence decreases) or totally certain (it is no longer a risk since the outcome is now known). In consequence, there are more risks at the early stages of a project than towards the end, and the probability of occurrence of those risks is much higher at the beginning. As explained by Yeo (1990), since there are more uncertainties and risks at the beginning of a project, the contingency amount has to be bigger. After activities have been completed and risks are known or unrealized, less contingency is needed to cover potential risks when the final estimate is coming closer. Table 1 shows an example of classes of estimate:

Class	Estimate	Probable error range	Purpose
V	Order of magnitude	± 25 - 40 %	Feasibility analysis
IV	Factor estimate	± 15 - 25 %	Early stage assessment
III	Budget estimate	± 10 - 15 %	Preliminary budget approval
II	Definitive estimate	± 5 - 10 %	Final budget approval
I	Final estimate	± 5%	Final cost data analysis

Table 1 – Example of Classes of Estimate (Yeo, 1990)

Table 1 gives a range of error and not a single value, because some projects bring more uncertainties and risks than others, so the contingency amount depends on the phase but also on the project and its own risk level. The problem is that standard practice is to allocate roughly the same amount for contingency without regards for specific project characteristics; however, different projects involve different exposure to risk. Therefore, projects should have different contingency amounts sized on the basis of the special risks they are confronting:

> The conventional method of contingency allocation is in danger of being overly simplistic and heavily dependent on an estimator's faith in his own experience. There are also times when contingency allocation degenerates into a routine administrative procedure that requires very little investigation and decision making on the part of the estimator. It is not surprising that an estimator would consistently apply a 30% contingency to all preliminary-study estimates and give little consideration to exceptions (Yeo, 1990).

Deterministic vs. Probabilistic

The method of allocating a percentage of the total project cost as a contingency is called a deterministic approach. The main categories of risk analysis modeling are *deterministic* and *probabilistic* (or *stochastic*). In a deterministic model, each variable is represented by a set single value. On the other hand, a stochastic model symbolizes variables by value range or probability distribution. A deterministic approach can be useful because it provides a decision maker quick results like the expected cost of a project with knowledge of potential risks. However, there is very little chance that the actual cost is going to match this figure. To make decisions, managers also need the minimum and maximum costs as well as information on the probability of occurrence, which are deduced with probabilistic tools (Sander and Spiegl, 2009). In consequence of those advantages, "in the last decade, probabilistic methods have been recommended […] as an alternative to deterministic approaches" (Barraza and Bueno, 2007). Deterministic tools and methods used in risk-management processes are not as robust compared to probabilistic ones. Probabilistic approaches involve more time and money to “quantify uncertainty and systematically assess the risks involved in a project” (Al-Bahar and Crandall, 1990) as well as their consequences. In deterministic models, it is assumed that the duration (for a schedule estimate) and the cost (for a budget estimate) are known with certainty, since each is represented by a single value only. However, as stated earlier, construction sites are not routine, and ranges of cost and duration as well as their probabilities are needed (Hartono et al., 2003). Back, et al., (2001) concluded that “without a probability based estimating and scheduling technique, it is not possible to determine the project cost and schedule with a sufficient degree of reliability and certainty to confidently minimize risk”.

The Risk-Management Process

Different methods of risk analysis fit into one of the two categories (deterministic or probabilistic). Before enumerating those methods, it may be useful to describe the risk-management process, which is made up of several steps in which the methods are used. Indeed, we will see that a risk-analysis tool might be useful for only one or two of the different steps.

The Project Management Institute (PMI) defines risk management as “the art and science of identifying, assessing and responding to project risk throughout the life of the project and in the best interests of its objectives” (Wideman, 1992). The process is cyclic and continuous. The whole process is always the same; nevertheless, the different steps have different names depending on the people or organizations which refer to them.

The Project Management Institute (PMI) and the Californian Department of Transportation (Caltrans) describe the risk-management process with roughly the same four steps (Wideman 1992; California Department of Transportation 2007).

The first step is *risk identification,* in which all risks that might directly or indirectly affect the project objectives (time, cost, and quality) are identified. It is important that the produced list be exhaustive and that no risk be forgotten, even those which might seem to have negligible consequences. However, it is also essential that the list not be redundant: if one risky event appears in two formalized risks in the list, it will be counted twice and thus introduce an error into the process. To avoid such redundancy, risks are usually classified by categories or groups of like risk. Finally in this first identification step, risks have to be documented as much as possible so the best decisions can be made in the next step.

The next step is called *risk assessment* by PMI and *risk analysis* by Caltrans, but it actually involves a risk assessment of identified risks followed by their analysis.

This assessment quantifies the risks previously listed in two ways. First, it assesses the likelihood of each risk, which is the possibility of that risk occurring. It corresponds to risk frequency. Second, it assesses the impact that those risks can have on the project. It corresponds to consequence severity. There are several ways to present those two characteristics (frequency and severity) for each risk. One is qualitative, so that frequency and severity are described with adjectives (e.g., "low" and "high"). Another is quantitative, a numerical description (e.g., probabilities for frequency, dollar amount for loss/gain for severity if the risk occurs). Those numbers can be single values (e.g., a given probability for losing/saving a given dollar amount) or ranges showed as distributions (a relationship between frequency and impact). Even though there is no rule, current practice is to use a quantitative approach (deterministic) for small projects with little uncertainty and a qualitative approach (stochastic) for larger projects with a lot of uncertainty.

As stated earlier, quantitative assessment is the recommended option for providing the best estimate regarding the project's objectives. It mostly involves statistical techniques and specialized software. With the probability distributions obtained at the assessment phase, the method iterates an important number of simulations and draws the results which also appear in a distribution format.

The following step, the "risk response", involves establishing a strategy "to enhance opportunities and reduce threats to the project's objectives" (California Department of Transportation). The main possible actions are *acceptance*, *avoidance*, *mitigation*, and *transference,* which were described previously.

The last step consists of tracking the identified and treated risks as well as identifying any new risk that might arise. It is called "*risk monitoring and control*" by Caltrans and "*risk documentation*" by PMI.

The International Organization of Standardization (ISO) describes the same risk-management process, but the steps are divided up differently (International Standard ISO, 2009). The first step (identification) is exactly the same. The second step, "*risk analysis*" (according to Caltrans terminologies) includes both assessment and analysis steps. The "risk response" described above is here divided into two stages: "*risk* *evaluation*" followed by "*risk treatment*". The evaluation compares the level of risk obtained through the analysis to the acceptable level established by the managers. The treatment is the actual response and decisions on the basis of this evaluation. The last step is the same as in PMI and Caltrans and is named "*risk monitoring and review*". The particularity of the ISO breakdown is that it calls "*assessment*" the set of identification, analysis, and evaluation.

<table>
<tr><th>PMI</th><th>Caltrans</th><th colspan="2">ISO</th><th>Thesis' choice</th></tr>
<tr><td>Identification</td><td>Identification</td><td rowspan="4">Assessment</td><td>Identification</td><td>Identification</td></tr>
<tr><td rowspan="2">Assessment</td><td rowspan="2">Analysis</td><td rowspan="2">Analysis</td><td>Assessment</td></tr>
<tr><td>Analysis</td></tr>
<tr><td rowspan="2">Response</td><td rowspan="2">Response</td><td>Evaluation</td><td rowspan="2">Response</td></tr>
<tr><td colspan="2">Treatment</td></tr>
<tr><td>Documentation</td><td>Monitoring and Control</td><td colspan="2">Monitoring and review</td><td>Monitoring and Control</td></tr>
</table>

Table 2 – Comparison of Risk-Management Processes from different organizations

Even though the risk-management process described by the three organizations seems different for all, it is actually the same with different names given to the different steps. For the sake of consistency throughout the report, the following is the process breakdown chosen for this thesis: identification, assessment, analysis, response, monitoring and control. Table 2 shows the relationship between all the three breakdowns presented above with the addition of the one used in the thesis.

The process described is iterative. As risks evolve, their probability or impact will likely change, and new risks can appear. As a result, risk management is a continual loop (Figure 1) in which the monitoring step is followed immediately by the identification step.

Among the five steps described above (identification, assessment, analysis, response, monitoring and control), risk-analysis methods and tools are mainly used in the first three (identification, assessment, analysis). Those methods are presented below.

Methods and Tools

A definition

Managing risk and uncertainty involves the use of tools and methods. The literature explains many of these but is rather vague concerning the definitions of and differences between the two terms. They both obviously refer to techniques that help decision makers in their risk-analysis process. When a technique is composed of several sub-techniques, some authors call the global technique the "*method*" and the sub-techniques "*tools*" (Yeo, 1990; Al-Bahar and Crandall, 1990; Dey et al., 1993; Sander and Spiegl, 2009): the general method uses different tools. However, some authors (Guikema and Imbeah, 2009; Hartono et al., 2003) do exactly the opposite, labeling as "*tool*" the most comprehensive technique and as "*methods*" the lesser ones. In addition, when the principal technique does not involve sub-techniques, it is called interchangeably "*method*" and "*tool*". With this broad usage in the literature, a clear relationship between the two terms is not at all evident. Taking this into account, this thesis will use both terms equally, and they will refer to the same concept: a technique that helps in the process of analyzing and taking care of risks.

Methods in the Risk-Management Process

Among the five steps of the risk-management process described above, only the three first use risk-analysis methods and tools:

- *Identification* of all the possible risks, their classification and documentation.
- *Assessment*, in which risks are qualified and/or quantified in terms of their frequency and severity.
- *Analysis*, in which simulations are run and different outcomes explicated with their probability of occurrence.
- *Decision techniques*, which are a not steps in the risk-management process but can be applied in all professional disciplines and used in the three previous steps. They are tools which help make decisions.

The different methods and tools found in the literature review are set forth in Table 3 and classified by category.

Identification	Assessment	Analysis
Interviews	Knowledge	Bayesian Theory / EV
Historical Databases	Expert Elicitation	Monte Carlo Simulations
Past Expericence	Judgment	Fuzzy logic / Fuzzy set
Checklists	Subjective Probability	Sensitivity Analysis & Diagrams
Crawford Slip	Membership Functions	
SWOT Analysis		Risk Matrices
Red Flag Items		4 Moments / Pearson Distrib.
Nominal Group Technique		Utility Theory
Risk Breakdown Structure		Scenario Analysis

Table 3 – Methods and tools [found in the literature] classified by step of the risk-management process

In detail

Identification techniques

Risks may differ greatly from project to project, and most are specific to one project. Therefore, it is not possible to standardize the identification of the risks encountered. The identification step relies mostly on the knowledge and experience of individuals. The identified identification techniques underlined in Table 3 will each be discussed below.

Interviews and Surveys

Experts are knowledgeable in particular fields and thus able to provide pertinent judgment. They can discover and identify new risks that the management team has not thought about. They also can document and explain them in depth. They may offer insightful opinions that contrast the managers first thoughts. For interviews to be worthwhile, experts have to be interviewed when the project scope is well known so that the risks have already been defined (Anderson et al., 2010).

Surveys consist of gathering information in the field – laborers, managers, sub-contractors and owners have an inside view of the uncertainties and risks that affect a project.

Those two methods help to diversify the viewpoints for risk identification input. However, it takes a lot of time to interview a large number of people.

Past Experience and Historical Databases

Historical databases and past experience record risks previously identified in past projects. Experience is gathered by people who become experts (knowledgeable in particular fields), while historical databases are the written record. In those records, risks should be documented so that similar situations can be easily found (Anderson et al., 2010).

Past experience and historical databases help risk managers refer to similar situations that happened in past projects. According to Li and Shi (2008), the historical databases depend very much on statistics, so are not a guarantee of useful information. An example of such a database is the HyperCard system created by

Christian and Mulholland (1999), which presents the most well-known schedule risks in a format that can easily be updated.

Checklists

A checklist is a formalized combination of historical databases and past experience. It is a list of risks classified by categories that were realized and/or identified in past projects (Anderson et al., 2010). When risk managers are not experts on the kind of project they are working on, checklists help them avoid overlooking important and common risks. However, potential risks are not limited to any given list. Very specialized risks (that can also be related to important consequences) could “slip through the net” of such checklists (Al-Bahar and Crandall, 1990). Therefore, checklists should not be used at first, but as a means of verifying whether any common, important risk was overlooked (Anderson, et al., 2010).

Checklist is the most common method used to identify risks (Simister, 1994), especially when there is no relationship between risk factors (Dey et al., 2002). Organizations have their own checklists, such as Caltrans, which breaks down risk into eight categories: Technical, External, Environmental, Organizational, Project Management, Right-of-Way, Construction, and Regulatory (California Department of Transportation, 2007).

Crawford Slip Method

The Crawford Slip Method is a fast and simple way to identify risks. It involves a brainstorming session where participants write down ten risks in ten minutes (one risk per minute). The risks of all participants are put together into a list and the duplicates eliminated. This method is totally unbiased, because no one is influenced by the general thoughts of the group. Each participant's risk selection is totally independent from those of others.

This method is used mainly at the beginning of risk identification to generate a first set of risk that will be analyzed in greater depth later.

Crawford Slip generates a list of many potential risks. However, it may overlook some, especially if the project is specific to a field in which the people participating in the identification are not expert (Anderson et al., 2010).

SWOT Analysis

SWOT stands for Strengths, Weaknesses, Opportunities, and Threats. This method consists of identifying and listing the strengths, weaknesses, opportunities and threats related to the project. Then, those four categories are used to identify risks (whether positive or negative in impact). SWOT Analysis helps identifying risks that would not be overlooked in a traditional brainstorming, but it cannot be considered as a way to obtain an exhaustive list of risks (Anderson et al., 2010).

Red Flag Items

Red Flag Items is a method that focuses on the critical risks of a project, those with the most severe potential impact. It keeps track of these major risks throughout the project, so that they are always considered and not forgotten at any phase (unless they are no longer dangerous).

The list of red-flag items can be created as early as possible in the project and will be useful during the entire life of the project from first studies to construction. Therefore it has to be updated by the addition of any new severe risk when it arises and removal of any that are no longer significant.

Red-flag items must be known by all people involved in the project who must feel concerned about them, pay attention to them and propose some updates to the list.

In this method, only the most severe risks are underlined. However, a risk is judged by both its impact and its probability. Risks with a low impact (not a red flag item) and a high probability may have more serious consequences than a risk with a high potential impact but a low probability of occurrence (Anderson et al., 2010).

Nominal Group Technique

NGT is a method of identifying risks which generates large numbers of them. It allows the creation of unexpected and extraordinary ideas.

A facilitator introduces and leads the workshop. Each participant is given three cards and ten minutes to write one potential risk per card. Then all risks generated are collected and exposed to all participants on a flip chart. On five new cards participants rank the five most important risks from the previously established list, adding new risks that emerge from reading other participants' risks. The most important risks are then determined according to the number of "votes" they receive and their ranking.

This method generates many potential risks, encourages creative ideas, and involves the participation of everyone. On the other hand, NGT has drawbacks; the main concern being the lack of interactions amongst team members (Navarro, 2009).

Risk Breakdown Structure (RBS)

Risk Breakdown Structure is a risk-identification method used to describe and explain the interrelationships between risks on a project (Anderson et al., 2010). Risks are classified by sets based on their similarities (Iranmanesh et al., 2007). Hillson (2002) defines RBS as "a source-oriented grouping of the project risks that organizes and defines the total risk exposure of the project".

The main issue with "classical" risk-identification techniques is that they usually come up with a simple list of risks without helping managers on focusing on areas with a high concentration of risks. Risks are considered one at a time and never as a whole which prevents taking into account any risk exposure patterns. RBS is different from other risk-identification tools since it addresses these concerns (Hillson, 2002).

As shown in the example of Figure 2, a risk breakdown structure establishes the relationships between project risk factors. The structure provided is always hierarchical which enables a categorization by groups of the risks as well as a representation of the overall project risk level (Holzmann and Spiegler, 2010; Iranmanesh et al., 2007). In this structure, the risk categories are "exhaustive and mutually exclusive" which means each possible can fit in a category but in one and only one.

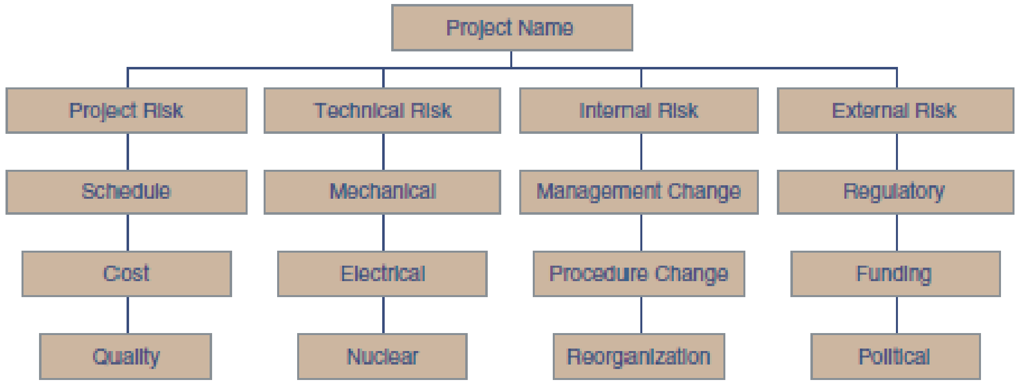


Figure 2 – Example of a risk breakdown structure from the DOE

Anderson et al. established that this tool is more appropriate to use on projects with a developed scope since more information is needed to build the hierarchical structure than other classical risk-identification tools. When risks are categorized, related risks receive a similar management strategy.

If there are several possible categorization options, managers should be driven by "risk cause rather than risk effect" (Anderson et al., 2010). It is also strongly advised that the RBS is standardized into a common framework that can be used for all projects (at least similar projects) within the company so that lessons learned and historical databases make a good combination to this method (Iranmanesh et al., 2007).

The major strength of RBS is its ability to comprehensively display the risk structure in a way that can be constantly updated by all stakeholders. This visual model also enables a view of the overall risk exposure and the areas with a high risk concentration which, therefore, should require specific concerns by management teams (Holzmann and Spiegler, 2010).

Table 4 summarizes the tools used for risk identification.

Method	Input	Output	Opportunities	Constraints
Interviews and Surveys	Experts, people	List of Risks related to the project	Unbiased judgment, diversified viewpoints	Length of time to complete
Past Experience and Historical Databases	List of Risks that occurred on past projects		Can be updated	Relies on statistics
Checklists			Important common risk are identified	Overlooks specific risks
Crawford Slip Method	Brainstorming		Quick, generates a lot of risks, unbiased	Overlooks some risks
SWOT Analysis	SWOT List		Identifies uncommon risks	Miss a lot of risks
Red Flag Items	Brainstorming		Keeps track of severe risks	Only severe risks are identified
Nominal Group Technique	Multiple individual thoughts		Generates a lot of risks, encourages participation and creative ideas	No interactions
Risk Breakdown Structure	Brainstorming	Hierarchical grouping of risks	Comprehensively displays the risk structure	Need of developed scope

Table 4 – Risk-identification tools

Assessment techniques

In this section, the assessment techniques identified in the literature and listed in Table 3 are presented and described.

Knowledge, Judgment, Expert Elicitation, Subjective Probability

The assessment step is usually done at the same time as identification because the same tools are generally used. When people are asked to identify risks (through interviews or surveys), they first point out risks but also their likelihood and potential impacts.

Subjective probability is assigned by an individual based on his/her judgment about the likelihood that an event will occur. It involves no calculation, but relies on the opinion, experience, and intuition of the person asked. In consequence, it may vary depending on the person answering – there is a high degree of bias (Akintoye and MacLeod, 1997).

It can be a very precise assessment or a fuzzier one. Indeed, it can be described with fuzzy adjectives (like "low probability" and "high impact") or with extremely precise terms (like "normal distribution of the risk with a mean impact of $X and a standard deviation of $Y").

Personal experience and historical data can also be used to assess frequency and severity. Even though projects are always different from one another, similarities towards risk exposure may be found that can help experts and decision makers to determine the assessment variables (Dillon et al, 2003).

Membership functions

A membership function is a curve that translates a fuzzy assessment (typically with adjectives like “low”, “weak”) into a score number (e.g., from 1 to 10) useable for analysis. Because it is difficult and can be inaccurate when translatating an adjective into a number, membership functions introduce the concept of membership degree. It represents “the degree of truth” of the conversion; therefore it is a number that ranges from 0 to 1. Current practice is to use triangular shapes (Dikmen et al, 2006) as shown in Figure 3. In that example a medium assessment would have a score of 5 with a degree of membership equal to 1, a 4 and a 6 with a degree of membership of 0.5, and all other subjective scores with a membership degree of 0.

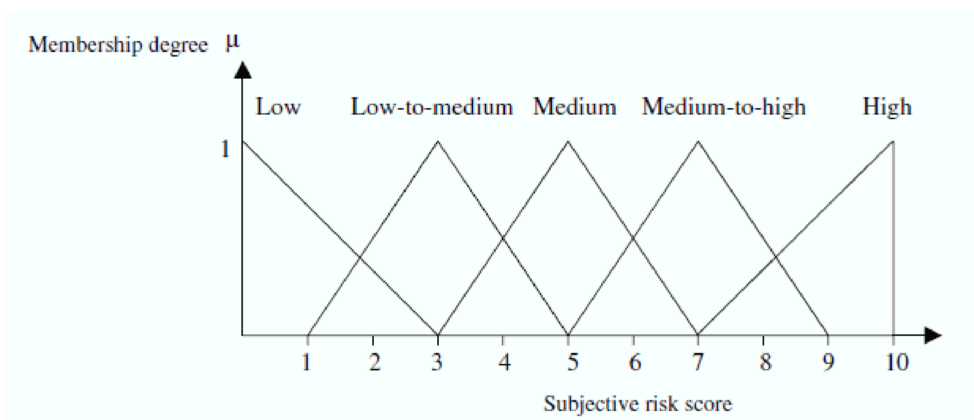


Figure 3 – Example of membership function for subjective risk score (Dikmen et al., 2006)

Membership functions are used mainly in fuzzy-set theory described in a later section, defining the value of a fuzzy variable.

Table 5 summarizes the tools used for risk assessment.

Method	Input	Output	Opportunities	Constraints
Knowledge, Judgment, Expert Elicitation, Subjective Probability	Personal opinion and intuition	Assigned probability and impact (adjective, number, distribution)	Diversity of information, Experts in a particular field	Bias
Membership function	Risk Matrices	Curve linking linguistic assessment terms to risk scores	Provides fuzzy assessment	Precision is not optimal

Table 5 – Risk Assessment Tools

Analysis techniques

Once risk risks have been identified and assessed (probability and impact), an analysis can be conducted to see the overall risk level of the project as well as determining which risk factors are to be more closely monitored. The analysis techniques identified in the literature and listed in Table 3 are presented below.

Bayesian Theory, EV

Bayesian Theory is the most basic probability format. It is the most commonly used and widely accepted interpretation format of probabilities. Bayesian Theory is based on hypotheses of outcome and their probability of occurrence. In cost and schedule estimations, Bayesian Theory is used in association with the Expected Value (EV). The EV is the probable weighted sum of all possible inputs. In other words, it represents the center of the distribution of a variable (probability of outcome). However, the expected value is different from the most likely value, which represents the value with the highest likelihood of occurrence. The EV represents the point at which 50% of the calculated outcomes fall before and 50% after the EV.

The EV is often used because it is an objective method – no subjective decision is required; it is about calculations. Furthermore, it is the best single-point estimate, since it is an unbiased representation with half of the possible outcomes lower and half higher. For Schuyler (2001), "EV is the only unbiased single-point forecast". The EV matches well with the Bayesian Theory calculation rules especially for addition and multiplication, the two essential rules used in Bayesian calculations. Given a chain of following risks that might affect the project objectives (schedule, budget), Bayesian probabilities and the expected value are used to calculate the total expected outcome of the project in terms of schedule and/or cost.

Very often, Bayesian rules and expected value are used with decision trees. The latter, which will be described in the decision tools section, is helpful for representing the risks and calculating the expected value. The following example (Figure 4) illustrates this. There are two risks here: one is in the cost of metal materials and the other is that of concrete. The outcomes represent the six possible solutions. The expected final cost is $9.1M. In this decision tree, the first risk is the price of metal and is used to assess concrete cost. However, Bayesian rules allow reversal of the tree so that concrete cost becomes the first uncertainty and metal cost probabilities can be calculated based on the assumption about concrete cost.

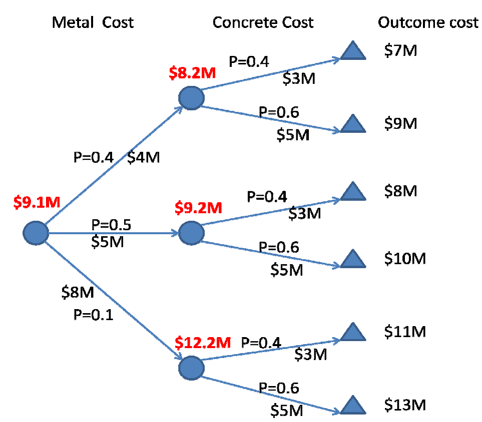


Figure 4 – Example of EV and Bayesian Theory use

EV is a basic concept with quick calculations. It is also the best single-point estimate. However, the major constraint is that it produces a single value estimate and, as a result, misses the range of possibilities for the decision maker to make a reliable decision (Schuyler, 2001).

Monte Carlo Simulation

Monte Carlo Analysis is a stochastic computerized method. It provides estimate *ranges* for cost and schedule. It is a simulation technique based on generated random numbers falling into probability distribution intervals. The process is iterative, and a large number of simulations are run (typically several thousand) to produce a distribution of outcomes (Anderson et al., 2010).

Most methods of analysis provide pessimistic, optimistic and/or most likely outcome values. Monte Carlo calculates the cumulative effect of all possible outcomes and aggregates them. Single-point estimates are replaced by distributions. All this gives the decision maker more information on the overall risk level, a richer and more detailed representation (Willmer 1991; Diekmann et al. 1997).

The process is simple – for each variable affected by risk, an input distribution is assigned. The most common are Normal, Triangular, LogNormal, and Uniform, but it also can be a discrete or custom-made distribution. MCS generates a value (which has to respect the probability distribution in terms of occurrence) for each uncertain variable with which a deterministic analysis is run. The process is repeated a large number of times (decided in advance), and the results are combined in a distribution format or cumulative format as shown in Figures 5 and 6. Those graphs make it possible to find levels of confidence for determining proper contingency amounts. Monte Carlo simulations also provide all statistical parameters as mean, standard deviation, most likely value, percentile, etc.

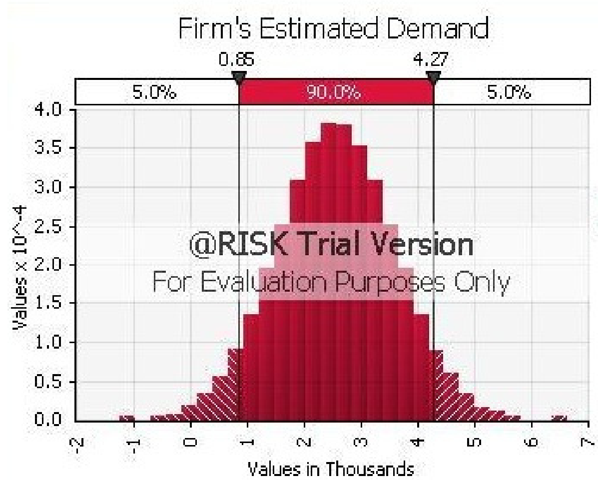


Figure 5 – Monte Carlo output distribution

Figures 5 and 6 show that there is a 95% chance that the firm's estimate demand will be below $4,270.

Figure 6 – Monte Carlo output distribution: cumulative curve

Monte Carlo is undoubtedly the stochastic tool most widely used for risk analysis. For Dawood (1998), among all analysis techniques, MCS is one of the most conservative.

As any techniques, Monte Carlo Simulations present both advantages and drawbacks. The major weakness has to do with the need for knowledge: the procedure cannot be started before all probability distributions are determined precisely (Akintoye and MacLeod, 1997). Another problem of this method is that it can be computationally time-consuming with a lot of time needed to run a large enough number of simulations. Also, it is an approximate solution since the numbers generated are random, so the solution is never exactly the same. Finally, when the probabilities are low, MCS gives poor simulation results (Schuyler, 2001).

On the other hand, MCS offers important advantages. The process is generally applicable to a wide variety of situations and accommodates complexity easily (Schuyler, 2001). It also allows variables to be correlated with one another and takes them into account in analysis in which correlation coefficients can be added (Diekmann et al., 1997).

Sensitivity analysis, another analysis technique discussed later in this presentation, can also be done with Monte Carlo Simulations.

Fuzzy logic/ Fuzzy set

It is not always possible to assess the probability or the influence/impact of a risk in numerical terms. In some cases, experts cannot be more precise when they use the adjectives “bad”, “poor”, “weak”, “excellent”, etc., because their judgment remains uncertain. The fuzzy-set theory translates linguistic descriptions into mathematical terms and functions, thus making possible the performance of sophisticated decision analysis based on those natural and “fuzzy” terms possible (Kangari and Riggs, 1989).

Fuzzy logic uses membership functions described earlier, which represent the degree to which an element belongs to a set – it is associated with a weight (Lee et al., 1993). The risks are first identified, and then assessed with fuzzy terms, which are finally translated into mathematical numbers through those membership functions. The variables (which contain risks expressed with fuzzy terms) can be added, multiplied and divided in the analysis of the desired outcome or the total risk, which is then translated back into fuzzy terms (Kangari and Riggs, 1989). The wider the range of fuzzy terms used to describe a single variable, the more precise the fuzzy assessment (Diekmann, 1992).

Fuzzy-set theory does not aim at a higher degree of precision than probabilistic theories. However, it is a very effective method when probabilistic databases are not available, because too many uncertainties still surround the risk, and the assessment has to stay fuzzy to be realistic (Lee et al., 1993).

For example, let us take an estimated formula cost of $C = \sum Q_i * \left(M_i + (W_i * L_i)\right)$ where Q_i is the quantity, M_i the material unit price, W_i the labor cost per hour, and L_i the labor unit work hours. Let us pretend that each of those variables is assessed with fuzzy terms. Then, they are associated with a membership function that will assess the degree of membership of the variable on a 1-10 scale. The variables are then multiplied and added together following the rules of the equation above. After the calculations, a membership function can be drawn for C, the estimated cost. The distance from this function to the normalized functions, which translate the fuzzy terms is calculated in order to make comparisons. The overall risk is fuzzy-expressed: it corresponds to the term associated with the closest normalized membership function to the cost membership function (Kangari and Riggs, 1989).

Sensitivity Analysis and Diagrams

Sensitivity analysis shows the effect of change of a single variable on the project outcomes. It is a non-probabilistic (i.e., deterministic) technique. The consequence of risks and uncertainties is a variation (positive or negative) on one or several items of the project estimate (budget, schedule, or other). Sensitivity analysis will analyze the possible cost or time consequences led by changes in the project variables affected by risks and uncertainties (Hayes and Perry, 1985).

A percentage range is defined for each risk variable. Sensitivity analysis assesses the effect of change of one variable at a time (each variable analyzed individually) on the final cost or time through the risk range (Willmer, 1991).

Humans have a natural tendency to be over optimistic in their estimates. Thus, it is essential for the success of the method that the assessment of the risk and the risk's consequence ranges to be realistic (Hayes and Perry, 1985).

When the analysis is performed on multiple variables, a useful tool for presenting the results and suggesting the most sensitive variable is a sensitivity diagram. The most common form of sensitivity diagrams is the spider diagram. Figure 7 shows an example of such a diagram for an offshore oil project.

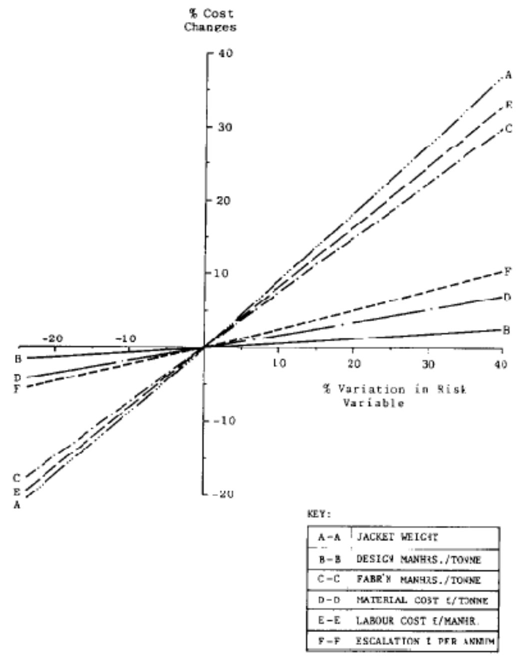


Figure 7 – Sensitivity analysis of an offshore oil project (Yeo, 1991)

The spider diagram in Figure 7 shows the effect of a variation of each of the 6 (from A-A to F-F) risk variables on the project cost. However, sensitivity diagrams also exist for other project performance indicators such as time. In some diagrams, there are probability contours, which link the different variables for a given probability of occurrence. For example a 90% probability contour means that 90% of the possible outcomes are estimated to fall inside the contour. It allows decision makers to judge the importance of a risk. Indeed, some risks can be very sensitive with a very low probability, while others are very likely to happen but with a low sensitivity on the diagram (Yeo, 1991).

Another format of sensitivity analysis is the Tornado diagram obtained through Monte Carlo Simulations, as shown in Figure 8. Tornado diagrams rank the variables with the greatest effect (positive or negative) on the project performance (cost or schedule).

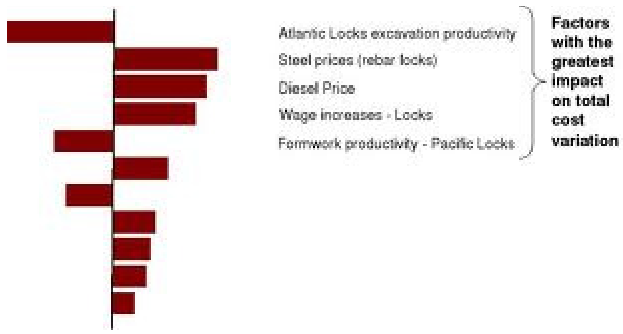


Figure 8 – Tornado Diagram from Monte Carlo Simulation

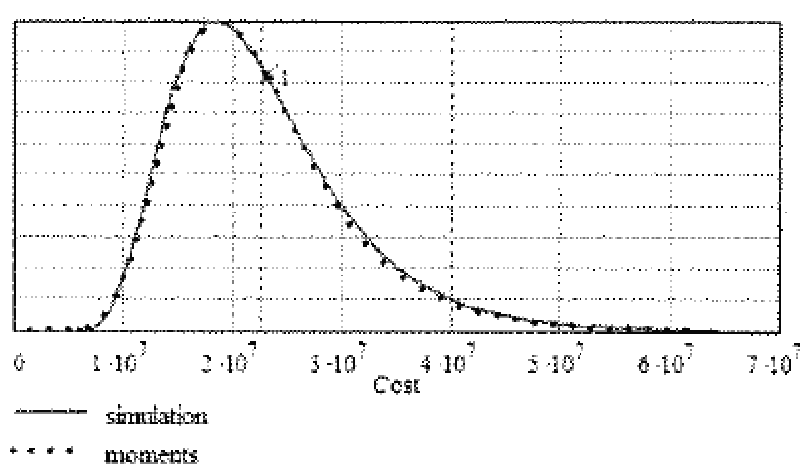
In current practice, sensitivity analysis is used and widely accepted for large-scale projects (Yeo, 1991).

This method offers two main opportunities: 1) it immediately shows the relative importance of a variable compared with others; 2) the way in which different projects resist uncertainties can be compared. On the other hand, there are some drawbacks: 1) variables are treated individually whereas is it likely they influence one another: a change in a variable may involve changes in others; 2) probability contours add a sense of probability in the analysis, but it cannot present the probability distribution of the outcome for each risk (Yeo, 1991).

4 Moments, Pearson Distribution

The four-moments method is a computational method that uses the four central moments (mean, variance, skewness, and kurtosis) to approach risk analysis. The method has been advocated in the past for risk analysis since its results are very close to those of Monte Carlo simulation.

The method assumes that the probabilistic characteristics of the project function (which aims at calculating the time or the cost of the project) variables are known. The four moments are calculated through a multivariate Taylor series. The distribution form is chosen among the Pearson distribution family, which covers a wide range of shapes to fit within a given probability distribution: Normal, LogNormal, Beta, Gamma, Exponential or Uniform. A computation of the project function is performed and releases a distribution result as presented in Figure 9. Those results are very close to a Monte Carlo Simulation of 100,000 iterations.



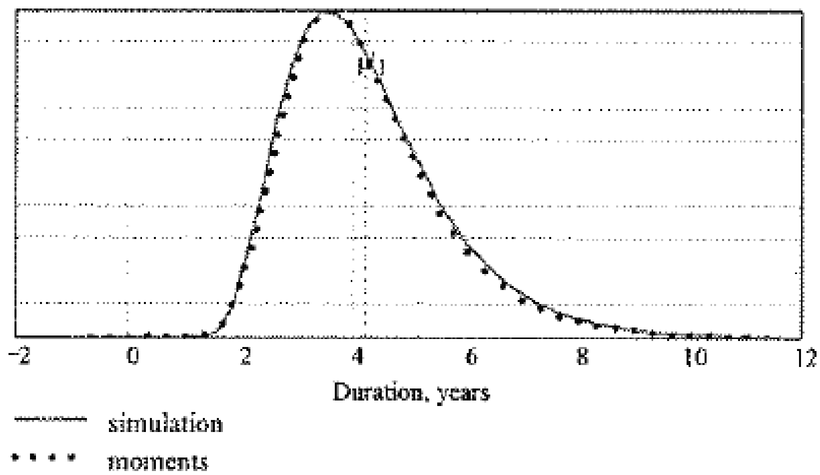


Figure 9 – Comparison of Pearson and Monte Carlo results for time and cost (Abdel Aziz and Russell, 2005)

If the results of Pearson and Monte Carlo methods are very close, it is because performance measures present a degree of linearity. A major drawback of this method occurs when there are highly non-linear patterns: in that case, the results differ significantly from those of Monte Carlo Simulations. Another drawback concerns the correlation between the variables, which have to be independent to give reasonable results (Abdel Aziz and Russell, 2005).

This method is as powerful as Monte Carlo, but it has limitations when there is a high degree of correlation between variables.

Utility Theory

Not everybody takes the same approach to a risk situation. Some people are risk seekers who are more willing to undertake actions under conditions of uncertainty than those who are risk-averse. Multiple factors influence the decision profile of a decision maker, such as the potential loss/gain of a risk. Utility theory introduces a central problem of decision making and uncertainty: the attitude of management towards risk (Perry and Hayes, 1985).

Most behaviors are conservative. Decisions involving important potential loss and gain may require conservatism, because the decision maker cannot afford losses if taking a risk results in negative consequences. Utility theory changes the analysis by introducing a conservative attitude (Schuyler, 2001).

A classic representation of utility is through utility graphs/functions. They translate the expected value into the perceived utility value. Figure 10 shows the two opposite behaviors (risk-seeking and risk averse) separated by a risk-neutral behavior in which the decision maker always uses the expected value to make his/her decision.

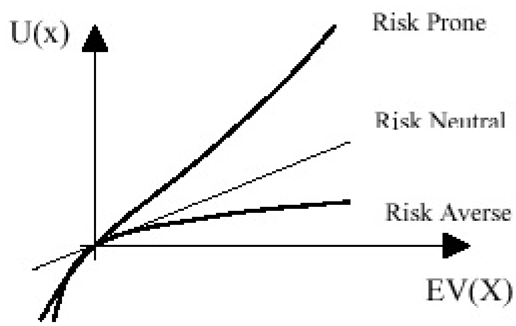


Figure 10 – Utility functions

Utility is often used in tools such as decision trees that involve expected value. It is also useful for assessing the results from sensitivity and probability analyses (Perry and Hayes, 1985). As Schuyler (2001) has defined it, “utility function is a powerful concept for a conservative company that wants to delegate decision making downward; it enables the decision maker at all levels in the organization to make consistent risk-versus-value tradeoffs".

Scenario Analysis

Scenario Analysis is a risk-analysis technique which tests alternative scenarios based on the risks which might occur on a project and their probable consequences. According to Hanagan and Norman (1995), "the aim is to consider various scenarios as options" to figure out which path is more likely and which ones are wanted to be avoided. By introducing "what if" considerations, it enables an analysis including a whole series of risks which are considered at the same time (instead of one after the other for other techniques such as sensitivity analysis) (Jobling et al., 2006).

After risks have been identified, the possible scenarios that lead to different risk outcomes can be identified. A scenario tree with all events can then be depicted. After this, consequences with their probability of occurrence are drawn so that it is easy to notice which risk(s) could lead to a worst case scenario if not properly addressed. The tool serves as a base to identify which risk(s) should deserve an important and specific attention (Oryang, 2002). "It establishes where stress may occur" (Jobling et al., 2006).

The two main strengths identified by Juhong and Zihan (2009) are the following:

- Scenario Analysis is a useful tool to find risks are a key to the project success. It enables managers to quickly see their consequences with a special emphasis on key risks.

- This risk-analysis method combines the analysis of present situation (known) as well as potential future occurrences. It helps "prevent, reduce and even eliminate" risk factors on the project.

Decision / Risk Matrices

Decision (or Risk) Matrices are tools that link the probability and severity of a risk factor in analysis of its overall probable consequence. It is also called a *Probability x Impact* matrix (PxI). It calculates the degree of risk (or risk rating), which equals the impact score multiplied by the probability score.

Risk matrices have two major purposes. They can be used to assess the global level of risk of a variable (=PxI) (assessment), and as a way to rank risks by their importance (analysis). An example of a risk matrix is given in Figure 11. Usually risk levels are classified into three categories with a color code: red (*high*), yellow (*medium*), and green (*low*). In Figure 11, the classification includes four categories, adding a level for *exceptional*. Risk matrices underline the tradeoffs between frequency and severity to help in the evaluation of risk levels (Anderson et al., 2010).

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

Figure 11 – Example of a Risk Matrix

This tool can be used at any time along the course of construction, since the assessment of probability and impact of a risk may vary during the project, and therefore the overall risk level changes.

The more cells in the table (i.e., the more possible description ranges for probability and impact), the more precise the result. However, it is not appropriate for comparing two risk level scores quantitatively, saying, for instance, that one risk is four times more important than another (if its probability and impact are twice as great). It can qualitatively compare two risk levels, ranking one as more/less/as important than/as the other (Ward, 1999).

Risk matrix clarifies the tradeoffs between frequency and severity well, but the method does have some drawbacks. First, it classifies risks into a limited number of categories (typically three: low, medium, and high). Then, it combines likelihood and impact levels into a single assessment, though both items of information are needed for an accurate decision. It is likely that the effects of a high-probability, low-impact risk would be different from those of a low-probability, high-impact one, while they could be of the same degree. As far as contingencies are concerned, the first kind would require a smaller contingency than the second (Williams, 1996).

Table 6 summarizes the tools used for risk analysis.

Method	Input	Output	Opportunities	Constraints
Bayesian Theory, EV	Single values of probabilities and impacts for each possible risk outcome	Expected value (cost, time)	Quick, basic, objective, unbiased, best single-point estimate	Provides a single value only, misses a lot
Monte Carlo Simulations	Impact vs. Probablity distribution for each risk	Estimate ranges for cost and schedule	Robust representation, accounts for complexity and correlation	Need for precise knowledge, computationally time consuming, approximative results, poor results with low probabilities.
Fuzzy Logic / Fuzzy Set	Fuzzy assessment terms	Overall risk of project	Helps when probabilistic databases are not available	Not as precise as probability theories
Sensitivity Analysis and Diagrams	List of risks and their assessment (Impact & Probability)	Ranks variables by their effect on project objectives	Shows relative importance between variables	Variables are treated individually
4 Moments, Pearson Distributions	Probabilistic characteristics of cost/schedule function	Distribution of cost and/or schedule	Close to Monte-Carlo results	Poor results when degree of non-linearity is high; variables must be independent to have acceptable results
Utility Theory	Expected Value	Perceived utility value	Helps make consistent tradeoffs of risk vs. value	
Scenario Analysis	All risks with their probable outcome scenarios	Risks which deserve a greater attention	Combines present and future occurrences, identifies which risk factors are drivers	
Risk Matrix	Probability and Impact Assessments	Overall classification of the risks	Tradeoffs frequency vs. severity	Only classifies the risks into 3 categories: L, M, H

Table 6 – Risk Analysis Tools

Decision techniques

These techniques are very helpful to help managers making decisions – they are more of a decision making support tool. As stated earlier, these techniques are not considered as risk-analysis methods and therefore will not be addressed in the research. However, as they appear very often in the literature and are often combined with risk-management techniques, a description of the three more frequent (MCDM Models, Decision Trees, and Influence Diagrams) is presented in Appendix A.

Point of Departure

Frameworks

Many risk analysis tools and methods exist and can be used in the three first stages of the risk-management process (identification, assessment, and analysis). The selection of a tool or method depends on the tool's characteristics, the knowledge of decision makers, the level of precision expected, the project, the organization, etc. If decision makers follow a formal risk-management process, they need to choose one or more methods from each category to successively identify, assess, and analyze the risks surrounding a project. To help them, engineers have devised frameworks which integrate the three steps previously described into a formalized process. These frameworks serve as a guideline for the decision maker. Analyzing these frameworks is beyond the scope of this thesis (a presentation of four of these frameworks is succinctly presented in Appendix B) but they lead to the research problem statement.

Problem Statement

Frameworks provide decision makers systematic ways of dealing with risk on a project. They offer a "package" that managers can apply to all of their projects. However, there is no "super method" that always offers the best estimates for cost and schedule: "there is a lack of an accepted method of risk assessment and management among professionals in the construction industry compared with the financial and health professions" (Christian and Mulholland, 1999). Indeed, each project is unique with individual characteristics and risks. Even though frameworks have been developed, there is not a selection method to determine the right tool or method based on the tool's opportunities and threats. The Problem Statement of this research is to understand how project characteristics and phases influence the selection of a risk-analysis tool.

Research Questions

In order to establish a systematic way for decision makers to choose the most appropriate tool or method for managing risk on the basis of project characteristics and phases, several intermediate questions need to be addressed.

For this research, the specific Problem Statement is *"How do project characteristics and phases influence the selection of risk-analysis methods and tools?"* To investigate this topic and benchmark the investigation, several intermediate questions need to be addressed:

- What are the existing methods and tools that exist to assess and analyze risks? What are their main advantages and disadvantages?
- What is the current state of practice in the construction industry for risk-analysis methods and tools?
- Which project characteristics point to the use of more rigorous risk management processes?
- How useful specific risk-analysis methods and tools are depending on project characteristics and phases?
- How should decision makers select the most appropriate risk-analysis method or tool based upon the specificities of his/her project?

CHAPTER III

METHODOLOGY

Research Framework

Framework

The framework used in this research is the *Center for Integrated Facility Engineering (CIFE) Horseshoe Research Method*. Figure 12 presents a graphical representation of this framework. It was developed at Stanford University by the CIFE laboratory which aims at designing "efficient and effective" research processes [CIFE website]. The CIFE Horseshoe includes a succession of steps that guides the researcher during his investigation.

Even though multiple frameworks exist, the CIFE Horseshoe makes the process explicit through successive steps that respond and relate to each other. In his report on formalizing construction knowledge, Fisher (2006) stated that anyone "who works with this method progresses more quickly to defensible research results and can understand each others' work more easily, quickly, and fully." The framework sets guidelines that keep the researcher on track. In addition, "it forces the researcher to develop a scope of work and research plan that is manageable and executable and leads to scientifically defensible and practically relevant results" (Fisher, 2006).

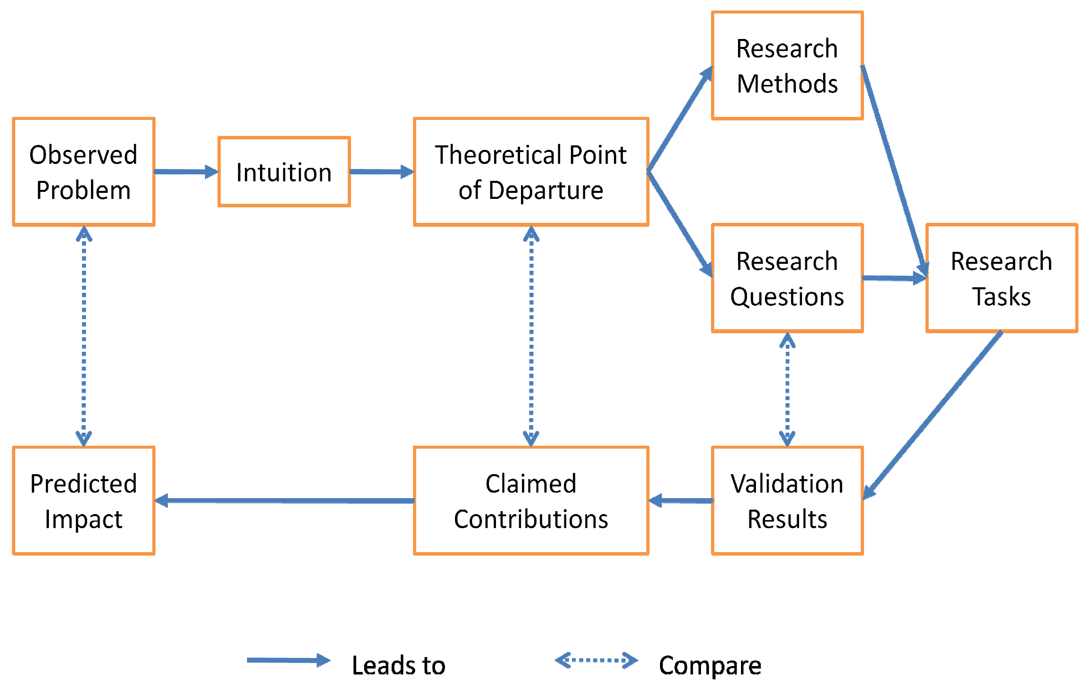


Figure 12 – CIFE Horseshoe Research Method

The nine elements that compose this framework are, in linear order: Observed Problem, Intuition, Theoretical Point of Departure, Research Questions, Research Methods, Research Tasks, Validations Results, Claimed Contribution, and Predicted Impact. To begin, experts identify a problem in industry. Through discussion, researchers develop intuition regarding what will help address the question. This step sets the orientation of the investigation and leads to the primary points of departure of the research. This in turn leads to literature streams that help inform the research and identify an existing gap in theory. To benchmark the investigation, the researcher formulates several questions to address the research. The method links each of these questions with a process to fill the gap left by each of those questions. The *research tasks* expound all pieces of work for the investigation from the point of departure to the expected results and model. Validation ensures that the results and model are valid. When validated, the results enable the investigator to claim a theoretical contribution to literature and a predicted impact on industry. This step relates to the initial problem observed in the field and responds to the gap identified in the literature.

I used the CIFE Horseshoe to address the research question in this thesis.

Observed problem

There are many examples that prove that cost and schedule overruns are unfortunate realities of a large number of projects. And in some cases, consequences can be very serious.

Companies willing to avoid such problems implement risk-analysis processes for their projects to identify, assess, and analyze risks and then, for example, determine contingency amounts. Researchers and engineers have been creating and developing different risk-analysis methods and tools. However, within a company, decision makers typically employ the same risk-analysis methods without regard to the particular project.

Intuition

It is my intuition that some project characteristics may make the selection of a risk-analysis method more or less relevant depending on the features of a particular project. For example, the Monte-Carlo simulation technique is very accurate and powerful but it requires a lot of information and thus a lot of time and money to implement. The method might be more useful when a high budget level is involved. On the other hand, if the involved costs are small, it might not be worth it to perform such a heavy analysis.

Other considerations, such as project phase, may also influence the selection of a risk-analysis method. At the very beginning of the project (front end planning), risks are not well defined and their assessment might remain fuzzy whereas towards the end (start-up/commissioning) most risks have been addressed and the residual risks are well known. Therefore, different risk-analysis methods might be used for those different stages.

Finally, risk-analysis methods have intrinsic characteristics that could be advantageous or disadvantageous depending on the circumstances in which they are used. Decision makers should be able to select a risk-analysis method for a certain project (with its own unique characteristics) on the basis of the benefits and drawbacks of the methods.

Theoretical Point of Departure

From a review of the literature, the main risk-analysis methods and tools were identified for the three levels of the risk-management process: identification, assessment, and analysis. These can be characterized by their inputs, output, opportunities, and threats. The optimal selection would be to choose a given method when its strengths are useful in a given situation and its weaknesses not significant. The establishment of criteria for the phases and the characteristics of the project would help decision makers select the most appropriate risk-analysis method for their project. The problem statement of this research is to understand how project characteristics and phases could influence the selection of risk-analysis methods.

Research Questions

To investigate this topic, several sub-questions need to be asked and addressed.

The first question has to do with the different methods that exist for managing risks and how they differ from one another: *What are the existing risk-analysis methods? What are their strengths and weaknesses?*

A second question examines what is currently done and why: *What is the current state-of-practice in the construction industry?*

The third question focuses on project characteristics: *Which project characteristics and phases would require a heavier use of risk management processes?*

The fourth question links the top project characteristics identified in the previous step to each of the most frequently used risk-analysis methods: *How useful are specific risk-analysis methods depending on project characteristics and phases?*

Finally, the last question is intended to helporganize the information collected and to explore a format for decision makers to select risk-analysis tools: *How should decision makers select the most appropriate risk-analysis method?*

Research Methods

Each of the research questions will be addressed through a different method. The first question, identifying the existing methods, is answered through a review of literature. The second, regarding the current state of practice in the construction industry, is addressed by means of a questionnaire sent out to hundreds of construction companies (mostly from the Construction Industry Institute). This questionnaire is also meant to determine, with enfolding literature, the project characteristics that involve the need for risk management processes (question 3). Finally the relationship between the usefulness of major risk-analysis methods and project characteristics is addressed by a second survey sent out to companies implementing risk-analysis and management processes.

Review of the literature

Gathering information and reviewing materials on the specific topic of the thesis is the main goal of the literature review. Numerous articles describe useful tools for managing risks and uncertainty in construction projects. Various major specialized construction management journals were consulted, e.g., *Journal of Construction Engineering and Management*, *International Journal of Project Management*, *Construction Management and Economics*, *Engineering Construction and Architectural Management*. For each article, information was tracked on a spreadsheet that combined the inputs, outputs, advantages and disadvantages of the methods. Finding multiple sources for each method was a key to comparing points of view and covering the different aspects of a method.

The literature review was also used to determine the project characteristics that would require the use of heavier risk-analysis processes due to the level of associated risk. Ideas from five different articles were combined to establish a list of the important project characteristics related to risk.

Questionnaires

A survey-based questionnaire was employed to determine the current state of practice of the industry and the usefulness of risk-analysis methods. A survey corresponds to interviewing a large number of people, asking them the same questions. Therefore, performing a survey saves time for the research team and allows it to reach out to a large number of potential respondents. Moreover, answering questions through a questionnaire removes the possible bias brought by the interviewer way to conduct the questions.

As stated earlier, two questionnaires are used in this research, both online surveys. The major advantage of designing surveys online is that it provides a clean interface, which encourages people to take the survey and therefore raises the response rate. Also, doing the survey online enables the researcher to adapt the questions to the answers of the previous. This branching enables routing the respondent to the adequate following question pages depending on his/her previous answers, and therefore keeping the survey short. Indeed, a key factor in a successful survey is its length: it has to be possible to fill it in quickly, so that the managers can take the survey when they have a short period of free time. The two surveys are designed to be answered in less than half an hour.

One constraint to an (online) survey is that it does not enable respondents to elaborate and give precise meaning to their answers. The ways in which people interpret the meaning of a question can vary, and thus the answers vary too. The next two paragraphs describe more specifically the two questionnaires and explain how and why they were designed.

The first questionnaire explores the current state of practice of risk-analysis methods in the construction industry. The companies to which the survey was sent were not randomly selected within the construction industry. Indeed, it is hard to select construction companies randomly since most are quite small and hard to contact. The goal of the survey is not to determine precisely the percentage of construction companies that use a specific risk-analysis method; it is more to figure out which methods are used more frequently than others. Therefore the survey was sent to companies that might implement risk-analysis tools. Typically, companies form large associations (e.g., PMI, CII) were consulted. Because of this non-randomly selected sample of companies, no inferential statistics are allowed. However, conclusions from the comparison of how different methods are used within the industry will be established.

The second questionnaire goes into greater depth as to the most frequently used risk-analysis methods and their usefulness based on project characteristics. This survey represents the core of the research. This survey was sent out to companies, most implementing multiple risk-analysis methods, that answered the first questionnaire and expressed their willingness to participate to further research on the risk-analysis methods topic. It was also sent out to AACEI members who are using risk-analysis tools. This survey is closer to expert interviews conducted with multiple companies. Indeed, this questionnaire is, for the most part, answered by risk experts of big companies that are implementing risk-management plans. For the same reasons as in the case of the first survey, no inferential statistics are used, since the sample of companies is not random. The goal of the survey is to have the inputs and experience of risk experts on the appropriateness of different risk-analysis methods based on conditions in which they are used (project characteristics, project phases).

Before launching, both surveys were pilot-tested by students, professors, and companies.

Research Tasks

The main tasks of this research are:

- *Setting the problem.* This first step was performed through a review of literature. Understand the topic; what has been done already and what remains unexplored are the main objectives of this problem setting. A thorough literature review provides more information and thus broader thinking.
- *Gather and analyze data from the construction industry.* The investigation is based mainly on information coming from surveys. The objectives of this second step are building a survey that fits the needs of the research, sending it out and obtaining a big enough response rate to be able to infer trends and conclusions.
- *Creation and development of a presentation format.* When results coming from surveys are analyzed, they need to be presented on a format that can be helpful to decision makers to select the most suitable risk-analysis method for a particular situation (given project characteristics and project phase). A usable and efficient framework is beyond the scope of this investigation. However, depending on the results condition, appropriate frameworks to present these results can be discussed and advised for future research.

Validation Results

This research tends to identify trends in the effectiveness of risk-analysis methods based upon the characteristics and phases of the project for which they are used. The data is collected from surveys sent out to managers in the construction industry. In order to decrease bias and irrelevant opinions and assessments, the surveys were designed with a preliminary question ensuring that the respondent has the requisite knowledge to answer the specific questions. In consequence, this preliminary question decreases the response rate since people who do not feel comfortable enough with the topic are advised not to go further. However, it is better to have fewer reliable responses than a lot of questionable responses including biased ones. With that being said, an adequate number of responses is needed to make the results reliable. Survey takers should aim at receiving a minimum of thirty responses.

The validity of the results also depends on their consistency. If the same patterns are found in the literature and both surveys then it gives sufficient evidence to infer the identified trends. However, for some conclusions, like the usefulness based upon project characteristics, the literature is elusive, and comparison between the respondents' answers and the scholars' points of view will be harder to make. In that case, the strengths and weaknesses of the methods will be used to support the trends identified in the surveys.

Claimed Contribution

This research intends to fill a void in the literature in regards to the selection of risk-analysis methods. If many tools are described with their advantages and disadvantages, there is no tool to help in selecting the most appropriate tools on the basis of the characteristics of a project. The identification of trends is intended to be helpful to decision makers in this way.

This contribution can be expanded in future research. Indeed a framework can be built so that a decision maker enters the attributes of his/her project (phase and characteristics) as an input and the model provides him/her the name of the optimal risk-analysis method. The model can also be refined adding new inputs in the model to make it more accurate and specific to the requirements of particular kinds of projects.

Predicted Impact

The results provide guidance to decision-makers in their selection of risk-analysis tools. Of course, this presupposes that companies willing to use and apply the results are already implementing multiple different risk-analysis methods so that the best choice can be made. If they are not, this research may open their eyes to the fact that no magical method exists which would always be the most appropriate, whatever the situation of the project.

Conclusion

This chapter presented the methodological process of this research and described the work done to prosecute the investigation. The CIFE Horseshoe is used to describe this process in a formalized manner.

Chapter 4 will focus on the research method design and especially how the surveys were crafted to address important questions.

CHAPTER IV

DATA COLLECTION

Introduction

This chapter presents the data collection efforts for the research. As discussed in the previous chapter, data came from two different surveys sent to managers of construction companies. The first survey was based on a comprehensive research project in risk management being conducted by the University of Colorado for the Construction Industry Institute titled "Applying Probabilistic Controls in Construction." Six out of thirty three questions were revised from this questionnaire. The second survey was designed specifically for the present study.

The first section of this chapter discusses the major concerns and struggles that were addressed in the process of designing the two surveys. The subsequent sections present the design of each survey.

Survey Design

A goal in any survey design is to ensure an adequate response rate with questions answered accurately by the respondents. The goals are to gather the maximum amount of relevant information, avoid bias, and limit length so that respondents are not answering incorrectly due to impatience.

To achieve these goals:

- questions need to capture only the necessary information for the research;
- questionnaires have to be sent to a large number of knowledgeable people – the more respondents the more reliable the results;
- respondents' answers on a question should match the answer possibilities in the survey; and
- questionnaires must be easy to understand by the respondents so that they are not struggling with the meaning of a question or response.

Another way to avoid potential bias and gain more responses is to offer the respondent the possibility of anonymity. Although information about the company and the qualifications of the respondent may be helpful in the analysis phase of the survey, it is often not essential. Anonymous responses also protect the respondents from any possibility that their answers could negatively impact them in any way.

Thus, each question was designed with the concerns that the following questions address:

- Why ask this question? How is it relevant to the research? What sort of answer will it elicit?
- Which question format is the most adequate? Why?
- Will people be able to elaborate on the question? How? Are all possible answers covered by the proposed answer choices?

Even though the populations consulted on both surveys are construction industry companies, there are not representative of the construction industry and by no mean the current investigation aims at drawing inferences on the current state of practice of the construction industry. The goal is more to gain inputs from professionals on a topic that has not been addressed by many authors in the literature. In order to extend the population and receive more responses, associations of construction companies were consulted. The first survey was primarily designed for CII (Construction Industry Institute) companies but it was also sent to other associations like PMI (Project Management Institute) and AACEI (Association for the Advancement of Cost Engineering International). The second survey was not specifically designed for a particular association; therefore, companies from the CII, PMI, and AACEI groups were consulted as well. For both surveys, the consulted companies are not an accurate representation of the association they were drawn from; they simply bring their knowledge on the investigated topic.

Survey 1: Risk-analysis methods and tools

The goal of the first survey was to have an idea on the current state of practice of risk-analysis methods and tools in the construction industry. The results of these questions were used to inform the design of the second questionnaire.

The survey was designed by the CII Research Team 280 working on "Applying Probabilistic Controls in Construction". Overall, the first survey contained thirty-three questions, of which questions 16, 17, 18, 19, 20 and 26 are particularly important to this research. These questions will be described and addressed below.

Project Phase

Question 16 deals with effectiveness of risk-analysis tools per project phase. The CII definitions for project phases were used; CII breaks down the construction process into five phases defined as follows (see Appendix C):

- Front End Planning: "The project phase that begins with defining the business need for a facility and ends with an original budget authorization."
- Detail Engineering: "The project phase that begins with the design basis and ends with the release of all approved drawings and specifications for construction."
- Procurement: "The project phase that begins with the procurement plan for engineered equipment and ends with all engineered equipment being delivered to site."

- Construction: “The project phase that begins with the commencement site works and ends with the completion of the mechanical systems.”
- Start-up: “The project phase that begins with the completion of the mechanical systems and ends with the custody of the project being transferred to the user/operator.”

This question disregards the kind of method used and was aimed at identifying the phases where risk analysis methods have the most value.

Project Characteristics

The goal of question 17 was to identify the project characteristics that would influence the use of risk-analysis tools. Again, this question is general and does not address any specific method. The question asked for nine project attributes:

- Cost
- Complexity
- Location
- Type
- potential for change
- duration constraints
- teams sharing risk
- delivery method
- contract payment method

To answer the last two questions about project phases and project characteristics, a subjective scale was used: Strongly disagree, Disagree, Uncertain, Agree, Strongly agree. The five possible answers are plainly identifiable, so the scale generates less bias in the answers. Question 18 allows an open-ended response to encourage the respondents to specify alternative project attributes. Thus, other project characteristics added several times by respondents are considered.

Use of risk-analysis methods

Question 19 focuses on the use of risk-analysis methods and tools. The goal of this question is to determine the extent of risk-analysis methods used in the survey population. Three methods addressed in the question are relevant to this research: Scenario Analysis, Simulation Analysis, and Qualitative PxI Rankings. Those three methods are broadly defined and may be seen as families of methods. Most risk-analysis tools fit in one of those families. Similar to question 18, question 20 allows respondents to elaborate and add other methods they are using that would not fit into the previous categories. Combined, the results for these two questions make it possible to draw a picture of risk-analysis tools, their use and frequency of use.

Finally, question 26 is especially important for the survey 2. It asks respondents if they are willing to participate in further research on the topic of risk-analysis methods and tools. Those who answer favorably will be consulted for the second survey. In this question, respondents expressing their willingness to participate in further research are asked to add their names and email addresses so that they can be easily contacted.

Survey 2: Application of risk-analysis methods and tools

The goal of the second survey is to link project characteristics and project phases to different risk-analysis methods. The usefulness of those methods is assessed and evaluated when subjected to different parameters (project characteristics and phases). The first section presents how the survey works and provides general information about it. The next section deals with how the survey inputs were selected (risk-analysis methods, project characteristics, project phase). Indeed, there are many risk-analysis methods and a very large list of project characteristics, but in order to keep the questionnaire short, it was impossible to ask questions about every method or project characteristic. Finally a description of each question is provided.

General information

This questionnaire administered through the Web. This method allowed for clear design, rapid dissemination and response, and ease of analysis.

The first two questions concern information about the respondent's employer. As stated earlier, these questions are all optional, so that if the respondent wishes to be anonymous, he has the option to do so without affecting the rest of the survey. The company information asked is minimal: the name and the project party the company belongs to. The name of the company was requested in case further information were needed.

Eight methods are presented in the survey, and the same questions are asked in a similar format for each method. Each risk-analysis method and its set of questions are presented in sequence. When questions about one method are completed, the respondent can go on to the second, and so forth. The main advantage of this repetitive format is that the respondent becomes more familiar with the questionnaire as he/she goes along. Therefore, the format reduces the time spent filling in and then increases the proportion of people returning complete responses.

At the beginning of the questionnaire a few sentences explain the goals and objectives of the survey, how much time the survey should take (no more than thirty minutes), and that the aggregate results will be available after completion of the questionnaire. Finally, the introduction thanks respondents for their participation and guarantees that their responses will remain absolutely anonymous.

For each risk-analysis method, before the set of questions regarding the method, a precise definition of the method is provided to minimize misinterpretation. Those definitions appear in Appendix D.

Selection of survey inputs

This questionnaire focuses on linking specific risk-analysis methods to project characteristics and phases. The survey presents eight risk-analysis methods, four project characteristics, and five project phases. Chapter 2 showed that more than eight risk-analysis methods are available for dealing with risk and uncertainty but the survey could not ask about all the methods or it would become too long and risk a lack of response. While not exhaustive, the questions addressed in the survey represent the most relevant methods for application as presented in this section.

Eight risk-analysis methods

The goal of selecting only a limited number of risk-analysis methods was to keep the survey short and gain an adequate response rate. The choice was made to go into greater depth on a limited number of methods than to try to cover more superficially. Choosing the methods is a critical step. In order to have useful answers on the specific questions about a method, it is essential that the method be used by a large number of organizations in the industry. All of the selected methods have to be heavily used in the industry and, if possible, cover the range of existing methods. The results of survey 1 and the literature review assisted in determining the final eight methods to include in the survey.

Two key articles were cited. The first article was written by Simister in 1994. It released the results of a survey sent out to risk managers in different industries (not only construction) asking about their usage and awareness of risk-analysis and management techniques. All respondents were people performing risk-management processes and using adequate tools. The twelve risk-analysis methods surveyed were "identified by the literature as being those most pertinent to PRAM" (Project Risk Analysis and Management). The results of this survey are compiled in Table 7.

Method		% use
1	Checklists	76%
2	Monte Carlo Simulation	72%
3	PERT	64%
4	Sensitivity Analysis	60%
5	Decisions Trees	44%
6	Influence Diagrams	28%
7	MCDM Models	24%
8	CIM Modeling	8%
9	Game Theory	8%
10	Utility Theory	4%
11	Fuzzy Set Theory	0%
12	Catastrophe Theory	0%

Table 7 – Use of PRAM techniques (Simister, 1994)

The second article is by Akintoye and MacLeod (1997). The principle is the same: survey of the current state-of-practice of risk-analysis methods and tools. The population is a little different: companies consulted were the top 100 companies in the UK construction industry. Forty three of them answered the questionnaire about twelve risk-analysis methods. However, the authors do not explain how and why they chose these twelve in particular. The results of their survey are presented in Table 8.

Method		% use
1	Intuition/Judgment/Experience	100%
2	Subjective Probability	46%
3	Sensitivity Analysis	38%
4	Monte Carlo Simulation	31%
5	Decision Trees	23%
6	Risk Premium	8%
7	Bayesian Theory	0%
8	Caspar	0%
9	Stochastic Dominance	0%
10	Algorithm	0%
11	Mean End Analysis	0%
12	Risk Adjusted Discount Rate	0%

Table 8 – Use of Risk Management Practices (Akintoye and MacLeod, 1997)

A third input for selecting the most often used risk-analysis practices was the results of the first survey, which are presented in greater detail in the next chapter. Table 9 provides a summary of the relevant information from this questionnaire. It consists of answers from questions 19 and 20 about the use of risk-analysis methods and tools. Respondents could say how frequently they use the five provided methods on a four-option subjective scale (Always / Often / Sometimes / Never). Table 9 reports the median answer for those five methods. This question also allowed the respondents to add any other risk-analysis method that they are using on their project. Those other methods are also displayed in Table 9.

Method		Median Answer
Scenario Analysis		Often
Influence Diagrams		Sometimes
Decision Trees		Sometimes
Simulation Analysis		Sometimes
Qualitative PxI Ranking		Often
Other	Risk Register	N/A
	Risk Breakdown Structure (RBS)	N/A
	Checklist	N/A
	Historical Databases	N/A
	Brainstorming	N/A
	Lessons Learned	N/A
	Workshops	N/A
	Risk Template	N/A

Table 9 – Frequency of use of risk-analysis methods (first survey)

In my effort to include the appropriate risk-analysis methods in one condensed list, I created priority rules:

- Eliminate methods used by fewer than 10% of respondents to the two surveys;
- Include methods that have been added in the first survey by several respondents;
- Combine similar methods into a broader category;
- Eliminate decision tools or framework as described in the literature review.

On the basis of these rules, Checklists, Monte Carlo Simulations, and Sensitivity Analysis were selected from the list in the first article (Simister). The second article contributed Intuition/Judgment/Experience, Subjective Probability, Sensitivity Analysis, and Monte Carlo Simulations as selected risk-analysis methods. From the first survey, I kept Scenario Analysis, Simulation Analysis, and Qualitative PxI Rankings. All relevant methods from the "other" section of survey 1 were retained. The next step was to combine similar methods and to add major methods identified in the literature review which were not yet on the list.

Intuition, Judgment, Experience, Experts, Knowledge, Subjective Probability, and Workshops were grouped in the category Brainstorming, which offers the advantage of matching methods identified from the literature review (e.g., Crawford Slip, SWOT Analysis, Red Flag Items, Nominal Group Technique). Historical Databases are included in the category Checklists, as they are the most commonly used kind of format for those databases. Similarly Simulation Analysis was related to Monte Carlo Simulation which is the most common format. To match the literature, Quantitative PxI Rankings was renamed Risk Matrices. Finally, Expected Value was added to the list, since it appeared in numerous articles (even though not in the two principal sources). The final list of the eight methods is as follows:

- Brainstorming
- Checklists
- Risk-Breakdown Structure (RBS)
- Expected Value

- Monte Carlo Simulations (MCS)
- Sensitivity Analysis
- Risk Matrices
- Scenario Analysis

This selected list is not intended to be exhaustive of all possible methods, but does cover almost all of the currently used techniques.

Four project characteristics

In this study the usefulness of the different risk-analysis methods is tested by project characteristics. There are a large number of project characteristics but some are redundant and, above all, the characteristics that represent a significant amount of risk and uncertainty in a project are limited. In keeping the survey brief, it was important to select only the most important. Since a question was to be asked about each project characteristics for the eight risk-analysis methods selected, a maximum of five characteristics looked reasonable. To select those characteristics, five articles were reviewed, each of which ranked characteristics as to their impact on the success or failure of a project. Also, the results of the first survey were used.

The five articles reviewed and analyzed were the following:

- "Ranking Construction Project Characteristics" by R. Favie and G. Maas (2008). This article lists an important number of project characteristics (forty three). This listing and ranking is done by two analyses: 1) a panel of 16 experts brainstormed in workshop sessions; 2) eight papers (different from the ones I reviewed) listing project characteristics were analyzed. The ranking proposed by this paper was based on the number of appearances in the workshops and the articles.

- “Appropriate Project Characteristics for Public Sector Design-Build Projects” by K. Molenaar (1996). Fifteen project characteristics are underlined in this article and have been submitted to eighty eight public owners’ evaluation concerning their impact on project success.
- “Effect of Project Characteristics on Project Performance in Construction Projects based on Structural Equation Model” by K. Cho et al. (2009). The characteristics (seventeen) identified in this paper come from “an intensive review of the literature”. The article does not expose precisely how many papers were reviewed for this purpose. The underlined characteristics are those affecting project performance.
- “Impact of Pre-Construction Planning and Project Characteristics on Performance in the US Electrical Construction Industry” by Menches et al. (2010). As the first article, this one identifies the characteristics during workshops in which experts are intervening; the list is then completed with “a comprehensive literature review”. This article identifies project characteristics for the electrical sector of the construction industry. Therefore, some characteristics are very specific to this particular field and have been disregarded. However, most of them are broad and address general construction projects.

- "Quantifying Impacts of Construction Project Characteristics on Engineering Performance: a Fuzzy Neural Network Approach" by L. Chang and M. Georgy (2005). It presents twenty-five project characteristics grouped into seven broad categories. Here also, the two authors do not specify how they found and selected those project attributes; they are simply presenting them as characteristics influencing project performance. The article does not rank the proposed characteristics, it just lists them.

From those five articles, a large number of project characteristics have been identified and most of them tally in their ranking. This database is a good start in establishing a ranking of those characteristics depending on their effect on project performance and therefore on the risk they bring to the projects. Table 10 summarized the relevant project characteristics found in those articles and the number of times they were mentioned. This enabled me to establish a first ranking. It also seems important to note than from the five articles, the first one (Favie and Maas, 2008) seems to be the most appropriate for this task since it proposes a large study and ranking. Of the twenty characteristics provided in Table 10, some are redundant and will be removed. For instance, *size* is directly linked to cost and/or scope; *location* fits in the *condition* characteristic; *communication* and *availability of information* refers to the same thing; etc.

#	Project Characteristics	Articles				
		#1	#2	#3	#4	#5
1	Complexity	X	X	X	X	X
2	Scope	X	X	X	X	X
3	Size	X	X		X	X
4	Cost / Value	X	X		X	
5	Schedule / Length	X	X		X	
6	Conditions (politic, economic, legal, market)	X	X			X
7	Type of Project	X		X	X	
8	Contract Type	X	X			X
9	Location / Site Conditions	X		X		X
10	% of repetitive elements	X		X		
11	Time to bid	X		X		
12	Level of technological advancement	X	X			
13	Funding	X	X			
14	Payment Method	X				X
15	Selection Process	X				
16	Communication			X		
17	Quality	X				
18	Availability of information	X				
19	Type of Client	X				
20	Number of bidders	X				

Table 10 – Most important project characteristics according to five articles

At this point, the results of the first survey were also used. Question #17 asked about the usefulness of implementing any risk-analysis method based on several project attributes (nine). Table 11 shows the median answer of the respondents for each of those characteristics. *Complexity* and *cost* appear as the two most relevant characteristics. *Contract payment method* and *Location* seem to be less relevant. All the other characteristics are relatively close in influence, even though *scope* and *duration* lead this grouping.

Project Characteristic	Median Answer
Level of project cost	Strongly Agree
Level of project complexity	Agree
Location	Agree
Type of project	Agree
Potential for project change	Agree
Duration Constraints	Agree
Team sharing risk	Agree
Delivery Method	Agree
Contract Payment Method	Agree

Table 11 – Usefulness of implementing risk-analysis methods per project attribute

Complexity, *scope*, *cost* and *schedule* are the top 4 characteristics in both classifications, excluding *size* which is redundant (literature and survey results). It seems obvious to select at least these four. Then, *conditions*, *type of project*, *contract type* are the three next characteristics identified from the articles, and the survey does not enable me to rank them clearly to pick the one with the greatest influence on project performance. Therefore, the four following characteristics were used:

- Complexity
- Scope
- Cost
- Schedule

This short list is a compromise between brevity and exhaustiveness. The goal was 1) to keep the list short to reduce the survey in length and 2) to keep the important characteristics that might distort the analysis.

Five project phases

The project phases are exactly the same as used in the first survey:

- Front End Planning
- Detail Engineering
- Procurement
- Construction
- Start-up

As discussed earlier, these phases are the ones used by CII and represent their standard project phase breakdown. The official CII description of these five phases is presented in Appendix C.

Questions asked

This section describes and explains how and why questions were asked. Please, refer to Appendix E, for the complete questionnaire.

At the beginning of this second questionnaire, a preliminary question was asked to ensure that the person taking the survey was knowledgeable enough about risk management to avoid bias in the results. If a person is not knowledgeable, his/her answers might introduce error into the overall results. The respondent has two options: 1) he/she has the knowledge, clicks on the "continue" option and takes the survey normally; 2) he/she does not have the knowledge and clicks on the cancel option so that the results are not taken into account. If the last option is chosen, the respondent is kindly asked to route the survey to any person within the company who is knowledgeable about risk management.

If the respondent answers this preliminary question positively, two questions are aked to gain information on the organization represented. Then, the format of the survey follows the same pattern: a set of questions is asked about the eight risk-analysis methods previously selected. Therefore, in the next paragraphs, only one set of questions is presented (i.e. for one risk-analysis method), to be repeated later seven times.

First, a definition of the method is provided (see Appendix D). The first question for each risk-analysis method asks whether the respondent uses the method or not. This question is important because, depending on the answers, the following questions for this specific method will be different. If the answer to the question is yes, the respondent may continue to answer those specific questions. In case of a negative answer, the respondent is oriented to another question asking why he/she is not using it (see description further). This question divides the format of the questionnaire into two parts, each of which presents a different set of questions, depending on the answer to it.

If the respondent uses the risk-analysis method presented (i.e., answers yes to the key question), four questions are then asked about this specific method. The first subsequent question concerns the frequency of use of this method. Several scales were considered in order to provide multiple answers. A subjective scale

(Always/Often/Seldom/Never) is not preferable since each respondent can make a different interpretation of these inexact terms. Frequency in terms of percentage of projects (e.g., we use method X on 30-50% of our projects) is hard to assess for managers. Therefore, we chose to break frequency into five categories: once a week, once a month, a few times a year, once a year, less than once a year.

The second and third questions deal with project phases (respectively project characteristics): it asks how appropriate the method is for each of the five construction phases (respectively project characteristics). For the same reason as in the last paragraph, the numeric scale (e.g., from 1 to 10, 1 being disagree and 10 being agree) was not chosen. To make it easier for the respondent, we chose a five-point subjective scale with relatively big gaps between the items to avoid misinterpretation: Strongly Disagree, Disagree, Uncertain, Agree, Strongly Agree. Translated into numerals, the scale would be -2/-1/0/1/2. Concerning a project-characteristics question, asking how a method is appropriate based upon a certain project characteristic (e.g., complexity) does not make sense. What is interesting is not the characteristic but how it is expressed in the project: for instance, is the level of complexity high or low? Therefore the third question poses polar opposites for the four project characteristics, which resulted in eight questions: high and low complexity, high and low cost, developed and undeveloped scope, compressed and uncompressed schedule.

The fourth and last question asked the respondent to elaborate on the strengths and weaknesses of the methods. In Chapter 2 we identified the strengths and weaknesses of the methods. It is useful to compare what professionals and scholars think about each method. This question has been left open-ended with a comment box in which respondents can elaborate as much as they want. Each person has his/her own view of the problem, therefore this format for the question seems appropriate. In the results analysis, similar answers will be combined.

The second path for each method is shorter, if the respondent is not using the method. It consists of only one question asking why the manger is not implementing the risk-analysis tool. For this specific question, multiple choices are proposed, and the respondent can choose all that apply. Four pre-identified reasons can be checked (Lack of knowledge or familiarity, Sophistication/Complexity, Time consuming, Large investment for minimal benefits), but a fifth answer is open-ended, so that the respondent can add a specific reason different from the other four.

Depending on how many risk-analysis methods the respondent is actually using, the questionnaire is longer or shorter (greater or fewer questions) and therefore takes more or less time to complete. The maximum number of questions (implementation of all methods) is forty-three and the minimum (none of the eight methods is implementing by the respondent) nineteen.

Conclusion

This chapter presented the two surveys designed and used in this investigation. It furnished an explanation of the questions and the manner in which they were asked. The next chapter focuses on presenting the results of those two questionnaires.

CHAPTER V

OUPUT DATA AND PRELIMINARY ANALYSIS

Introduction

This chapter presents the results of the two surveys described in Chapter 4. To begin, I present the results for the relevant questions from the first questionnaire, followed by the results from the second questionnaire. Preliminary, only the questions relevant for this study and described in the previous chapter (six questions out of thirty-three) are discussed. A general presentation of the results from the second questionnaire follows. Also, first conclusions are drawn at the end of each section.

Survey 1: Risk-analysis methods and tools

As established in Chapter 4, this survey was designed to determine the current state of practice for risk-analysis methods and tools in the construction industry. It also influenced the design of the second survey. The questionnaire was sent out to hundreds of construction companies. As this survey was conducted by CII, an important part of the respondents were affiliates of this organization (24%). Overall, two hundred thirty-two (232) people responded to the first questionnaire. One hundred twenty-eight (128) of these responses were not used in the analysis because the respondents answered that they did not have the knowledge to complete or did not complete the survey. When multiple answers were received from one company, the answers were combined (i.e., through averaging or adding responses as required by the question). A total of one hundred four (104) responses constitutes the data available for analysis. The next section presents the relevant data from survey 1.

Risk-analysis methods vs. Construction stage

The first question (question 16) concerned how effective and useful risk-analysis techniques were in the five construction phases (Front End Planning, Detail Engineering, Procurement, Construction, Start-Up). Respondents were asked to judge on a five-point subjective scale: Strongly Agree, Agree, Uncertain, Disagree, Strongly Disagree. The results for all respondents (104 respondents for this question) are displayed in the bar chart of Figure 13. When multiple responses were received from one company, these data were averaged.

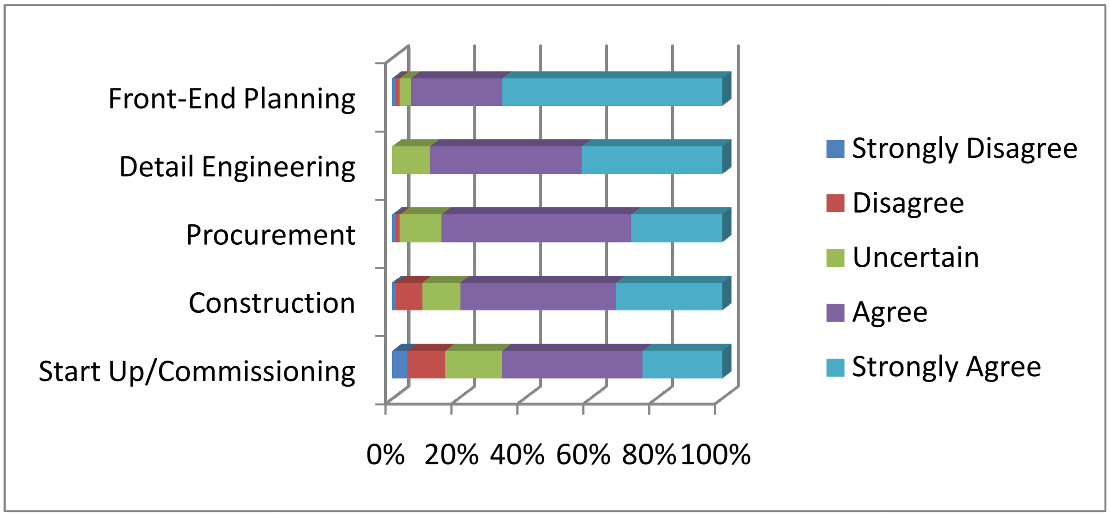


Figure 13 – Effectiveness and usefulness of risk-analysis methods per construction stage

From this bar chart and the median answer for each phase, shown in Table 12, it can be inferred that organizations use risk-analysis tools throughout the project phases, but more predominantly at the beginning of the project. The front-loaded use must not obscure another characteristic of the results provided by the chart: at all stages at least 70% of the respondents think that implementing risk-analysis methods is important for the project performance and success.

Project phase	Median Answer
Front End Planning	Strongly Agree
Detail Engineering	Agree
Procurement	Agree
Construction	Agree
Start-Up	Agree

Table 12 – Median answer for the usefulness of risk-analysis techniques based upon project phases

This first set of answers provides insight into how risk-analysis methods are used along the course of the project. They are useful and effective during the entire duration of the construction process, but they are more important at the beginning.

Risk-analysis methods vs. Project characteristics

The second and third questions (questions 17 and 18) focused on project characteristics. The first proposed to identify how the eight selected project characteristics would make more essential the use of risk-analysis techniques. The respondent is asked to assess this usefulness on the same five-point scale as applied to the previous question. Additional project characteristics can be added in question 18. Data for 104 companies was obtained for question 17 and 47 individual responses were provided for question 18. The results are shown in Figure 14.

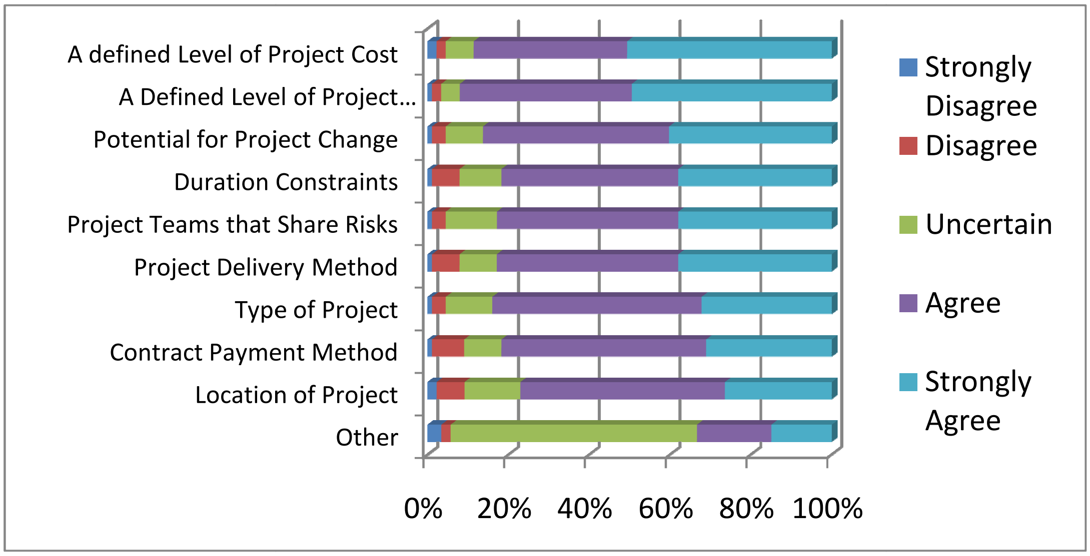


Figure 14 – Need for implementation of risk-analysis techniques based on project attributes

Seventy-five percent of the respondents or more agree that any attribute presented would require proper risk-analysis. However, there are significant differences between the project characteristics. As shown in Table 13, *cost* and *complexity* are the only two with a median answer of "strongly agree", and from the bar chart it is obvious that they are the two most important. *Scope* appears to be the third most-important characteristics before *schedule*, *team sharing risk*, and *project delivery method*, which seem to be of equal importance. *Type of project*, *contract payment method* and *location* appear to be a bit less important.

These results validate the selection of the four project attributes for the second survey; they are the first four of the ranking in Table 13:

Project Characteristic	Median Answer
Level of project cost	Strongly Agree
Level of project complexity	Strongly Agree
Project Change	Agree
Duration Constraints	Agree
Team sharing risk	Agree
Delivery Method	Agree
Type of Project	Agree
Contract Payment Method	Agree
Location	Agree
Other	Uncertain

Table 13 – Median answer for the usefulness of risk-analysis techniques based upon project attributes

The second question (question 18) affords the opportunity to elaborate and add other important project attributes to the list. The most frequent answers are the *Design Status*, the *Project Phase*, the *Type of Client* and the *Project Size*. Project Phase is very important (most frequent answer to question 18) but has been addressed in question 16. Project Size is redundant in terms of scope and cost and Design Status is closely related to project phase. The type of client also seems relevant for the respondents but cannot be considered a top project characteristic.

These two questions show that some project characteristics can bring more uncertainties and therefore require more intensive use of risk-analysis methods. All eight of the pre-selected project attributes are important, but cost and complexity first followed by scope and schedule seem to be those which managers need to consider very carefully. Other significant characteristics were identified, such as the type of client.

Use of risk-analysis methods

The fourth and fifth questions (questions 19 and 20) assessed which risk-analysis methods are most often used by the survey population. Respondents were asked to state how often they use/implement the five methods proposed (Scenario Analysis, Influence Diagrams, Decision Trees, Simulation Analysis, Qualitative PxI Rankings) on a four-point subjective scale (Always, Often, Seldom, Never). As with the question about project characteristics, respondents could add methods or elaborate in an open-ended response (question 20). The results for these two questions (104 respondents for the first and 37 for the second) are presented in the bar chart of Figure 15.

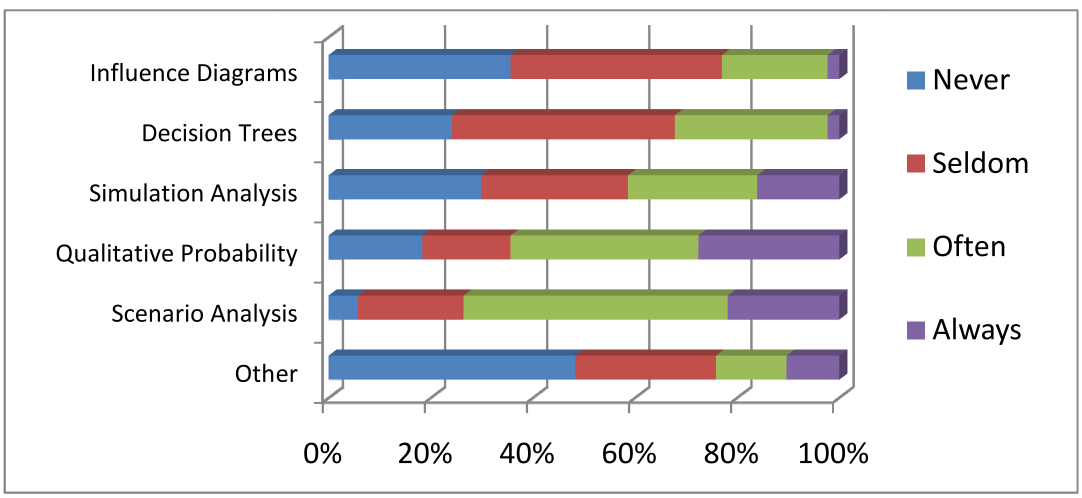


Figure 15 – Use and implementation of risk-analysis techniques

As noted in the previous chapter, *Influence Diagrams* and *Decision Trees* are not considered not risk-analysis methods but general-decision tools, and therefore these two categories will be disregarded for further analysis. The three other categories as well as the "other" category (which can include other methods that are implemented in the industry) are important to identify which techniques are more used and deserve further investigation in the survey 2.

It appears that *Qualitative PxI Rankings* and *Scenario Analysis* are the two methods most often used. However, there is a difference between them. *Qualitative Rankings* are more systematically applied than *Scenario Analysis* (28% vis-a-vis 22% for Always) but almost all project managers occasionally implement *Scenario Analysis*, which is not the case for *Qualitative Rankings* (8% vis-a-vis 17% for Never). Table 14 supports the idea that they are the two more used methods since they have the higher median answer (Often). Simulation Analysis appears to be third, but it is still widely used given the fact that it is a complex and time-consuming method. Indeed, almost half of the respondents (46%) affirm that they are using it *often* or *always*, and only 26% *never* implement it.

In the second survey, among the eight risk-analysis methods selected, the three previously selected have been included, since they are widely used in the construction industry, and thus respondents should be able to answer questions about their usefulness and appropriateness under certain conditions (goal of the second survey). Except for *Scenario Analysis*, the names have been changed so that they match the terms employed in Chapter 2. *Quantitative PxI Rankings* are also known as *Risk Matrices* and *Simulation Analysis* as *Monte-Carlo Simulations*.

Risk-Analysis Technique	Median Answer
Qualitative PxI Rankings	Often
Scenario Analysis	Often
Simulation Analysis	Seldom
Decision Trees	Seldom
Influence Diagrams	Seldom
Other	Seldom

Table 14 – Median Answer for the use of risk-analysis techniques

Even though the previously proposed risk-analysis method categories are broad enough to fit most of the existing ones, they offered possibility of adding other implemented methods is important. Most frequently used methods are included in the second survey. Table 15 shows the methods added by the respondents to question 20.

Ten extra methods have been underlined by the respondents. The four majors (more than one person mentioning them) are *Brainstorming* (4 mentions), *Risk Register* (3), *Checklist* (2) and *Lessons Learned* (2). *Brainstorming* is a broad category that describes discussions and interactions for generating ideas. It presents the advantage of embracing several risk-analysis tools described in Chapter 2. *Risk register* will not be taken into account, since it is a risk-monitoring and allocation tool, and is not used in the identification, assessment or analysis steps (for focus of this study). *Checklists* and *Historical databases* refer to same concept (a list of realized/identified risks in previous projects). *Lessons Learned* is also important but it is redundant with *Brainstorming* and *Checklists* so will not be considered. The six others have been mentioned only once, which means that those techniques are used but less frequently than the others. Elaborating the top eight risk-analysis methods list, *Brainstorming* and *Checklists* have been added and the others have been taking into consideration.

Method	**Frequency**
Brainstorming, Workshops	4
Risk Register	3
Historical Database, Checklist	2
Lessons Learned	2
RBS	1
Assumption Analysis	1
Risk Bow Ties	1
Parametric Modeling	1
Risk Templates	1
Kneper Tregoe	1

Table 15 – "Other" risk-analysis methods pointed out by respondents and their response frequency

These two questions allowed us to draw a picture of the use of risk-analysis methods in the industry. Inferential statistics cannot be used because the population is not randomly selected. However, a ranking of the techniques is legitimate for the survey population. *Risk Matrices*, *Scenario Analysis*, and *Monte-Carlo Simulations* are, in this order, the three most often used techniques. *Brainstorming* and *Checklists* also seem to be widely used in the construction industry to deal with risk and uncertainties.

Survey 2: Application of risk-analysis methods and tools

This section presents the results of the second survey regarding the usefulness and the appropriateness of risk-analysis methods depending on project circumstances (phase and characteristics). This Chapter presents a discussion of the results at the aggregate level (considering risk-analysis techniques altogether) and the following Chapter 6 presents an in-depth analysis of these results at the individual level (comparison between the techniques).

The consulted population is composed of many groups to which the survey was sent to. First, 60 respondents of survey 1 were willing to pursue further research on the topic (those ones indicated their name and email address in survey 1). The survey was also sent to three associations: PMI, AACEI, and RiskSIG. It is not possible to know the total number of people that received the survey since the main contacts within each association was responsible for routing the questionnaire to the knowledgeable persons.

A total of 55 responses were registered: 34 complete answers and 21 partial. Ultimately, 27 were determined to be valid for analysis. Indeed, the partial answers were disregarded and among the complete responses, five respondents felt that they did not possess the required knowledge to take the questionnaire and clicked the "cancel" option at the preliminary question. Also, two responses were not included because the respondents said they did not use any of the eight presented methods and answered none of the other questions (not even their reasons for not using them).

Respondents and frequency of use

The first two questions of the questionnaire asked information about the companies for which the respondents worked. Data for the name, type of the company, and business unit were gathered. For privacy and confidentiality purposes, the individuals' responses, including the company names, will only be released in aggregate results. Table 16 shows the distribution of the company types.

	Percentage
Private Owner	22%
Public Owner	11%
A/E	7%
Constructor	7%
E/P/C	7%
Design Build	11%
CM	0%
Consulting	15%
Other	19%

Table 16 – Company Type

Most respondents are owners (41%) and the remainder of the respondents are fairly equally distributed between the other categories. In the results of the first survey, in which one hundred four responses were analyzed, the distribution was very similar. 42% of the respondents were also owners, and the other 58% fell into the same proportions between the other categories. This breakdown does not intend to be representative of the consulted associations or the construction industry; it presents how the respondents of this survey were distributed among the different company types, and thus gives insight on how to interpret the results.

Eight risk-analysis methods were analyzed. Because managers need to be knowledgeable about a method to be able to answer questions about it, each set of questions (for a particular method) was initiated with a yes/no question to determine whether the respondent implemented the method in his/her company. Table 17 summarizes the results for this question for the eight methods.

Depending on their answers (yes or no), the respondents were asked different questions. People answering “yes” were then asked questions about the usefulness of the method. Those answering “no” were not asked these questions, because the goal was to gather inputs and insights of knowledgeable persons, i.e., people using the method. On the other hand, if a respondent does not use the method, he/she is asked instead to explain why he/she is not using it (results presented later in this section). For each method, the number of respondents using the method (Table 17) represents the response rate for the following questions about the usefulness of the method. Similarly, the number of respondents answering “no” is also shown in Table 17.

	Yes	No
Brainstorming	81%	19%
Checklist	67%	33%
RBS	48%	52%
EV	59%	41%
MCS	52%	48%
Sensitivity Analysis	44%	56%
Risk Matrices	74%	26%
Scenario Analysis	30%	70%

Table 17 – Proportion of respondents using the eight risk-analysis methods

The two most often used methods were Brainstorming and Risk Matrices with more than seventy-five percent of the respondents using them. Checklists are also heavily used as well as expected-value principles. Simulation analysis (MCS and sensitivity analysis) is also widely used (about half of respondents). Scenario analysis appears to be the least-used method of the eight with about a third of the respondents implementing it (30% of respondents). None of the eight selected methods is seldom used, which means that appropriate methods were selected.

Only four of the eight methods match with the categories of the first survey results presented in Figure 15: Monte Carlo Simulation and Sensitivity Analysis (Simulation Analysis), Qualitative PxI Rankings, and Scenario Analysis. The percentage scores correspond well for Simulation Analysis and Qualitative PxI Rankings, but, results are surprisingly different for Scenario Analysis. The first survey established that only 7% of the respondents never used the method, while in this survey the rate reaches 68%. This difference might be explained by a misinterpretation of the definition of the method. In the second survey a clear and precise definition of each method was provided in order to avoid such misinterpretation and to ensure that all respondents understand the idea in the same way.

The frequency of use was the first question asked in cases of positive answers to the "use" question. Respondents chose from a subjective scale between once a week, once a month, a few times a year, once a year, and less than once a year. This scale is more precise than the simple Always/Often/Seldom/Never used in the first survey. Results for this question are displayed in Table 18.

	Once a week	Once a month	A few times a year	Once a year	Less than once a year
Brainstorming	10%	30%	50%	5%	5%
Checklist	6%	18%	53%	6%	18%
RBS	0%	17%	58%	0%	25%
EV	6%	31%	50%	6%	6%
MCS	8%	17%	67%	0%	8%
Sensitivity Analysis	8%	17%	50%	0%	25%
Risk Matrices	5%	20%	65%	0%	10%
Scenario Analysis	25%	38%	25%	0%	13%

Table 18 – Frequency of use of the eight risk-analysis methods

Except for Scenario Analysis, the distribution is similar for all methods. This means that all these methods are equivalently implemented. Scenario Analysis appears to be more frequently used than the others. Finally, Brainstorming, Monte-Carlo simulations, and Risks Matrices seem to be the three next in terms of frequency of use.

For respondents who did not use a certain method, the only question was why they did not use it. They had the choice between four different reasons plus the opportunity to elaborate another reason in the category, “other”. Results for this question are presented in Table 19. As it appears that most “other” reasons refer to the fact that the method was inappropriate, this category has been added to the table. Therefore, the category “other” gathers all the additional reasons that are neither the four choices nor the “bad” method option. In this table, percentages do not add up to one hundred, since respondents were encouraged to check multiple reasons.

	Lack of Knowledge or Familiarity	High Degree of Sophis-tication / Complexity	Time Consuming	Large Investment for Minimal Benefits	Inappro-priate Method	Other
Brainstorming	50%	0%	33%	0%	0%	17%
Checklist	20%	0%	10%	10%	50%	10%
RBS	50%	0%	13%	19%	0%	19%
EV	31%	0%	8%	31%	31%	0%
MCS	20%	35%	20%	10%	0%	15%
Sensitivity Analysis	35%	5%	20%	20%	10%	10%
Risk Matrices	56%	11%	22%	0%	0%	11%
Scenario Analysis	38%	8%	31%	15%	0%	8%

Table 19 – Reasons for not using the eight risk-analysis methods

The reason most often cited for not using a method was that they did not feel familiar with or knowledgeable enough about it. This was especially true for Brainstorming, Risk Breakdown Structure, and Risk Matrices. The complexity of a method was seldom a reason except for Monte-Carlo Simulation, which is a complex process. Between one-third and one-fourth of the respondents think that each of the method is time consuming except for the expected value (8 percent) and risk checklists (10 percent). A quarter of the non-using respondents indicated that Risk Breakdown Structure, Sensitivity Analysis, and the Expected Value were not worth the implementation. Finally the category, "inappropriate" method, was not proposed as a choice and respondents elaborated on it. Only two methods were deemed not useful for analyzing risk on a construction project: Expected Value and Checklists.

Usefulness of risk-analysis methods by project phase

This question is the first of the two questions representing the core of the investigation. It describes the relationship between each of the eight selected risk-analysis methods and the five construction phases. If using a method, the respondent is asked to assess how useful the method is for each of the five construction stages on an adjectival scale of Strongly Disagree (SD), Disagree (D), Uncertain (U), Agree (A), Strongly Agree (SA). Because this scale is not a numeric scale, the only relevant descriptive statistics that can be used can to describe the studied population is the median. Table 20 shows the median answer obtained for this question for the eight risk-analysis methods.

Median Answer	Front End Planning	Detail Engineering	Procu-rement	Cons-truction	Start-up
Brainstorming	SA	A	A	A	A
Checklist	SA	A	A	A	A
RBS	A	A	A	A	U
EV	SA	A	A	A	A
MCS	A	SA	SA	SA	A
Sensitivity Analysis	A	A	A	A	A
Risk Matrices	SA	SA	A	SA	A
Scenario Analysis	SA	A	A	A	SA

Table 20 – Usefulness of the eight risk-analysis methods based upon project characteristics

From this table, the general pattern that can be identified is that most of the methods are assessed to be more useful at the beginning of the project than towards the end. It is especially the case for Brainstorming, Risk Checklists, RBS, and EV. Except for RBS at the Start-Up phase, all median answers are "Agree" or "Strongly Agree" which means that all the risk-analysis techniques are all useful along the project course. This confirms the main conclusions drawn from Survey 1 (Figure 13): risk-analysis methods are used throughout the entire project but predominantly at the beginning.

Two little exceptions emerge from Table 20. MCS is very useful at the middle phases (Strongly Agree is the median answer for detail engineering, procurement, and construction) and scenario analysis is not only very useful at the beginning of the project but also at the end (median answer is Strongly Agree for the two extreme phases front end planning and start-up).

The problem of presenting the results only with their median answer is that it only provides information on the central tendency but misses a lot of information on the variability of the responses. In order to better analyze the result for each method, the frequencies for each category (SD, D, U. A, SA) need to be displayed in a same table in order to take into account this variability. This analysis is performed in the next chapter and is associated to the individual comments of the respondents as well as the inputs from the literature findings.

It is also important to point out that the eight risk-analysis methods are not used at the same stages of the risk-management process defined in Chapter 2. Assessment and analysis can be combined, since they involve the same methods, but identification should be separated. For instance, the results for Monte Carlo Simulation and Risk Breakdown Structure do not provide meaningful comparison. This observation also applies in the next section (project characteristics) and will be a key point of the detailed analysis in Chapter 6.

Usefulness of risk-analysis methods based on project characteristics

As previously stated, this question focuses on the usefulness of the eight selected risk-analysis methods in relation to project characteristics. Four characteristics were presented to the respondents for analysis: Complexity, Cost, Schedule, and Scope. Those four characteristics were found to have the greatest impact on project performance. However for each risk-analysis method, eight project characteristics questions were investigated, two per project characteristic, the two being the opposite extremes of the characteristic (e.g., low and high complexity).

This question is very similar to the previous one: respondents were asked to assess the usefulness of the different risk-analysis methods applied to each of the eight project characteristics on the same subjective scale (SD/D/U/A/SA). The results for each risk-analysis methods are shown in Table 21 (median answer).

As for project phases, the eight risk-analysis methods address well the four (eight considering their opposite terms) selected project characteristics: except for scenario analysis, all respondents agreed or strongly agreed they are useful techniques to analyze risk under the four project attributes. Scenario analysis has not been assessed as an inappropriate tool (Median of "Strongly Agree" for high complexity and cost and for compressed schedule) but it is the only technique with two "Uncertain" medians for low complexity and cost.

Median Answer	High Com-plexity	Low Com-plexity	High Cost	Low Cost	Develo-ped Scope	Undeve-loped Scope	Uncom-pressed Schedule	Com-pressed Schedule
Brainstorming	SA	A	A	A	A	SA	A	SA
Checklist	SA	A	SA	A	SA	A	A	SA
RBS	SA	A	SA	A	SA	A	A	A
EV	SA	A	SA	A	A	SA	A	SA
MCS	SA	A	SA	A	SA	A	SA	SA
Sensitivity Analysis	A	A	A	A	A	A	A	A
Risk Matrices	SA	A	SA	A	SA	SA	A	SA
Scenario Analysis	SA	U	SA	U	A	A	A	SA

Table 21 – Usefulness of the eight risk-analysis methods based upon project characteristics

From Table 21, it can be inferred that the eight selected risk-analysis tools address very well a high complexity, a high cost, and a compressed schedule. Another interesting point is that the eight methods are consistently more useful (at least as useful) for one of the opposite for each project characteristics. Indeed, all eight methods are better (at least as good as) when complexity is high (vs. low), when cost is high (vs. low), and when schedule is compressed (vs. uncompressed) since the median score is higher (or the same). However, for the project attribute *scope*, some methods have been assessed by respondents to be more useful when scope is undeveloped (brainstorming, EV), some when it is developed (Checklists, RBS, MCS), and the others get the same median answer (sensitivity analysis, risk matrices, scenario analysis).

This chapter does not go into depth in the analysis of the results for each risk-analysis method. All the information referring to each individual risk-analysis method will be analyzed more specifically in the next chapter.

Conclusion

This chapter presented the results of the surveys. The first survey drew an initial picture of risk-analysis methods, while the second asked specific questions about each of the eight selected methods. However, the results of the second survey were also presented for purposes of comparison. Results of the two are relatively close.

The analysis of each method considered individually for the purpose of establishing their strengths, weaknesses, and best implementation situations, will be presented in the following chapter.

CHAPTER VI

METHODS USEFULNESS

Introduction

Often, decision-makers must determine appropriate risk-analysis methods to use on a project. This chapter helps to inform these decisions through the survey data and the literature. It presents the strengths and weaknesses of each risk-analysis method along with the project characteristics and phases during which the performance of risk-analysis is warranted. Appendix F provides detailed results for each of the eight methods and their associated charts.

To reiterate, the eight risk-analysis methods selected for analysis include those for risk-identification (brainstorming, checklist, risk breakdown structure) and risk-analysis (expected value, Monte-Carlo simulation, sensitivity analysis, risk matrices, scenario analysis).

The chapter presents each method followed by responses regarding the method's usefulness based on project phase and project characteristics and responses regarding the strengths and weaknesses of these methods. It concludes with a summary intended to help decision-makers select appropriate risk-analysis methods based upon projects.

Individual analysis of the eight methods

The results for each of the eight selected methods integrated in survey 2 are presented in this section. It focuses on the individual methods only; some comparisons are drawn afterward.

Brainstorming

The large majority of the respondents implement brainstorming between once a month and a few times per year. Of the twenty-seven responses analyzed, twenty-two mentioned implementing brainstorming. The assessment of the usefulness of this technique in the following paragraphs is based on those responses.

Definition

Brainstorming is a broad category that involves group discussions and interactions between members to generate ideas (Al-Bahar and Crandall, 1990; Anderson et al., 2010). Examples of brainstorming include interviews and nominal group techniques.

Brainstorming is used mostly in the identification step but can also be implemented as an informal risk-analysis technique.

Project Phase

The results from the responses for the usefulness of brainstorming based upon project phases are shown in Table 22. Brainstorming has been rated as an especially effective tool at the front-end planning phase, with 100 percent of the respondents agreeing (33 percent) or strongly agreeing (67 percent) that it is a useful tool at the very beginning of a project. Construction (76 percent of the respondents agreeing or strongly agreeing) and Start-Up (38 percent of the respondents strongly agreeing) are also relevant phases in which the use of brainstorming is considered useful.

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	10%	10%	14%	29%	38%
Construction	5%	14%	5%	52%	24%
Procurement	5%	10%	29%	43%	14%
Detail Engineering	0%	14%	29%	43%	14%
Front End Planning	0%	0%	0%	33%	67%

Table 22 – Usefulness of brainstorming based upon project phases

Anderson et al. (2010) argued for the use of brainstorming in the early phases in order to generate risks that would be analyzed in greater depth at later phases. At front-end planning (cf. Appendix C) not all risks are identified, and the assessment of these risks may be inexact, so a detailed analysis will not be precise. One respondent said, "It is the first step in a continual process of assessing and mitigating risk," but it "does not provide the detailed information required to further develop the risk management plan". Often, this technique is used in combination with another method.

Project Characteristics

The results for the usefulness of brainstorming based upon project characteristics are shown in Table 23. For two of the eight project characteristics (considering the opposites) brainstorming was rated as useful by the respondents: high complexity (67 percent strongly agreeing and 24 percent agreeing) and undeveloped scope (57 percent strongly agreeing and 33 percent agreeing).

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	0%	10%	14%	19%	57%
Uncompressed Schedule	0%	0%	14%	57%	29%
Undeveloped Scope	0%	5%	5%	33%	57%
Developed Scope	0%	19%	5%	38%	38%
Low Cost	5%	10%	14%	43%	29%
High Cost	0%	10%	5%	38%	48%
Low Complexity	5%	10%	14%	43%	29%
High Complexity	0%	10%	0%	24%	67%

Table 23 – Usefulness of brainstorming based upon project characteristics

Schedule is a characteristic that divides the respondents' opinions. When the schedule is compressed most respondents (57 percent) strongly agreed that brainstorming is a useful technique, but the variability of the results is rather high. On the other hand, for an uncompressed schedule, most respondents agreed "only" on the usefulness of the technique, but the variability is smaller. Overall, it does not seem that this particular characteristic has an influence on the perceived usefulness of brainstorming.

Benefits and Barriers

Most respondents agree with Akintoye and MacLeod (1997) and Anderson et al. (2010) that brainstorming fosters diverse viewpoints. It allows project stakeholders to offer their input, and thus brings experience from a variety of different backgrounds and disciplines. In addition, even though it generates a high number of risks, the process can be quick (Anderson et al., 2010; Dillar et al., 2003). As one respondent described it, "Brainstorming guided by checklists generated from lessons learned tends to cover most situations and identify more risk items". Respondents specified that another advantage of brainstorming is that it facilitates the development of collaborative solutions. Indeed, when a quick decision is needed, managers can meet and work together on a solution. On small projects with few risks, brainstorming obviates the need for risk-analysis methods which cost more time and money.

There are a few limits to brainstorming that would prevent managers from identifying risks. Some respondents (a third of respondents not implementing the technique – cf. Table 19) explained that they are not using the method because it is time-consuming. This aspect was also pointed out by some authors who have argued that these discussions (though beneficial) may last too long (Li and Shi, 2008). A weakness not mentioned in the literature, but highlighted by a respondent, is that brainstorming brings together people from high levels in the organization who may not be aware of details of the risks involved. People in all levels of an organization may have useful knowledge and input to bring to the discussion but would often not be included in the identification process. Finally, two respondents argued that this method lacks the in-depth quality of more quantitative approaches. Indeed, brainstorming does not include any quantitative process which would make the analysis more reliable and is based on the subjective opinions of participants (even though it leads to a consensus).

Summary

Brainstorming is especially useful during the front-end planning phase and on projects involving a high degree of complexity and/or undeveloped scope. It generates risk-gathering from discussions between stakeholders. It is particularly powerful when used in combination with checklists. The drawback of the method is the amount of time it takes to implement and the need for long meetings between risk managers.

Risk Checklists

About half of the respondents (53 percent) implement risk checklists a few times a year, but a significant number of them (18 percent) use the checklists less than once a year. Out of the twenty-seven analyzed responses to the survey, eighteen favor implementing risk checklists. The assessment of the usefulness of this technique in the following paragraphs is based on those responses.

Definition

Risk checklists are lists of risks realized and/or identified in previous projects. They are used typically to classify risks into meaningful categories (e.g., technical risks, external risks, environmental risks). Checklists are the classic format using historical databases (Al-bahar and Crandall, 1990; Anderson et al., 2010; Dey et al., 2002; Li and Shi, 2008; Simister, 1994).

Project Phase

The results for the respondents as to the usefulness of risk checklists based upon project phases are shown in Table 24. Respondents indicated that checklists are helpful during risk-identification at all stages of project development. This method is widely used in practice, with over 75 percent of respondents agreeing or strongly agreeing on the usefulness of checklists. The method seems to be particularly useful for front-end planning, since all respondents at least agreed (61 percent strongly agreed). For the four other phases, respondents rated checklists similarly. The frequency and variability are comparable.

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	12%	0%	12%	29%	47%
Construction	12%	0%	0%	47%	41%
Procurement	6%	6%	12%	53%	24%
Detail Engineering	6%	6%	6%	47%	35%
Front End Planning	0%	0%	0%	39%	61%

Table 24 – Usefulness of risk checklists based upon project phases

As stated in Chapter 2, whatever the project phase, checklists should not be used as the only method of identifying risks, since they tend to overlook specific uncertainties (Al-Bahar and Crandall, 1990; Anderson et al., 2010).

Project Characteristics

The results of the respondents for the usefulness of risk checklists based upon project characteristics are shown in Table 25. Responses indicate that this method is useful in almost all aspects of a project. None of the respondents strongly disagreed about the usefulness of the method under each of the eight project attributes, and only one (representing only 6 percent) disagreed for undeveloped scope and high complexity. It is the only method in this situation.

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	0%	0%	12%	29%	59%
Uncompressed Schedule	0%	0%	18%	53%	29%
Undeveloped Scope	0%	6%	12%	35%	47%
Developed Scope	0%	0%	12%	35%	53%
Low Cost	0%	0%	29%	35%	35%
High Cost	0%	0%	17%	28%	56%
Low Complexity	0%	0%	22%	44%	33%
High Complexity	0%	6%	11%	28%	56%

Table 25 – Usefulness of risk checklists based upon project characteristics

If high complexity and high cost are well addressed by checklists, respondents also emphasized that this method is particularly useful when those two characteristics (complexity and cost) are low (respectively 77 and 70 percent of the respondents agreeing or strongly agreeing). With 59 percent of the respondents strongly agreeing and 29 percent agreeing, risks in a project with a compressed schedule have been assessed as very well identified by means of risk checklists. The responses for scope are extremely similar between the two opposites (developed and undeveloped scope), which means that the state of this project attribute does not influence its usefulness.

Benefits and Barriers

For many of the respondents, using checklists is helpful to begin the risk identification process. It enables managers to ensure that all standard risks have been assessed and that no major risk has been overlooked. This contradicts the recommendation of Anderson et al. (2010), who state that checklists are best used at the end of the identification process (to make sure that no major risk has been overlooked) so as not to inhibit brainstorming effectiveness or project-team ownership of the risk list. Risk checklists also help to categorize the risk elements, and, as stated earlier, they are useful tools for processing lessons learned from previous projects to be captured in the organizational memory. As one respondent stated, risk checklists are particularly useful when a company or department is always performing the same kind of projects in similar environments and thus with similar risks and uncertainties.

The major detriment of using risk checklists is that they may not take into consideration the unique aspects of the current project. Indeed, despite similarities in project type, each job is different from any other. Therefore, the technique may overlook specific risks to the project that will have to be identified with another tool. Overlooking specific risks is the major disadvantage mentioned in the literature (Al-Bahar and Crandall, 1990; Anderson et al., 2010). Another major drawback that respondents indicated was that the method can turn into a routine in which risks are not identified seriously. Of the respondents not implementing this method, 50% justified their responses by arguing that the method is bad. Because they may limit the thinking of people using them and categorize risks too broadly, checklists are considered at best "superficial roadmaps" (again contradicting Anderson et al.).

Summary

Respondents indicated that checklists are useful for multiple project phases and characteristics; however, they are most frequently used when projects have compressed schedules. Although the technique can be powerful, it may overlook project-specific risks and therefore may need to be used in combination with another technique. As respondents indicated, "Checklists shouldn't be used as the only means of identifying risks"; they "address lessons-learned items, and brainstorming can then supplement the list". Finally, the usefulness of the checklists depends more on the checklist itself: "Much depends on the structure and content of the checklist as to whether or not it is a useful tool".

Risk Breakdown Structure

RBS is one of the least used methods: none of the respondents implement it on a very frequent basis (once a week), and the majority (58 percent) use the method a few times a year. One fourth of the respondents said they use this tool rarely, i.e., less than once per year. Out of the twenty-seven analyzed responses to the survey, thirteen mentioned implementing RBS. The following assessment of the usefulness of this technique is based on those responses.

Definition

A risk-breakdown structure (RBS) is a method used to organize risks in a hierarchal categorization. This type of categorization illustrates risk interrelationships and provides a framework for the management of risks depending on their similarities (Anderson et al., 2010; Hillson, 2006; Holzmann and Spiegler, 2010; Iranmanesh et al., 2007). The RBS for risk is analogous to a work-breakdown structure for project controls.

Project Phase

The results of the respondents as to the usefulness of RBS based upon project phases are shown in Table 26. Contrary to risk checklists, respondents indicated that RBS is not equally useful at all phases of the construction process. It seems that the usefulness decreases along the course of a project's phases. Indeed, responses indicate that the tool is quite useful at the front-end planning stage, with 50 percent of the respondents strongly agreeing, 25 percent agreeing, and 0 percent strongly disagreeing. For the four other phases, the proportion of respondents disagreeing with the usefulness of the method is rather high: 27 percent for detail engineering, 38 percent for procurement, 42 percent for construction, and 45 percent for start-up. This last phase (start-up) appears to be the least appropriate phase for implementing RBS, and, as stated in the last chapter, it is the only case in which the median answer of the respondents is "uncertain" (cf. Table 20).

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	27%	18%	9%	18%	27%
Construction	17%	25%	0%	17%	42%
Procurement	9%	27%	9%	18%	36%
Detail Engineering	18%	9%	0%	27%	45%
Front End Planning	0%	8%	17%	25%	50%

Table 26 – Usefulness of risk breakdown structure based upon project phases

RBS is a complex and time-consuming method to implement (compared to brainstorming and risk checklists), and therefore needs to be initiated early in the project to be worthwhile (Anderson et al., 2010).

Project Characteristics

The results of the respondents as to the usefulness of RBS based upon project characteristics are shown in Table 27. Scope is the project characteristic that makes a significant change in the usefulness of RBS in identifying risks. Indeed, almost 82%

of respondents strongly agree that RBS is useful if the scope is developed, compared to the only 36% when the scope is undeveloped. When the scope is developed, it is easier to implement this method, since changes are less likely to happen (Anderson et al., 2010).

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	8%	0%	17%	33%	42%
Uncompressed Schedule	9%	0%	18%	27%	45%
Undeveloped Scope	9%	9%	18%	27%	36%
Developed Scope	0%	0%	18%	0%	82%
Low Cost	8%	8%	8%	50%	25%
High Cost	0%	0%	25%	17%	58%
Low Complexity	8%	8%	25%	17%	42%
High Complexity	8%	8%	0%	17%	67%

Table 27 – Usefulness of risk breakdown structure based upon project characteristics

For cost and complexity, responses indicate that a high of level of the characteristic would make RBS more useful, but the differences between the two opposites (high and low) are not as significant as for scope. Finally, for schedule, the distribution of the respondents' assessments is very similar, which means that the attribute schedule does not have a major influence on the method's usefulness.

Benefits and Barriers

The main strength of RBS is that it helps into organizing project risks and in creating a historic database (Molenaar et al., 2010). It is considered a risk-identification tool, but is more about categorizing risks that have been identified so that they can be better assessed and analyzed. The tool also helps to identify new risks from discussion resulting in this categorization (Hillson, 2006). Respondents also emphasize that it helps determine if "some risks demand shifts on other resources". Moreover, RBS is very valuable for communicating on the topic of risks with other stakeholders and for updating the breakdown. The method allows for modification.

Surprisingly, respondents implementing the method did not elaborate on any weaknesses of this risk-identification tool. However, about half (52 percent, cf. Table 17) are not using RBS to identify risks, and for 50 percent of them (Table 19) it is because they either do not know the method or are not familiar enough with it.

Summary

Respondents indicated that RBS is useful in the early phases (and rather less useful in the later phases) and under a developed scope. Although the technique takes time to implement, it provides very useful help in risk categorization for the sake of future discussion of adequate response and allocation. However it seems that a lot of managers are not using it, especially because of a lack of training in the use of that tool.

Expected Value

A large majority of the respondents (81 percent, cf. Table 18) implement expected value between once a month to a few times a year. Out of the twenty-seven analyzed responses to the survey, sixteen implement EV. The assessment of the usefulness of this technique in the following paragraphs is based on those responses.

Definition

Expected value (EV) is a probability-weighted sum of all possible inputs (Schuyler, 2001). For example, if a risk has a fifty-percent chance of occurrence and a value of $100 if it occurs, the expected value for the risk is 0.5 x $100 = $50.

Project Phase

The results of the respondents for the usefulness of EV based upon project phases are shown in Table 28. EV is assessed by respondents as useful across the five project phases. However, respondents established that this method is useful in front-end planning (63 percent of respondents strongly agreeing) and procurement (80 percent of the respondents agreeing and 0 percent disagreeing).

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	0%	7%	33%	13%	47%
Construction	0%	6%	19%	25%	50%
Procurement	0%	0%	20%	40%	40%
Detail Engineering	0%	7%	20%	33%	40%
Front End Planning	0%	13%	6%	19%	63%

Table 28 – Usefulness of expected value based upon project phases

EV is a basic tool which provides a single-point estimate, which raises a problem: providing a single estimate, it misses the range of uncertainty (Schuyler, 2001). That is why the usefulness of EV is not dependent on a project's phases but on its characteristics.

Project Characteristics

The results of the respondents for the usefulness of EV based upon project characteristics are shown in Table 29. According to respondents, expected value is useful for highly complex projects. Indeed, all the respondents agreed that EV is a useful tool for analyzing risk in a project (75% strongly agreed and 25% agreed). Whether is useful or not does not depend on scope (similar distributions for developed and undeveloped scope).

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	0%	0%	13%	27%	60%
Uncompressed Schedule	0%	13%	20%	33%	33%
Undeveloped Scope	0%	0%	20%	27%	53%
Developed Scope	0%	7%	7%	40%	47%
Low Cost	0%	7%	27%	27%	40%
High Cost	0%	0%	13%	25%	63%
Low Complexity	0%	13%	13%	33%	40%
High Complexity	0%	0%	0%	25%	75%

Table 29 – Usefulness of expected value based upon project characteristics

The two other project attributes which make EV useful are high cost and compressed schedule (87 percent of respondents agreeing including more than 60 percent strongly agreeing).

Benefits and Barriers

EV is the simplest application of quantitative analysis and is easy to use. Respondents pointed out that it is a good method for defining potential impact value and can serve as a basis for discussion with management teams. Very often people place more value on quantitative than on qualitative analysis. Despite this quantitative characteristic, the literature confirms that EV is also quick and basic (Schuyler, 2001). The method determines and quantifies the potential impact of risk items. As it is the best single-point estimate, it projects the probable general outcome. Also, the method is useful for determining contingencies. EV enables managers to calculate the base cost of the project, to which a contingency amount is added. However, as we saw in Chapter 2, even though it has been standard practice in the industry, this method of applying contingency amounts deterministically can lead to a bad bid or an under-estimation of risk level (Back et al., 2001; Yeo, 1990).

There is a large consensus on the weaknesses of the EV method. The major constraint is accuracy of assessment. As established in Chapter 2, EV provides only a single-point value and therefore misses a large quantity of information (Schuyler, 2001). As one respondent observed, reliance on EV alone can lead to "false explanations of magnitude of risk". For reliable EV analysis, data must be valid, which is seldom the case, especially in the early phases of the project. Respondents not implementing EV to analyze risk confirm this conclusion, saying that the method is not accurate enough to help them make decisions.

Summary

Regardless of project phase, respondents indicated that EV can be used as a basis for discussion between risk managers, especially if the level of complexity is high. The main reason to support that it is not useful for in-depth analysis is that it misses information. However, it is an effective single-point estimate.

Monte-Carlo Simulation

Two third of the respondents implement Monte-Carlo simulation a few times a year. Out of the twenty-seven analyzed responses of the survey, fourteen implement MCS. The assessment of the usefulness of this technique in the following paragraphs is based on those responses.

Definition

Monte-Carlo Simulation (MCS) is a computerized probabilistic simulation-modeling technique that uses random-number generators to draw samples for probability distributions. MCS involves repetitive trials to generate overall probability distributions for project cost and schedule (Akintoye and MacLeod, 1997; Anderson et al., 2010; Dawood, 1998; Diekmann et al., 1997; Schuyler, 2001; Willmer, 1991).

Project Phase

The results from the respondents as to the usefulness of MCS based upon project phases are shown in Table 30. Respondents indicated that MCS is a particularly useful tool for analyzing risk in construction, with 79 percent of the respondents strongly agreeing and 14 percent agreeing. To run a Monte-Carlo simulation, an assessment of risk probability and severity (expressed in terms of distributions) is needed and constitutes a larger amount of data than required by other techniques (Akintoye and MacLeod, 1997).

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	7%	7%	21%	29%	36%
Construction	7%	0%	0%	14%	79%
Procurement	0%	14%	14%	14%	57%
Detail Engineering	0%	7%	14%	21%	57%
Front End Planning	0%	7%	14%	29%	50%

Table 30 – Usefulness of Monte-Carlo simulation based upon project phases

The responses also show that MCS is useful in the first three phases, for which the distribution of the respondents' assessments is similar (around 80% agreeing including around 55% strongly agreeing on the usefulness of the method). Finally, respondents indicated that MCS is less useful in the last phase (start-up), with only 36 percent of the respondents strongly agreeing and a significant variability in the results. The MCS process is work-intensive and therefore may not be as appropriate less data-intensive techniques.

Project Characteristics

The results from the respondents as to the usefulness of MCS based upon project characteristics are shown in Table 31. From these results we can infer that MCS is especially useful when complexity and/or cost are high. Indeed, all the respondents agreed on the effectiveness of this method of analyzing risk in a project, with 86 percent and 79 percent of the respondents strongly agreeing in regard to those two characteristics (high complexity and cost respectively).

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	0%	0%	7%	21%	71%
Uncompressed Schedule	0%	0%	7%	29%	64%
Undeveloped Scope	0%	0%	21%	29%	50%
Developed Scope	0%	0%	14%	14%	71%
Low Cost	0%	8%	15%	31%	46%
High Cost	0%	0%	0%	21%	79%
Low Complexity	0%	14%	21%	29%	36%
High Complexity	0%	0%	0%	14%	86%

Table 31 – Usefulness of Monte-Carlo simulation based upon project characteristics

A developed scope has also been assessed by respondent as a project attribute that would make MCS a useful risk-analysis method (71 percent strongly agreeing). However the difference between a developed and an undeveloped scope is smaller than what it is between the opposites of the two project characteristics complexity and cost. Finally the distribution of the frequency for schedule is similar when it is either compressed or uncompressed, and, therefore, the usefulness of MCS does not depend on this project characteristic.

Benefits and Barriers

Monte-Carlo simulation is a formal method for generating probability distributions for cost and schedule. This powerful tool "allows for in-depth analysis if done properly for complex projects". This point, highlighted by a respondent, confirms that high complexity is extremely well addressed by the MCS method. This was also established in Chapter 2, since the literature emphasized that the major strength of the method is that it accounts for complexity (Schuyler, 2001). Another advantage of MCS emphasized in the literature (Dawood, 1998; Diekmann et al., 1997; Willmer, 1991) and confirmed by respondents is robustness of representation. It can take both quantitative (and qualitative) inputs and produce quantitative output. These results are a basis for management discussion and risk-management decisions, since the tool generates a lot of statistical output.

As for expected value, as the analysis relies on only numeric assessment of a risk's probability of occurrence and probable impact, the numbers put into the simulation must provide a first basis for analysis. MCS also allows for the modeling of relationships amongst risks. Therefore the advantage of MCS over expected value is the capability to enter ranges and distributions for input rather than a single point-estimate value. This need for precise data was underlined in the literature (Akintoye and MacLeod, 1997). As a result of the uncertainty in the data input into the model, the accuracy of the model can be questioned, with only possible and approximate results of the model being simulated (Schuyler, 2001). 35 percent of respondents not implementing MCS indicated that the technique requires a high degree of sophistication. Indeed, even though software has been developed, the process is complex and requires training for mastery. 20 percent of respondents also indicated that it is time-consuming to compute, which confirms a major drawback established in Chapter 2 (Schuyler, 2001).

Summary

Monte-Carlo simulation is a major risk-analysis tool which provides useful results that can be applied in undertaking the most appropriate actions to manage risks. MCS has been assessed as a useful tool along a project's phases, even though its usefulness varies: it is of especial usefulness in construction. Respondents also emphasized the significant usefulness of the method when applied in a project with high cost and/or complexity, confirming the main consensus of the literature. The software used to compute the method enables managers to apply this heavy process to a wider range of projects, even the smallest.

Sensitivity Analysis

Like risk-breakdown structure, sensitivity analysis is one of the least-used methods with half of the respondents using it a few times a year and one fourth less than once year. Of the twenty-seven analyzed responses to the survey, twelve implement sensitivity analysis. The assessment of the usefulness of this technique in the following paragraphs is based on those responses.

Definition

Sensitivity analysis is a deterministic technique that shows the effect of change of a single variable on project outcomes (Hayes and Perry, 1985; Willmer, 1991; Yeo, 1991). It also analyzes the possible cost or time consequences implied by those changes. It is an integral part of the Monte-Carlo simulation, but not exclusive to simulation techniques.

Project Phase

The results from the respondents as to the usefulness of sensitivity analysis based upon project phases are shown in Table 32. The proportion of respondents who strongly agreed on the usefulness of the method in each of the five phases is rather low (maximum of 36 percent for detail engineering and minimum of 17 percent for construction). Also, about a third (between 27 and 36 percent) of the respondents disagreed or strongly disagreed about the usefulness of sensitivity analysis for front-end planning, procurement, and start-up. Even though the overall picture provided by respondents shows that it is a useful technique, it seems to be less appropriate than other risk-analysis methods, especially for the three phases cited above.

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	9%	9%	9%	45%	27%
Construction	8%	8%	0%	67%	17%
Procurement	0%	27%	9%	45%	18%
Detail Engineering	0%	9%	9%	45%	36%
Front End Planning	0%	18%	18%	45%	18%

Table 32 – usefulness of sensitivity analysis based upon project phases

Project Characteristics

The results from the respondents as to the usefulness of sensitivity analysis based upon project characteristics are shown in Table 33. Respondents indicated that there is significant difference in the usefulness of the method depending on the states of complexity and cost. When complexity and cost are high, sensitivity analysis is rated as useful, with respectively 100 percent and 90 percent agreeing. On the other hand, when these two characteristics are low, respectively 45 percent and 36 percent of the respondents disagree or are uncertain about the usefulness of the tool.

According to the results provided in Table 33, sensitivity analysis is more useful when scope is developed, even when the difference between undeveloped and developed scope is minor. Finally, the distributions of the respondents' assessment of uncompressed and compressed schedule are quite similar. If complexity and cost make an important difference in the usefulness of sensitivity analysis, it seems not to be the case for schedule.

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	0%	0%	9%	55%	36%
Uncompressed Schedule	0%	0%	18%	55%	27%
Undeveloped Scope	0%	27%	0%	45%	27%
Developed Scope	0%	8%	8%	33%	50%
Low Cost	9%	9%	18%	36%	27%
High Cost	0%	0%	9%	45%	45%
Low Complexity	9%	9%	27%	27%	27%
High Complexity	0%	0%	0%	50%	50%

Table 33 – Usefulness of sensitivity analysis based upon project characteristics

Benefits and Barriers

Sensitivity analysis can help managers understand the depth of the risks and prioritize them. The main strength of the method underlined in the literature is its ability to show the relative importance of variables (Yeo, 1991). This has been confirmed by respondents who use the method to determine which risk factors are drivers and therefore determine the critical path: "sensitivity analysis determines which tasks impact the critical path the most and have the widest possible range of outcome."

As for other formal risk-analysis techniques presented earlier, the data used in the process absolutely needs to be strong, otherwise "this tool is just building on a weak foundation". Another drawback of the method underlined by respondents is the difficulty of determining which variables are useful and which should not be included in the analysis. However, in Chapter 2, we established that the main limitation is that the method treats variables individually and therefore does not take into account correlation (Yeo, 1991). Respondents not using the methods justify their choices by claiming a lack of knowledge of the method (35 percent), that it is an overly time-consuming technique (20 percent), or that it constitutes a large investment for minimal benefit (20 percent).

Summary

The results showed an important variability in the respondents' assessment of the usefulness of sensitivity analysis based upon project phases. It seems useful in construction and detail engineering, even though the proportion of respondents agreeing is lower than for other techniques. Complexity and cost are the two project characteristics indicated by respondents that would influence the effectiveness of the technique. The method is good for prioritizing risks and determining which should have the greatest impact on the project objectives. Therefore, some respondents indicate that it is helpful to use sensitivity analysis in combination with another risk-analysis tool: "sensitivity analysis should be used to test assumptions, values and probabilities used in other risk methods".

Risk Matrices

About two thirds of the respondents (65 percent, cf. Table 18) implement risk matrices a few times a year. Of the twenty-seven analyzed responses of the survey, twenty implement risk matrices. The assessment of the usefulness of this technique in the following paragraphs is based on those responses.

Definition

A risk matrix is a method of risk analysis that links the probability and severity of risk factors in the analysis of their overall probable consequences (Anderson et al., 2010; Ward, 1999; Williams, 1996). It is also called a Probability x Impact matrix (PxI). It is formed by combining each risk's probability of occurrence (frequency) with its impact on project objectives (severity) to rank risks or determine the level of priority to be assigned to each risk (e.g., high, medium, low, etc.).

Project Phase

The results from the respondents as to the usefulness of risk matrices based upon project phases are shown in Table 34. Respondents indicated that risk matrices are very useful at almost all stages of project development and especially during the three middle phases, with 95 percent, 89 percent, and 100 percent of the respondents agreeing on the usefulness of the method for, respectively, detail engineering, procurement, and construction. Start-up has been assessed as a bit less useful, with 21 percent of respondents disagreeing or uncertain.

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	5%	11%	5%	32%	47%
Construction	0%	0%	0%	45%	55%
Procurement	0%	0%	11%	42%	47%
Detail Engineering	0%	5%	0%	40%	55%
Front End Planning	0%	11%	5%	26%	58%

Table 34 – Usefulness of risk matrices based upon project phases

Project Characteristics

The results from the respondents as to the usefulness of risk matrices based upon project characteristics are shown in Table 35. Respondents indicated that risk matrices are useful under almost all of the studied characteristics. The most significant one is compressed schedule, with 74 percent of the respondents strongly agreeing and 26 percent agreeing on the usefulness of the method in a project with a compressed schedule. The distribution for scope is rather similar, a project with a developed scope being a bit more suited to risk matrices.

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	0%	0%	0%	26%	74%
Uncompressed Schedule	0%	6%	11%	44%	39%
Undeveloped Scope	6%	6%	0%	28%	61%
Developed Scope	0%	0%	6%	22%	72%
Low Cost	6%	0%	17%	33%	44%
High Cost	0%	5%	0%	32%	63%
Low Complexity	6%	6%	17%	28%	44%
High Complexity	0%	5%	0%	32%	63%

Table 35 – Usefulness of risk matrices based upon project characteristics

Risk matrices have also been assessed as useful by respondents when cost and/or complexity are high (63 percent strongly agree and 32 percent agree). However, the interesting part of the results is that the method has also been assessed as relatively good for analyzing risks in a project with a low complexity and/or cost. The respondents rating is relatively higher than of other methods for those two characteristics (low cost and complexity), since three fourths of the respondents agreed on the usefulness of risk matrices in this particular kind of situation.

Benefits and Barriers

Risk matrices identify risk priorities by sorting them and determining which should be monitored closely by managers. The tool is very easy to use, and prioritization enables decision makers to undertake appropriate action. A risk matrix provides a view of risk factors in a less quantitative format; it allows decision makers to compare and classify risks. It is an effective meeting-discussion tool, since it is visual and easily updated. In addition it is often a handy format enabling the client to understand risk levels and observe their probable evolution. Various authors have indicated that the major advantage of risk matrices is their ability to depict the tradeoffs between frequency and severity (Anderson et al., 2010; Ward, 1999; Williams, 1996). This leads to an interesting point mentioned by one of the respondents: the method saves time spent focusing on less relevant risks. "Without this tool, one could spend hours planning a response to a risk that is not a high priority. It is used most effectively if there are definitions accompanying the measures of probability and impact. Otherwise, there may be considerable lengthy discussion as to the measures of the risk."

Respondents did not ascribe many drawbacks to this method. One emphasized by the literature and underlined by some respondents is that the model might be too simple. It is a two-dimensional matrix that classifies risk in a limited number of categories, – typically three – Low, Medium, High. Another problem raised in the literature

(Williams, 1996) is that two different risks can have the same medium consequence arising from the risk matrix, but they can be very different (low probability with high impact versus high probability with low impact). These two risks with the same expected consequence must be addressed differently. That is why definitions and explanations of probability and impact must accompany the matrix so that appropriate action can be taken to address each risk. 56 percent of respondents not implementing risk matrices indicated that they lacked knowledge of or familiarity with the method.

Summary

Risk matrices are a simple yet frequently used method of risk analysis in all project phases and characteristics. They are of especial usefulness during construction and in projects with compressed schedules.

Scenario Analysis

Scenario analysis is often implemented by respondents (63 percent are using it between once a week and once a month). Even though the frequency of implementation is high, of the twenty-seven analyzed responses to the survey, only eight implement scenario analysis. The following assessment of the usefulness of this technique is based on those responses.

Definition

A scenario analysis identifies and defines the possible scenarios that can lead to different outcomes. The probability of occurrence of all those scenarios can determine the most likely scenario (Hanagan and Norman, 1995; Jobling et al., 2006; Juhong and Zihan, 2009; Oryang, 2002).

Project Phase

The results from the respondents as to the usefulness of scenario analysis based upon project phases are shown in Table 36. Respondents indicated that scenario analysis is not equally useful in all phases of the construction process. They asserted that the method is particularly useful at front-end planning and start-up, with respectively 75 and 63 percent of the respondents strongly agreeing and none disagreeing. To a smaller extent construction is a phase in which respondents think it is also useful to implement scenario analysis.

Project phases	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Start-Up	0%	0%	13%	25%	63%
Construction	0%	0%	0%	63%	38%
Procurement	13%	0%	13%	38%	38%
Detail Engineering	0%	13%	13%	38%	38%
Front End Planning	0%	0%	0%	25%	75%

Table 36 – Usefulness of scenario analysis based upon project phases

On the other hand, the method seems to be less useful for detail engineering and procurement, since 26 percent of the respondents disagree on its usefulness and only 38 percent strongly agree.

Project Characteristics

The results from the respondents as to the usefulness of scenario analysis based upon project characteristics are shown in Table 37. Scenario analysis is the only method for which the median answer for the usefulness based a project characteristic is "uncertain". It happens for low cost and complexity. It is especially relevant that when cost and/or complexity are high, respondents indicated that scenario analysis is quite useful (63 percent of respondents strongly agree for both).

Project Characteristics	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Compressed Schedule	0%	0%	0%	38%	63%
Uncompressed Schedule	0%	0%	13%	63%	25%
Undeveloped Scope	0%	0%	13%	50%	38%
Developed Scope	0%	0%	0%	63%	38%
Low Cost	13%	0%	38%	50%	0%
High Cost	0%	0%	13%	25%	63%
Low Complexity	0%	13%	38%	50%	0%
High Complexity	0%	0%	0%	38%	63%

Table 37 – Usefulness of scenario analysis based upon project characteristics

Respondents also indicated that the tool addresses well a project with a compressed schedule. However, the distribution of the responses is not very different from those for an uncompressed schedule. As far as scope is concerned, the results of the survey show that this characteristic does not have a major influence on the method's usefulness, since the respondents' assessments are the same for both uncompressed and compressed schedule.

Benefits and Barriers

As emphasized in the literature (Haganan and Norman, 2005; Oryang, 2002), the main advantage of scenario analysis is that it enables managers to identify and prepare responses to potential chain-of-events scenarios before their occurrence. These often take the format of "what-if" and "if-then" chains, and these considerations make possible the assessment of the effect of uncertainty in advance of actual problems. This explains why the method rates highly in front-end planning versus middle phases of project development (detail engineering and procurement). Juhong and Zihan (2009) also elaborate on the strength of this method at an early phase. Respondents indicated that the tool is efficient for showing management "the potential effects of the multiple choices they might have concerning a decision that needs to be made". Another advantage of the method is that, by proposing chains of events, it involves various disciplines and their perspectives in the scenario.

None of the respondents clearly established a specific disadvantage of using scenario analysis as a risk-analysis tool. However, it lacks the advantages of other methods during the middle phases of the construction process. 38 percent of respondents not implementing the technique are unfamiliar with it or believe it is time-consuming and do not feel they would have enough time to implement it and make it worthwhile.

Summary

Respondents indicate that scenario analysis, considering risks in advance of actual problems, is more useful during front-end planning and start-up (extreme phases). In terms of project characteristics, they also indicated that, in projects with low complexity and cost, risks should not be analyzed with this method.

Across comparison of the methods

Although it was not the goal of the survey since the questions were addressed to one specific risk-analysis technique, it is possible to compare the eight selected methods across project characteristics and phases. However, only comparable items can be compared: risk-identification techniques cannot be compared to risk-analysis techniques, since they are not used for the same purposes.

Except sensitivity analysis, all methods have been assessed by respondents as useful for front-end planning. However, scenario analysis (respectively brainstorming and checklists) appears to be the most effective risk-analysis (respectively risk-identification) technique.

For detail engineering, procurement, and especially construction, respondents rated Monte-Carlo simulation and risk checklists as the most useful methods for risk-analysis. In terms of risk-identification, checklists seem to be the most useful of the three techniques analyzed. But, as stated before, the main recommendation of the respondents is to use those checklists in combination with another method.

Finally for start-up, from the respondents' individual answers, we can establish that scenario analysis is the most effective technique at this stage.

As far as the project characteristics are concerned, all methods address well projects with high complexity and cost. However, Monte-Carlo simulations and expected value are particularly efficient under high complexity, and MCS, risk matrices, and scenario analysis under high cost. On the other hand, when complexity and/or cost are low, respondents indicated that sensitivity analysis and scenario analysis should not be used to analyze risk.

Scope is a project characteristic with very different results amongst the analyzed techniques. For risk-identification methods, responses indicate that RBS is more useful when the scope is undeveloped while brainstorming is more effective when the scope is undeveloped. For risk-analysis tools, the methods are as useful when scope is undeveloped while MCS and risk matrices appear to be most useful when scope is developed.

Finally, project with a compressed schedule are best addressed by checklist (for risk-identification) and risk matrices and scenario analysis (for risk-analysis). Responses also indicate that when the schedule is uncompressed, the best method is MCS.

These trends between the different methods are the most significant ones but further research would be needed to exactly compare the tools. Survey 2 did not aim at comparing the methods but focused on analyzing each method individually.

Conclusion

In this chapter, an in-depth analysis of risk-analysis methods is presented in order to elaborate upon the strengths and weaknesses of each vis-a-vis project phases and characteristics. Some trends have been established for each method, but conclusions cannot always be drawn regarding each project attribute or characteristic. Therefore, the next chapter will summarize the investigation, limitations and future opportunities to expand the current study.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Introduction

This chapter begins with a brief summary of the research. Moreover, the contribution of the study to research and to general knowledge of the topic is explained. Limitations and barriers are also explored, and, finally, directions for future research.

Research Summary

The review of the literature presented in Chapter 2 established the basis for the investigation. Publications relating to risk-analysis methods were reviewed, listed and categorized according to steps of the risk-management process to which they refer, along with the strengths and weaknesses of each study. If most papers dealing with risk-analysis techniques present new methods or explain and apply existing ones, no one had as yet compare risk-identification and analysis methods based upon project phases and characteristics. In the literature the methods are presented and described but, as pointed out by Christian and Mulholland (1999), there is not any accepted risk-analysis method that would be always advised for use. In any explication of risk-analysis methods, little consideration has been given to their effectiveness based upon project phases or characteristics. From this assessment, the following research questions were established:

- What are the existing methods and tools that exist within the engineering and construction industry to assess and analyze risks? What are their main advantages and disadvantages?
- What is the current state of practice in the construction industry for risk-analysis methods and tools?
- Which project characteristics point to the use of more rigorous risk management processes?
- How useful are specific risk-analysis methods and tools are depending on project characteristics and phases?
- How should decision makers select the most appropriate risk-analysis method or tool based upon the specificities of his/her project?

The methodology of this investigation is described in Chapter 3 and was supported by the CIFE horseshoe. This framework consists of a succession of nine steps (Observed Problem, Intuition, Theoretical Point of Departure, Research Methods, Research

Questions, Research Tasks, Validation Results, Claimed Contributions, Predicted Impact) and served as a guideline for the investigation. The nine steps followed were described in terms of their applications to the specific topic of this research.

The current investigation is based on data collected through two surveys sent out to construction industry professionals. Chapter 4 presented the surveys' designs and explained why they were designed as they were. The first survey was used both for depicting the current use of risk-analysis methods in the construction industry and for designing the second questionnaire, which represents the core of the investigation. The second survey was shortened to focus on the most used risk-analysis methods and the project characteristics with the greatest effect on project performance.

Chapter 5 draws a picture of the use of risk-analysis methods in the construction industry based on the results of both surveys. The first questionnaire describes the use of risk-analysis tools in general, while the second questionnaire provides information about eight specific risk-analysis tools (typically those most often implemented). The results of the two surveys are compared, both leading to similar results.

Chapter 6 presents the frequency of responses regarding the appropriate timing of the eight selected risk-management tools according to project characteristics and phases. Individual data are analyzed and compared with findings from the literature (presented in Chapter 2). Respondent's comments are also included in the discussion. Chapter 6 presents a description of each method and of the project characteristics and phases that would increase/decrease its usefulness, as well as a listing of its strengths and weaknesses. Managers dealing with risks can then see the trends and tradeoffs between the methods and decide which method(s) they should or should not use to identify and analyze risk factors.

Conclusions

Risk management

The results of the two questionnaires show how the survey respondents are using risk-analysis techniques. When compared with the literature, these findings provide an indication as to the state of practice on risk identification and analysis tools. The surveys address the usefulness and concerns of the methods. The first survey considers risk management methods holistically, while the second analyzes each method individually.

Risk-analysis methods were assessed by respondents to both surveys as useful during the entire duration of the construction process, even though they are even more important and necessary in the early phases of a project.

Not all project characteristics are equal in the ways in which they bring risk and uncertainty to projects. Complexity and cost were found the two project attributes that required additional use of risk-analysis techniques. These two were followed by schedule and scope.

Brainstorming, risk checklists, risk matrices, and Monte-Carlo simulations were the most frequently used risk-analysis tools by respondents. The surveyed population (organizations members of construction associations like CII, PMI, AACEI, Risk SIG) implement the eight most often used selected techniques at a high rate. Indeed, at least 63% use the risk-analysis tools between "once a month" and "a few times a year". More qualitative techniques (such as brainstorming) are used more often than quantitative techniques (e.g., scenario analysis).

Usefulness patterns

The analysis of the results of the second survey in Chapter 6 allows us to report on some trends for risk-identification and risk-analysis methods used in the construction industry.

As far as the risk-identification techniques analyzed in this study are concerned,

- Checklists are essential tools at all stages of the project development but respondents recommended using them in combination with another method due to the chance that project-specific risks would be overlooked. During front-end planning, checklists can be used with brainstorming to encourage diversified viewpoints and interactions. They also address well almost all project characteristics and especially a compressed schedule.
- Respondents indicated that brainstorming is particularly useful during front-end planning on projects involving a high complexity and/or undeveloped scope. The major inconvenient is the needed time to implement.

- Risk breakdown structure is more useful in the early phases of the project development and under undeveloped scope.

Risk-analysis methods analyzed in this study:

- Respondents did not recommend using sensitivity analysis without another risk method. However, it helps to prioritize risk factors and determine which ones are the drivers. In consequence, it should be used in support of other risk-analysis techniques and/or to test their assumptions.
- Monte-Carlo simulations and risk matrices are useful through the course of the project and particularly in the middle phases (procurement, construction, and start-up). MCS requires a lot of information and precise data, which may not be available in the front-end planning phase. A strong argument can be made for risk matrices: the probability and severity of risks can rarely be assessed precisely and reliably at an early phase. MCS is also not as appropriate at start-up, since such a heavy process might not be necessary so late in the project. Risk matrices and MCS differ from each other by the project characteristics they address best. MCS has the advantage of accounting for complexity and therefore is highly recommended when there is high complexity and/or cost. On the other hand, risk matrices are relatively appropriate for projects with low complexity and/or cost.
- Scenario analysis enables managers to consider potential problems, and thus is useful in the front-end planning and start-up phases. Scenario analysis best addresses projects with a compressed schedule and high complexity while

respondents indicated it is not very useful when complexity and/or cost are low.

- The effectiveness of expected value is more dependent on project characteristics than project phases. It is useful when complexity is high. However, the major constrain of the method is that it only gives a single point estimate and therefore misses information.

Results in practice

The patterns established in the previous paragraphs advise the use of multiple techniques, since each has its strengths and best situations for implementation. A combination of techniques may be needed based on a project's characteristics and phases. Most methods require support and training to manage properly.

Contribution to Base of Knowledge

This investigation was initiated to fill the gap in the literature in regard to the usefulness of different risk-analysis methods. From experience, it is reasonable to assume that most companies in the construction industry that implement a formal risk management process on their projects use at best only a couple. The study shows that there are multiple techniques available and therefore alternatives for decision makers. All these techniques do not have the same particularities; each offers advantages and constraints that may determine its optimal application. The study demonstrates that project characteristics and phases influence how risk-analysis methods should be used.

In addition, some managers are unaware of the different risk-analysis methods and their benefits and limitations. The research presents the eight major tools with their advantages and disadvantages in an effort to help decision makers select the most appropriate method.

Limitations of Research

The findings of this study have many limitations. The research has not generated clear patterns of statements about all risk-analysis methods because the data is limited. Indeed, the literature does not provide information about the usefulness of methods for specific project phases and/or characteristics. Moreover, the number of respondents, 27, is relatively small, therefore only important and distinctive patterns have been revealed. A higher response rate would be needed to go further in such analysis. Also, the population surveyed is limited to members of associations of construction companies and some different inputs could be brought by selecting companies more randomly.

Project characteristics and phases were analyzed individually for each technique, which made the comparison between methods difficult with the second-survey data alone. Therefore, the results of the investigation are presented in Chapter 6 as a list, which is not a desired format for managers since the risk-analysis tools are inputs, whereas they should be outputs of the decision model. A useful decision-support system would have the characteristics and phase entered as inputs to provide the most appropriate or less useful techniques as output.

It is probable that more characteristics would have a significant influence on the effectiveness of risk-analysis tools. Those characteristics have been omitted in order to keep the survey as short as possible, though it might overlook some important information (for instance, contract type, type of project, location, delivery method, etc.).

Future Research

The limitations of this investigation can be addressed in future research. Little has been published on this topic; therefore many related topics could be identified for future research. These include:

- Additional data collection through increased number of surveys to increase the validity of the results.
- Alternative populations for the survey, for example a sampling of the top 100 owners, designers and contractors.
- Alternative data collection method, such as case studies, to provide in-depth knowledge through open-ended responses and the ability to pose additional questions of the informants.

- Including additional project parameters, such as delivery method, in the analysis.

This research analyzed the usefulness of risk-analysis methods based upon two elements, project phase and project characteristics, considered separately. However, future work could assess the combination of methods into a decision-support tool, directly usable by managers. An example is to build a table for each project phase with advice about all characteristics of all relevant risk-analysis methods. Appendix G shows such tables as models. A checkmark means that the method can be used, a cross that it should not be used, and a blank indicates no specific recommendation. However, such tables cannot be considered reliable decision-support tools until they are validated.

This research does not intend to revolutionize the use of risk-analysis tools, but, as no study has been released for a better use of the existing methods to deal with risk, it hopes to be the kick start of further research in this area. Decision makers can use the present investigation to document themselves on how to better use the techniques they are already implementing as well as identifying which techniques they should start using based on the specificities of their activities and projects.

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Appendix A

OVERVIEW OF DECISION TOOLS FOUND IN THE LITERATURE

Decision tools are not risk-analysis techniques; they are support tools that help decision-makers. However, they are very often linked in the literature to risk-analysis methods. Therefore, there are out of the scope of this investigation but this Appendix presents them in the same format as the identified techniques in Chapter 2 to clarify what they refer to.

MCDM Models / AHP

Multi-Criteria Decision Making is a method of dealing with uncertainty when complexity is involved: multiple alternatives, goals and/or criteria. The outcome is a ranking of possible alternatives.

In this sort of process, the different alternatives and objectives to be met are identified. Attributes are defined to assess how well the different alternatives meet the stated objectives. Then the level of each attribute (for each alternative) is quantified as well as weights for ranking the different attributes by order of importance. Finally, alternatives are ranked, and a sensitivity analysis can be performed (Schuyler, 2001).

All previous steps are standard except for the weight-assessment stage. Multiple methods exist, but the most often used method is AHP (Analytic Hierarchy Process). In this method attributes are compared by twos to determine which of each pair is the more important. Each attribute is compared to all other attributes, and the comparison results in a number, usually from 1 to 9, 1 being *equal importance* and 9 *extreme importance* (Al-Bahar and Mustafa, 1991). The results of those judgments based on pairwise comparisons are compiled in a matrix table as shown in the following table:

Attribute/ Factor	A	B	C	D
A	1	2	5	7
B	1/2	1	4	6
C	1/5	1/4	1	3
D	1/7	1/6	1/3	1
Total	1.84	3.42	10.33	17.00

AHP Pairwise Comparison Matrix Example

Weights are calculated from this table. At the end, a consistency ratio can be calculated to measure the degree of accuracy between judgments (Schuyler, 2001).

AHP "has been found to be very effective in construction practice, because risk factors are numerous, particularly in large projects, and the ability of humans to assess many factors at the same time is very limited" (Zhi, 1995).

Schuyler underlines the consistency problems of the AHP method, and Al-Bahar and Mustafa (1991) have observed that a large number of judgments is needed to be consistent.

Nonetheless, AHP is recognized to be flexible, robust, simple, and easy to understand. It provides a comprehensive framework for multi-criteria decision problems and enables subjectivity, experience, and knowledge (Al-Bahar and Mustafa, 1991; Dey et al., 1994; Schuyler, 2001).

Decision Trees

A decision tree is a tool that represents in a tree format the sequence of risks and their possible outcomes. It is a way to represent graphically the Expected Value (EV) calculations described above. It helps the decision maker to pick the best alternative for achieving the project objectives (Akintoye and MacLeod, 1997).

The tree is built from left to right: an uncertainty leads to several outcomes, which have their own consequences and probability of occurrence. Each outcome is then subject to other risks. The final tree has as many branches as the number of possible outcome combinations for all risks. Therefore, the difficulties of implementation increase when the risk chain is long and/or the number of outcome per risk is high.

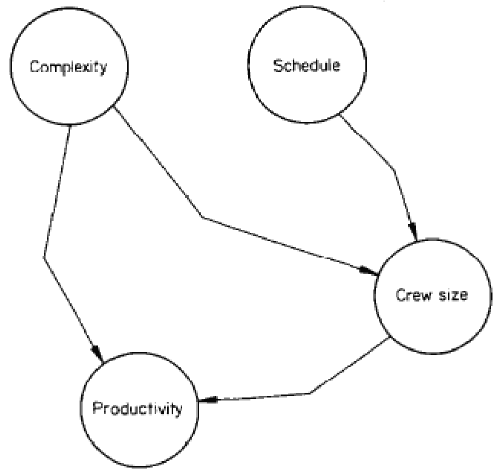
A decision tree can be drawn up quickly on a piece of paper when it is simple and a quick decision is needed. However, when things are more complicated (long risk chain and numerous alternatives), the method is generally computed (Schuyler, 2001).

The major advantage of decision trees is their format: it is quick to implement, graphical, and easy to read. It is an efficient tool for evaluating alternatives, especially when the probabilities are low. On the other hand, a major drawback of decision trees is that they do not allow continuous distribution: they work only with discrete distribution. In addition, when the problems are complex with multiple possible alternatives per decision, they become cumbersome and impractical (Schuyler, 2001).

Influence Diagrams

An influence diagram is a representation of a risk model. It graphs the uncertain variables and the relationships between them (their dependence) (Dikman et al., 2006; Huseby and Skogen, 1992). It is made up of nodes which represent the uncertain variables and are connected by arcs that symbolize the influences and dependences between the linked variables (Diekmann, 1992).

The below figure shows an example of a simple influence diagram with four uncertain variables which is, to a large extent, self-explanatory. Complexity influences both productivity and crew size. The schedule also influences the crew size. Finally, crew size influences productivity. An influence diagram has three layers: input (e.g. schedule and complexity), intermediate (e.g. crew size) and output (e.g. productivity). The relationships between variables are mostly conditional-probability statements (Huseby and Skogen, 1992). In the example provided in the below figure, a simple statement could be, "If all crew sizes increase by one man, the productivity will increase by 25% (probability = 0.3), by 10% (probability = 0.5), or will not change (probability = 0.2).



Example of an influence diagram with four variables (Diekmann, 1992)

Influence diagrams are used to represent and solve decision problems (Diekmann, 1992). They are used mostly during problem formulation. Indeed, they provide a straightforward and powerful way to communicate the structure of problems.

Compared to decision trees, influence diagrams provide more compact and efficient representation models (in an influence diagram 1 variable = 1 node, whereas in a decision tree 1 variable = 1 sub tree). They are also easy to understand.

The drawbacks are that influence diagrams stay fuzzy about the precise nature of dependence between the linked variables. They suppress a lot of information and are less appropriate for EV calculations (Huseby and Skogen, 1992; Schuyler, 2001).

The following table summarizes the decision tools described in the above paragraphs:

Method	Input	Output	Opportunities	Constraints
MCDM Models / AHP	Alternatives, Criteria	Alternatives ranking	Flexible, Robust, Simple, Easy to understand; enables subjectivity, experience and knowledge	Large number of judgments needed, Consistency problems
Decision Trees	Risks chain with the possible outcomes and respective probabilities	Select overall outcome with the highest EV	Quick to implement, graphical, easy to read; excellent with low probabilities	Does not fit continuous probabilities; cumbersome and impractical when complex problem
Influence Diagrams	Risk variables	Graphic representing and linking uncertain variables	Compact and efficient representation model, easy to understand	Suppresses a lot of information, less appropriate for EV calculations

Decision Tools

Appendix B

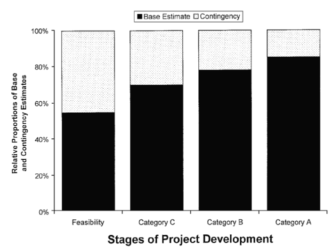
OVERVIEW OF SOME RISK-MANAGEMENT FRAMEWORKS FOUND IN THE LITERATURE

Chapter 2 presents an in-depth review of the literature concerning risk techniques used in the identification, assessment, and analysis steps of the risk-management process. However, researchers also came up with frameworks that integrate those three steps in a whole big technique. The study of these frameworks is beyond the scope of this thesis but four of the most frequently cited ones are presented below.

ERA

Estimating using Risk Analysis (ERA) aims at calculating the most appropriate contingency amount in a project. As established earlier, risk levels decrease while the project progresses and contingency amount should follow the same pattern.

In ERA, identification and assessment steps are computed through past experience and records (historical databases). From those, an average (50% chance of being exceeded) and a maximum (10% of being exceeded) risk allowance are calculated for each risk. The final cost is determined from the sum of the base (risk free) and a weighted average of risk allowances for each risk (Mak and Picken, 2000). While the project is progressing, the method improves, providing a more accurate estimate with decreasing uncertainty. Thus, contingencies can be indexed based on uncertainty level: the next figure illustrates it.



Proportion of total risk allowance versus stages of project development (Mak and Picken, 2000)

JRAP

Judgmental Risk Analysis Process (JRAP) addresses only schedule risks, which are identified through experience and judgment. Assessment of probability distributions and minimum/maximum durations (impact) for each risk are also determined by experience and judgment. However, heuristics, statistical studies, cycle time analysis or queuing theory can also be used in this assessment step. Next, the organization builds an activity risk-factor matrix that exposes the influence of each risk on all activity durations. The last step of JRAP is to model and run simulations of the schedule network with a Monte Carlo Simulation (Okmen and Oztas, 2004).

PERT

Project Evaluation and Review Technique (PERT) addresses only schedule risks but is heavily used in the industry to forecast project schedules under risky situations. There is a lot of software (e.g., Pertmaster) that computes this method (Simister, 1994).

The first step of PERT is to determine the risk affecting each task of the overall schedule as well as its probability distribution (judgment). With this information, the optimistic (O), pessimistic (P), and most likely (M) durations for each task are calculated. The expected time of the task is then obtained with the following formula: $E = \frac{O+4M+P}{6}$. When all expected times for each task are calculated, the schedule is built with the Critical Path Method (CPM) (Hatush and Skitmore, 1997).

APRAM

The Advanced Programmatic Risk Analysis and Management (APRAM) framework was originally created for aerospace use, and spread to the construction industry to address cost, schedule, and technical aspects.

First, project alternatives are identified. From the reserve budget of each alternative (difference between budget and actual cost), possibilities of improving technical aspects and avoiding related failures are analyzed through expert elicitation and historical databases. The same procedure is done to avoid budget and schedule problems. Then, the optimal allocation is calculated for the residual budget between technical aspects on one hand and budget and schedule aspects on the other. This is usually done with decision trees and expected value calculations, which select the alternative that maximizes owner utility, i.e., that minimizes the potential cost of failure (Dillon et al., 2003).

This method is powerful, but as the project size grows bigger, there are more tasks and subsystems, and it is harder to implement (Guikema and Imbeah, 2009).

Appendix C

CII PROJECT PHASE DEFINITION TABLE

The following table describes the CII breakdown of the construction phases which is used in this thesis. For each of the five defined phases, the starting and stopping points are explained, as well as the typical activities and cost elements.

Project Phase Definition Table

Project Phase	Start/Stop	Typical Activities & Products	Typical Cost Elements
Front End Planning Typical Participants: • Owner Personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	**Start: Defined Business Need that requires facilities** **Stop: Total Project Budget Authorized**	• Options Analysis • Life cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering	• Owner Planning Team Personnel Expenses • Consultant Fees & Expenses • Environmental Permitting Costs • Project Manager / Construction Manager Fees • Licensor Costs
Detail Engineering Typical Participants: • Owner Personnel • Design Contractor • Constructability Expert • Alliance / Partner	**Start: Design Basis** **Stop: Release of all approved drawings and specs for construction (or last package for fast-track)**	• Drawing & Spec Preparation • Bill of Material Preparation • Procurement Status • Sequence of Operations • Technical Review • Definitive Cost Estimate	• Owner Project Management Personnel • Designer Fees • Project Manager / Construction Manager Fees
Procurement Typical Participants: • Owner Personnel • Design Contractor • Alliance / Partner	**Start: Procurement Plan for Engineered Equipment** **Stop: All engineered equipment has been delivered to site**	• Supplier Qualification • Supplier Inquiries • Bid Analysis • Purchasing • Engineered Equipment • Transportation • Supplier QA/QC	• Owner Project Management Personnel • Project/Construction Manager Fees • Procurement & Expediting Personnel • Engineered Equipment • Transportation • Shop QA/QC

Project Phase Definition Table (Cont.)

Project Phase	Start/Stop	Typical Activities & Products	Typical Cost Elements
Construction Typical Participants: • Owner Personnel • Design Contractor (Inspection) • Construction Contractor and its Subcontractors	**Start: Commencement of foundations or driving piles** **Stop: *Mechanical Completion***	• Set Up Trailers • Procurement of Bulks • Issue Subcontracts • Construction Plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punchlist • Demobilize Construction Equipment	• Owner Project Management Personnel • Project Manager / Construction Manager Fees • Building Permits • Inspection QA/QC • Construction Labor, Equipment & Supplies • Bulk Materials • Construction Equipment • Contractor Management Personnel • Warranties
Start-up / Commissioning Note: Not usually applicable to infrastructure or building projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Suppliers	**Start: *Mechanical Completion*** **Stop: Custody transfer to user/operator (steady state operation)**	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and Obtain First Product • Hand-off to User/Operator • Operating System • Functional Facility • Warranty Work	• Owner Project Management Personnel • Project Manager / Construction Manager Fees • Consultant Fees & Expenses • Operator Training Expenses • Wasted Feedstocks • Supplier Fees

Appendix D

DEFINITIONS OF THE EIGHT SELECTED RISK-ANALYSIS METHODS AS RELEASED IN THE SECOND SURVEY

Risk-Analysis Method #1: **Brainstorming**

Brainstorming is a broad category of risk identification and assessment methods that involves group discussions and interactions between members to generate ideas. Examples of brainstorming methods include interviews, expert elicitation, and the nominal group techniques.

Risk-Analysis Method #2: **Risk Checklists**

Risk checklists are lists of risks that were realized and/or identified on previous projects. Risk checklists typically classify risks into meaningful categories (e.g., technical risks, external risks, environmental risks, etc.).

Risk-Analysis Method #3: **Risk Breakdown Structure**

A risk breakdown structure (RBS) is a method to organize risks in a hierarchical categorization. This type of categorization illustrates risk interrelationships and provides a framework for the management of risks depending on their similarities. The risk breakdown structure for risk management is analogous to a work breakdown structure for project controls.

Risk-Analysis Method #4: **Expected Value**

The expected value (EV) is a probability weighted sum of all possible inputs. For example, if a risk event has a 50 percent chance of occurrence and a value of $100 if it occurs, the expected value for the risk is 0.5 x $100 = $50.

Risk-Analysis Method #5: **Monte-Carlo Simulations (MCS)**

Monte-Carlo analysis is a computerized probabilistic simulation modeling technique that uses ransom number generators to draw samples for probability distributions. Monte-Carlo analysis uses repetitive trials to generate overall probability distributions for project cost and schedule.

Risk-Analysis Method #6: **Sensitivity Analysis**

Sensitivity analysis is a deterministic technique that shows the effect of change of a single variable on the project outcomes. It also analyzes the possible cost and time consequences led by those changes. It is an integral part of the Monte-Carlo simulation, but it is not exclusive to simulations techniques.

Risk-Analysis Method #7: **Risk Matrices**

A risk matrix is a method for risk analysis that links the probability and severity of risk factors in the analysis of their overall probable consequence. It is also called a Probability x Impact matrix (PxI). It is formed by combining each risk's probability of occurrence (frequency) with its impact (severity) on project objectives to rank risks or determine the level of priority to be assigned to that risk on a project (e.g., high, medium, low, etc.).

Risk-Analysis Method #8: **Scenario Analysis**

A scenario analysis identifies and defines the possible scenarios that can lead to the different outcomes. It can be helpful in the risk-identification and risk-analysis processes. The probability of occurrence of all those scenarios can determine the most likely scenario.

Appendix E

SECOND SURVEY: APPLICATIONS OF RISK-ANALYSIS METHODS AND TOOLS

Page 1

The goal of this questionnaire is to establish the most appropriate risk-analysis methods and tools for engineering and construction projects based on project characteristics. The questionnaire follows a previous study on the current state of practice for risk analysis.

Thank you for participating. Your participation and responses are anonymous and will be included only in an aggregate summary of the results. The survey will take less than 30 minutes of your time. Preliminary results of aggregate responses are available upon completion of this survey.

1) Completion of the following questionnaire requires basic knowledge of the use of risk-analysis methods and tools. Please select the continue option below if you have this knowledge. If this is not your area of expertise, select the cancel option and kindly forward the questionnaire to an appropriate colleague.
   - ❑ <u>Continue</u> – By selecting continue, I acknowledge that my answers may be anonymously used as part of this study. [Go to page 2]
   - ❑ <u>Cancel</u> – By selecting cancel, I acknowledge that I do not have knowledge only organization's risk-analysis methods or do not wish to participate. We ask that you please route the questionnaire to the appropriate person in your organization who has the knowledge to answer these questions. [Skip to the end]

Page 2

NOTE: In this questionnaire, you will always be able to go backward using the back button on your browser.

1) Name of the organization (i.e., company, firm, agency, etc.) (Please note that this information will be used only to aggregate responses from the same organization. The name of the company will never be shown in the results).

2) Which of the following best describes your organization? (Please check only one)
   - ❑ Private Owner
   - ❑ Public Owner
   - ❑ Architect/Engineering Firm
   - ❑ Constructor
   - ❑ Engineer/Procure/Construct Firm
   - ❑ Design/Build Firm
   - ❑ Construction Management Firm
   - ❑ Consulting Firm
   - ❑ Other, please specify:

From a review of the literature and the responses to a previous state of practice questionnaire, eight primary risk-analysis methods and tools have been selected for analysis in this questionnaire. You will be asked to answer questions on each of the methods and tools.
The questionnaire first presents each method and then, based upon your response, asks some brief questions about the method.

Page 3

Risk-Analysis Method #1: **Brainstorming**

Definition: Brainstorming is a broad category of risk identification and assessment methods that involves group discussions and interactions between members to generate ideas. Examples of brainstorming methods include interviews, expert elicitation, and the nominal group techniques.

1) Do you use brainstorming as a risk-analysis tool?
   - ❑ Yes [Go to Page 4]
   - ❑ No [Skip to Page 5]

Page 4

1) How often do you use brainstorming as a risk-analysis method?
   - ❑ Once a week
   - ❑ Once a month
   - ❑ A few times a year
   - ❑ Once a year
   - ❑ Less than once a year

2) Please indicate if brainstorming is an appropriate risk-analysis method for each of the five construction phases.

Phase	Strongly Disagree	Disagree	Un-certain	Agree	Strongly Agree
Front End Planning	❑	❑	❑	❑	❑
Detail Engineering	❑	❑	❑	❑	❑
Procurement	❑	❑	❑	❑	❑
Construction	❑	❑	❑	❑	❑
Start-Up	❑	❑	❑	❑	❑

3) Please indicate if brainstorming is a useful risk-analysis method based upon the project characteristics listed below.

Project Characteristic	Strongly Disagree	Disagree	Un-certain	Agree	Strongly Agree
High Complexity	❑	❑	❑	❑	❑
Low Complexity	❑	❑	❑	❑	❑
High Cost	❑	❑	❑	❑	❑

Low Cost	❑	❑	❑	❑	❑
Developed Scope	❑	❑	❑	❑	❑
Undeveloped Scope	❑	❑	❑	❑	❑
Uncompressed Schedule	❑	❑	❑	❑	❑
Compressed Schedule	❑	❑	❑	❑	❑

4) Why do you use brainstorming? Please elaborate the strengths and weaknesses of this risk-analysis method.

[ ]

[Skip to Page 6]

Page 5

1) Why don't you use brainstorming? (select all that apply)
   - ❑ Lack of Knowledge or Familiarity
   - ❑ High Degree of Sophistication/Complexity
   - ❑ Time Consuming
   - ❑ Large Investment for Minimal Benefits
   - ❑ Other, please specify: [ ]

[Go to Page 6]

Pages 3 to 5 are iterated seven extra times for the other seven risk-analysis methods (Risk Checklists, Risk Breakdown Structure, Expected Value, Monte-Carlo Simulation, Sensitivity Analysis, Risk Matrices, and Scenario Analysis).

Last Page

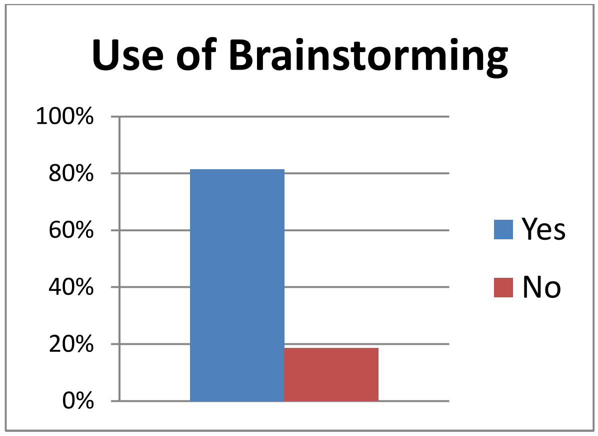
Thank you for taking our survey. Your participation is extremely important for our research and is greatly appreciated!

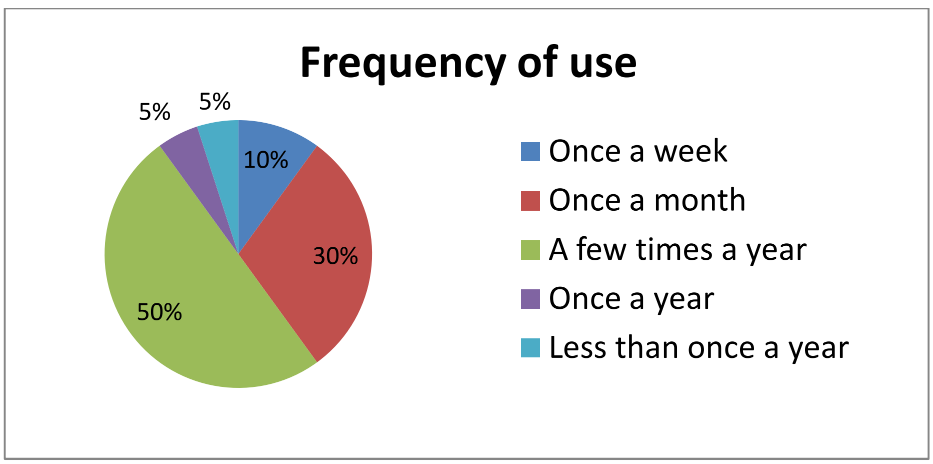
Your participation and results will remain anonymous. Only aggregated results will be shown or published.
The cumulative results from prior survey participants can now be accessed.

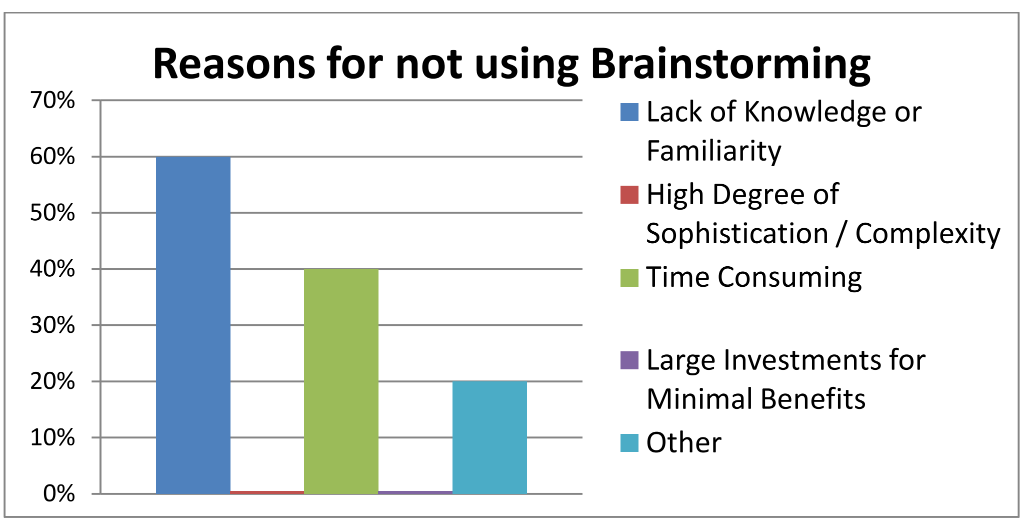
Appendix F

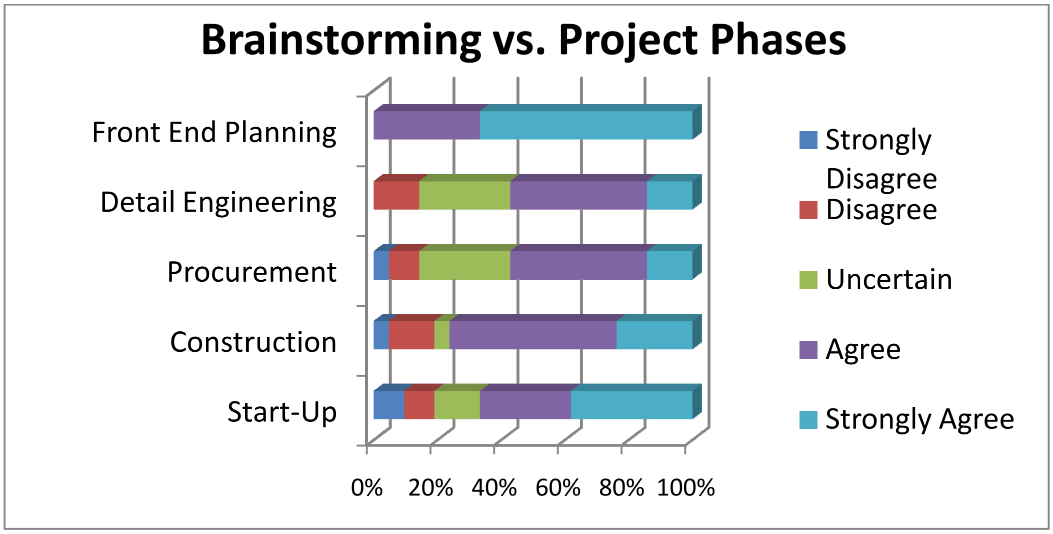
DETAILED RESULTS OF THE SECOND SURVEY

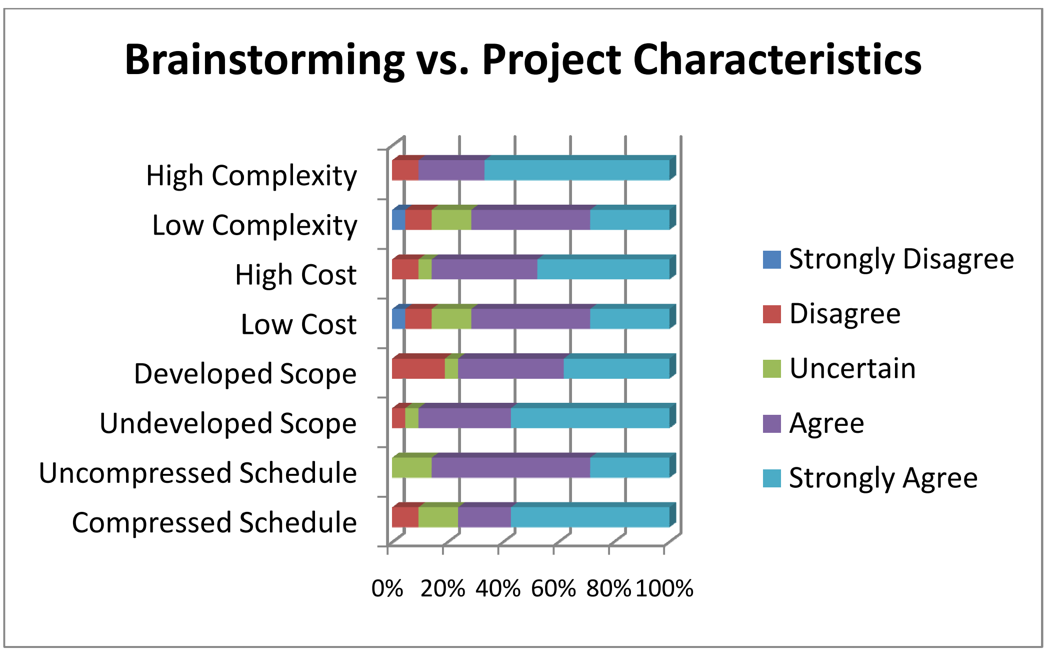
Risk-analysis method 1: Brainstorming








Brainstorming vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree


Brainstorming vs. Project Characteristics
High Complexity
Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
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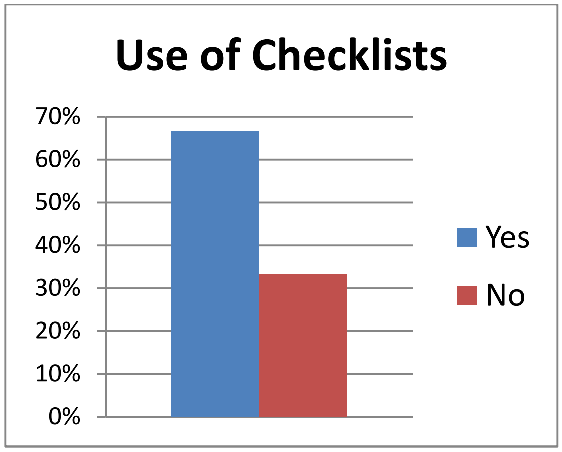
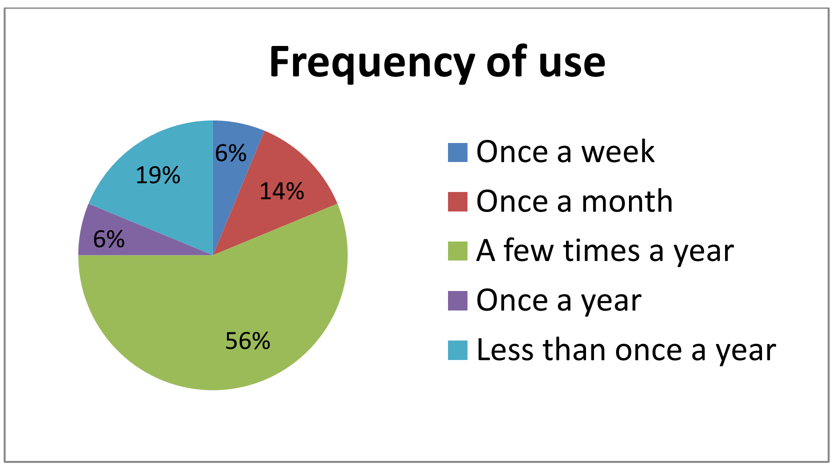
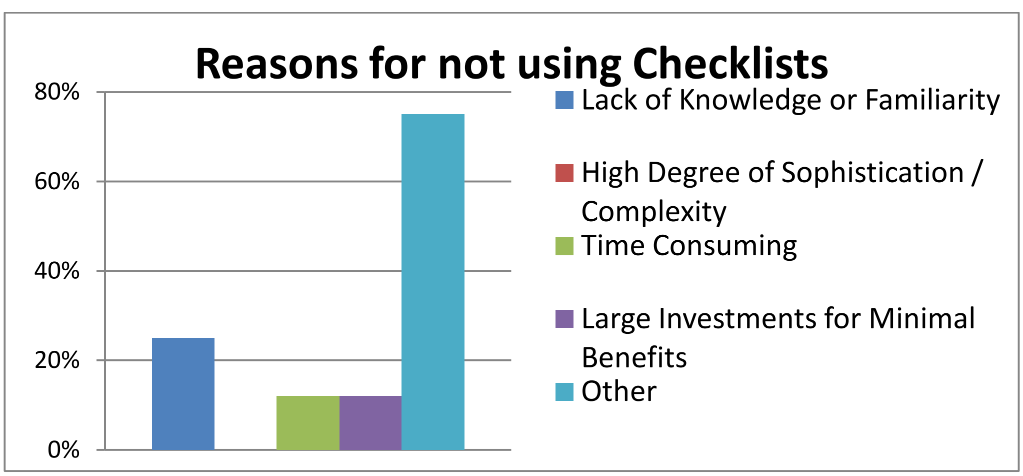
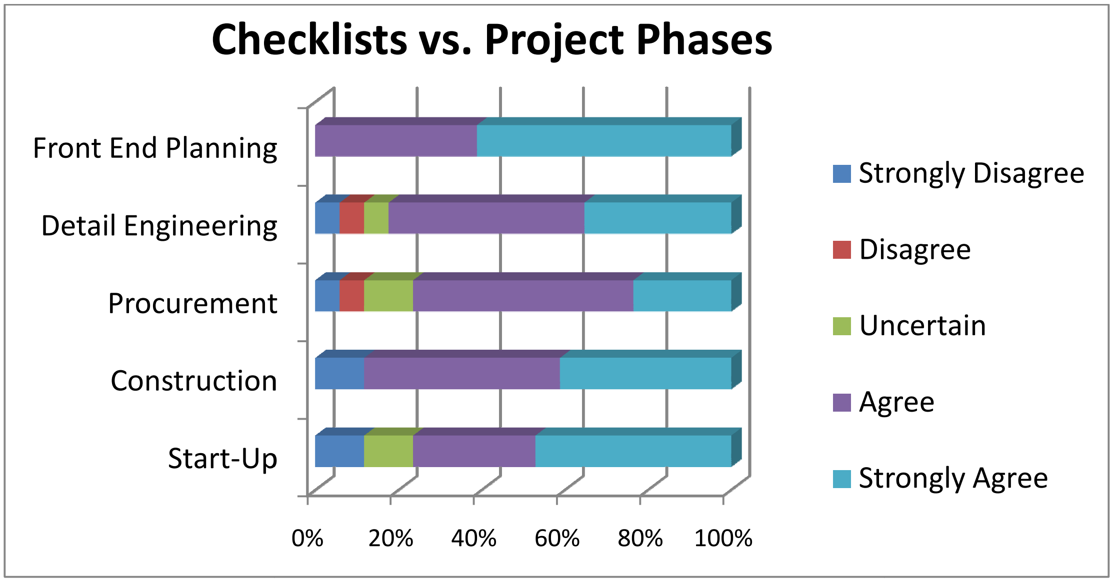
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

Risk-analysis method 2: Risk Checklists








Checklists vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
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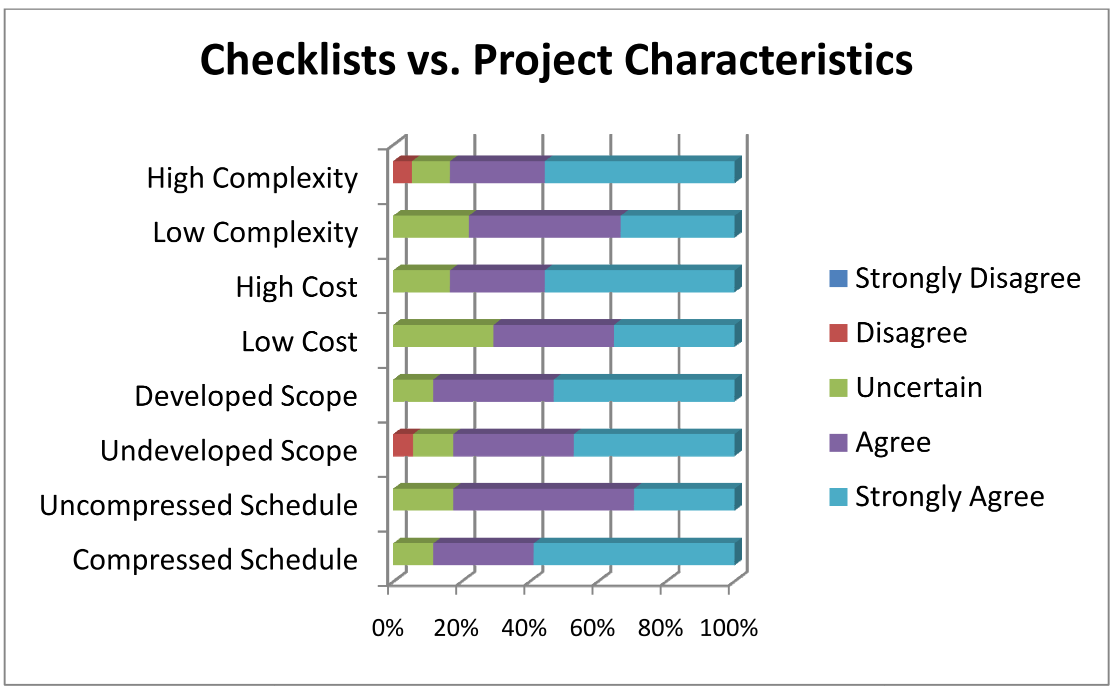
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree


Checklists vs. Project Characteristics
High Complexity
Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
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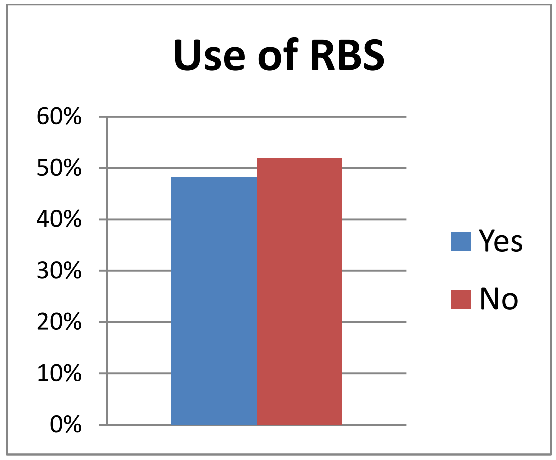
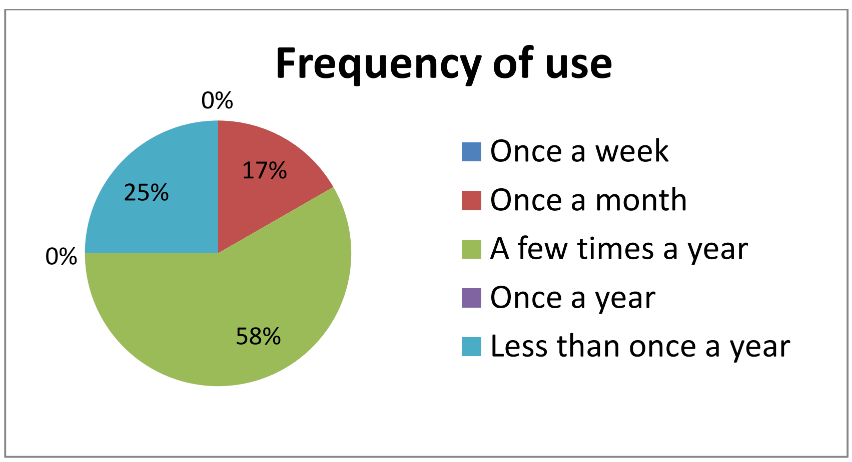
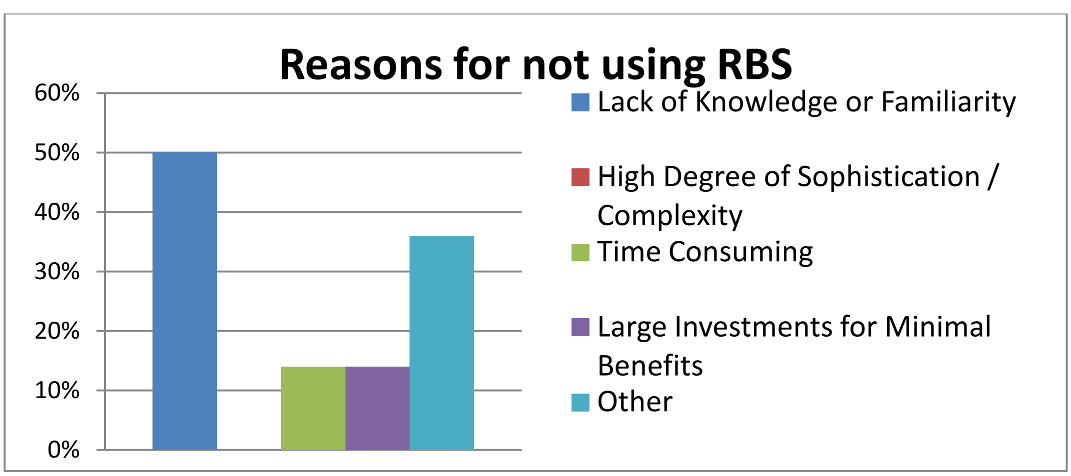
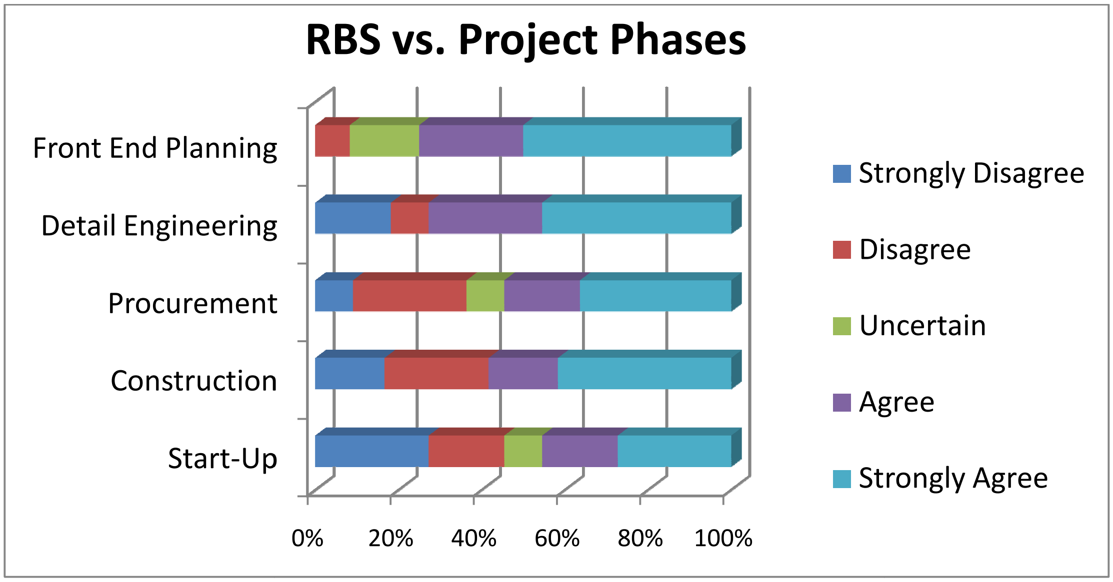
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

Risk-analysis method 3: Risk Breakdown Structure








RBS vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
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80%
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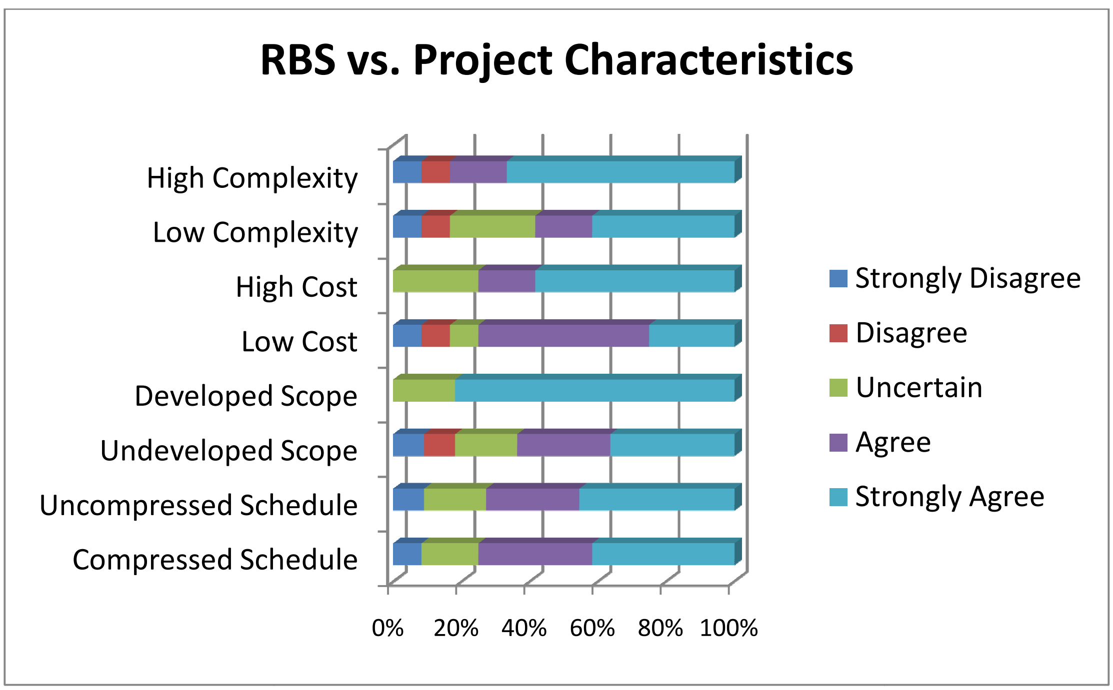
Disagree
Uncertain
Agree
Strongly Agree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Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
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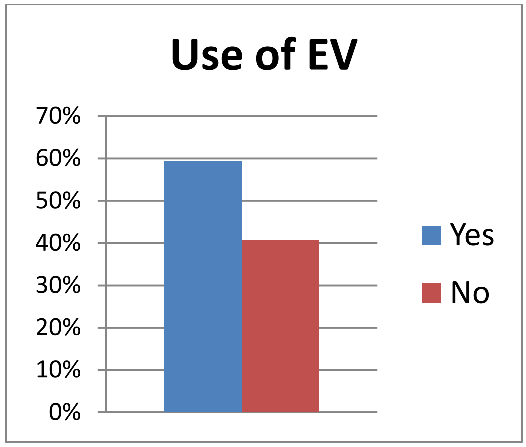
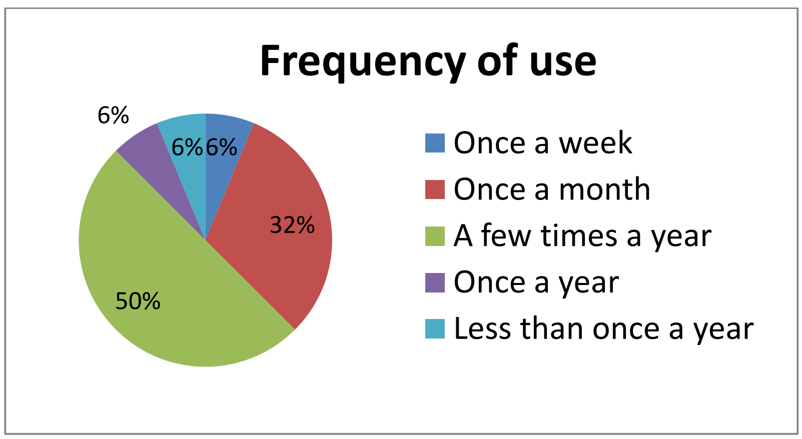
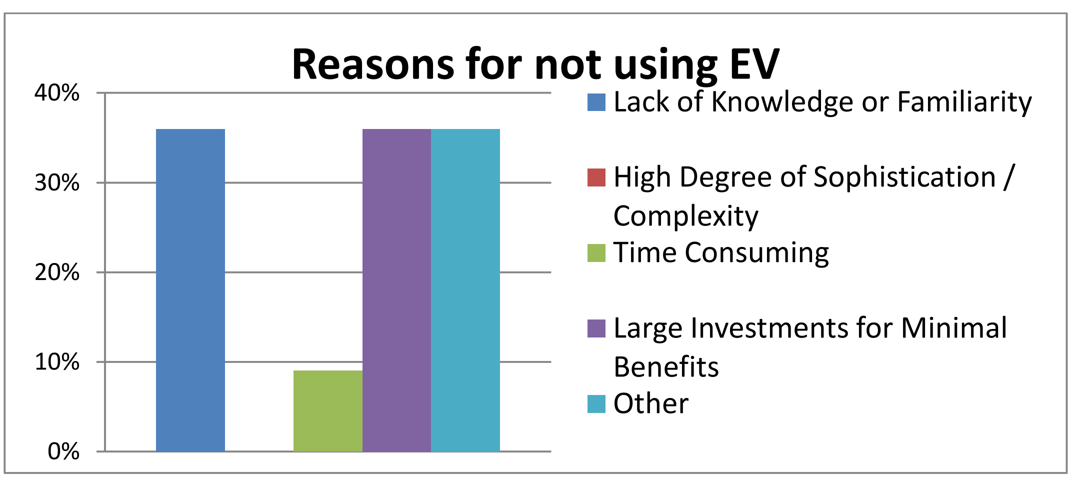
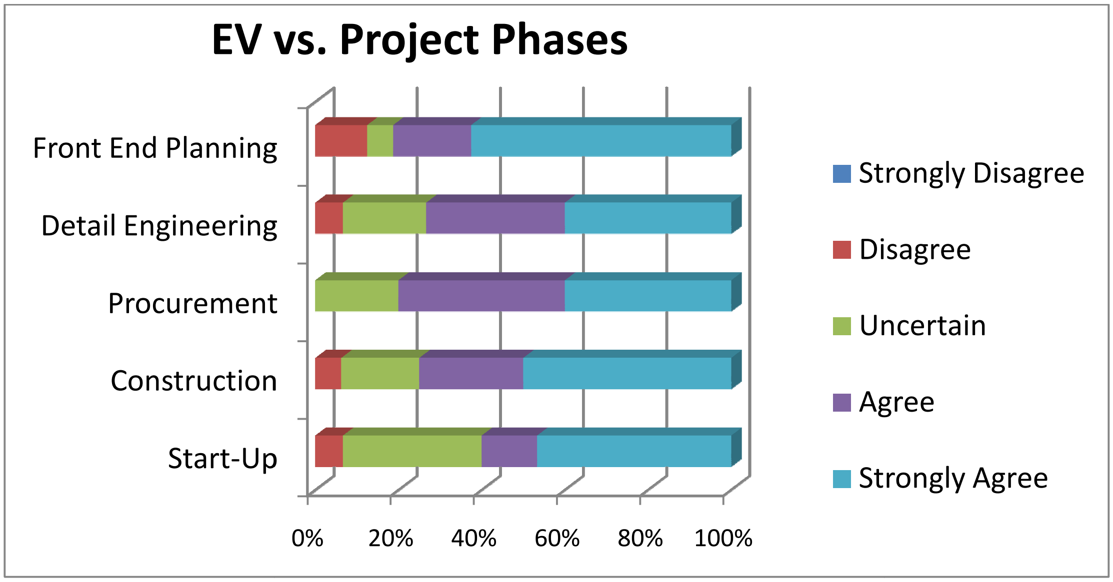
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

Risk-analysis method 4: Expected Value








EV vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
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40%
60%
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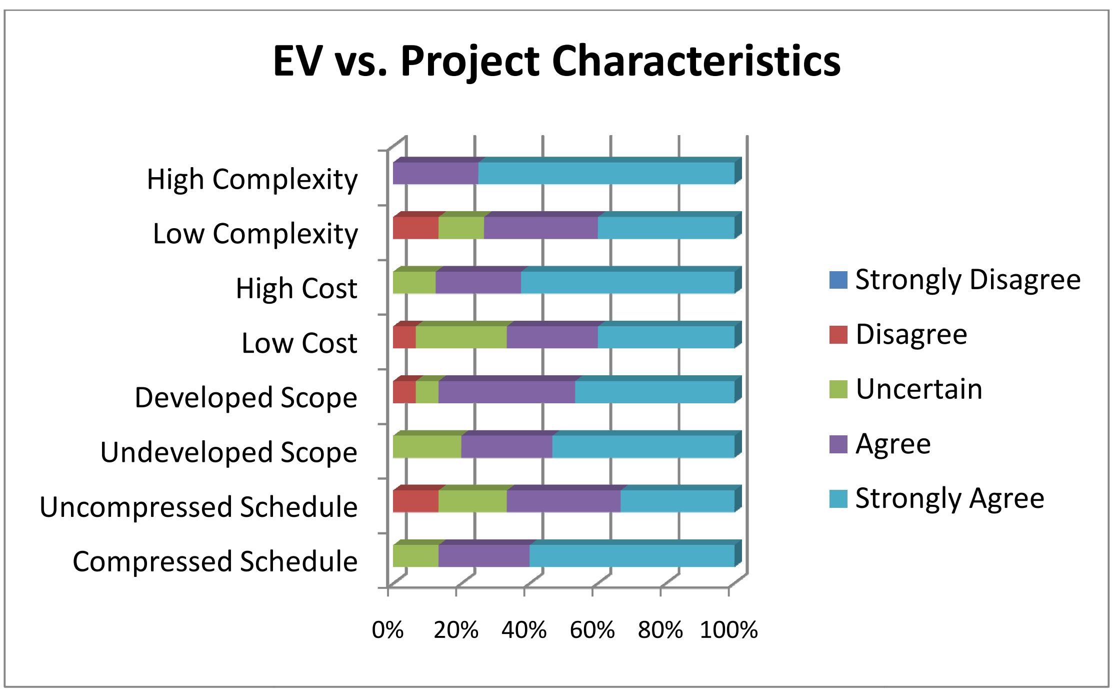
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree


EV vs. Project Characteristics
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Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
0%
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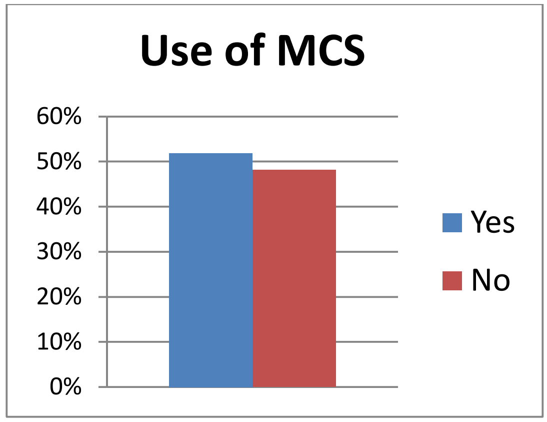
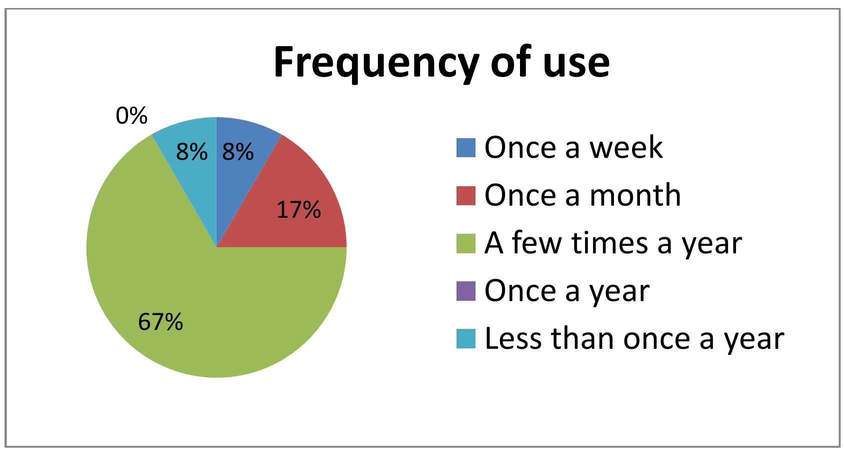
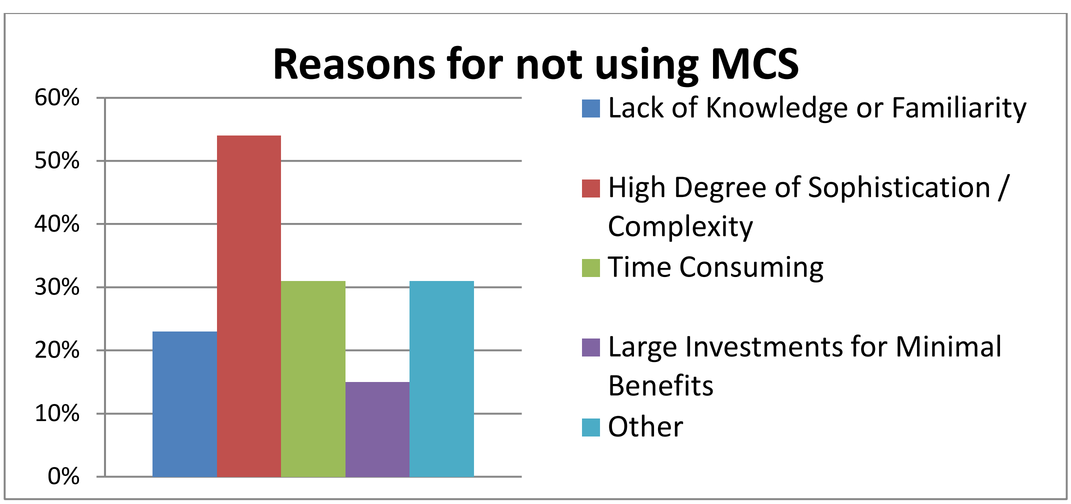
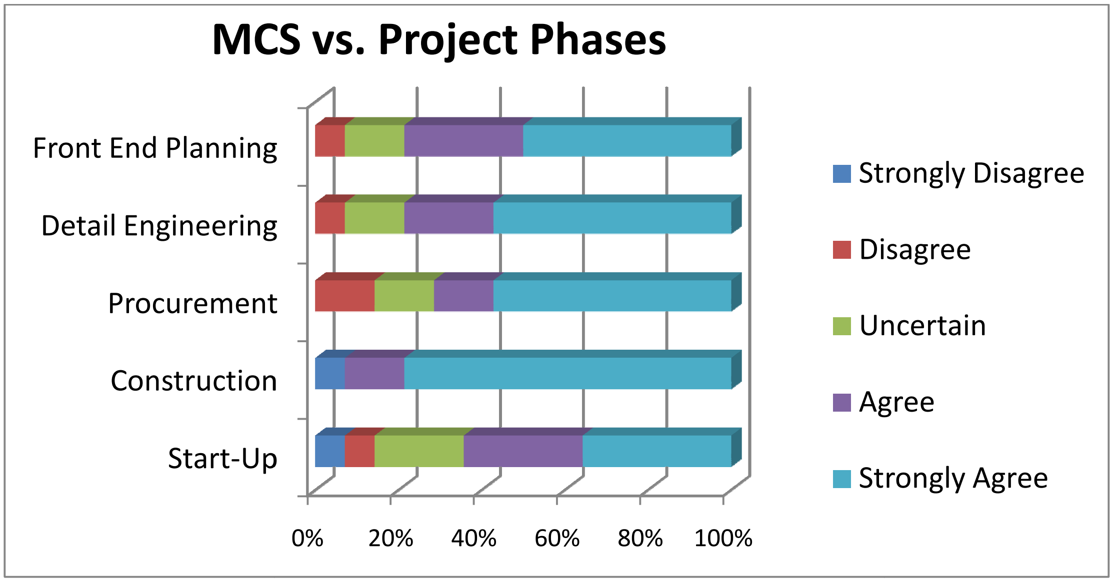
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

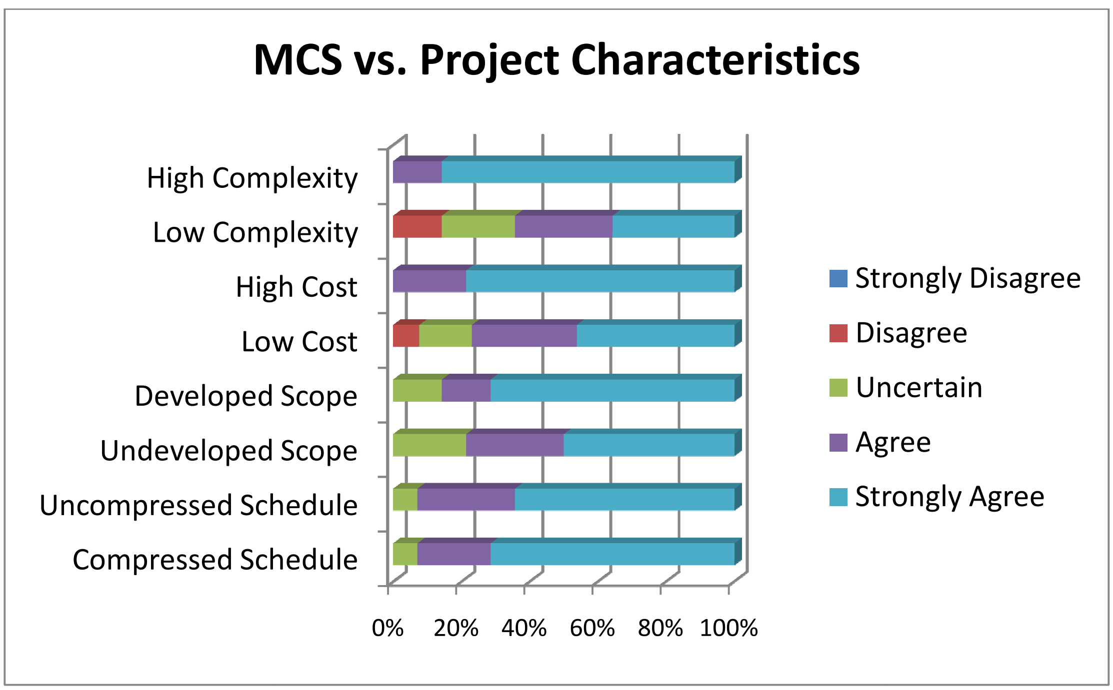
Risk-analysis method 5: Monte-Carlo simulation



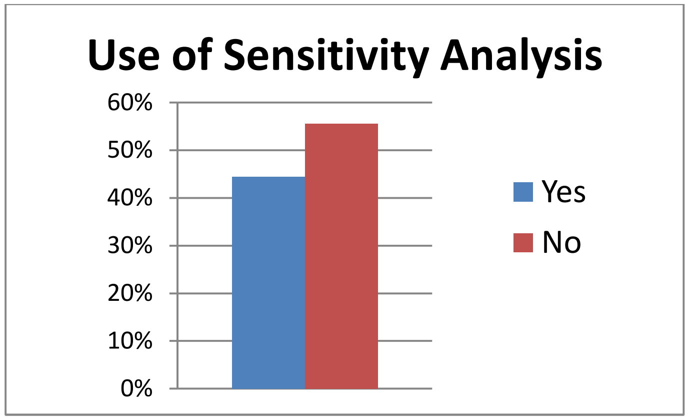


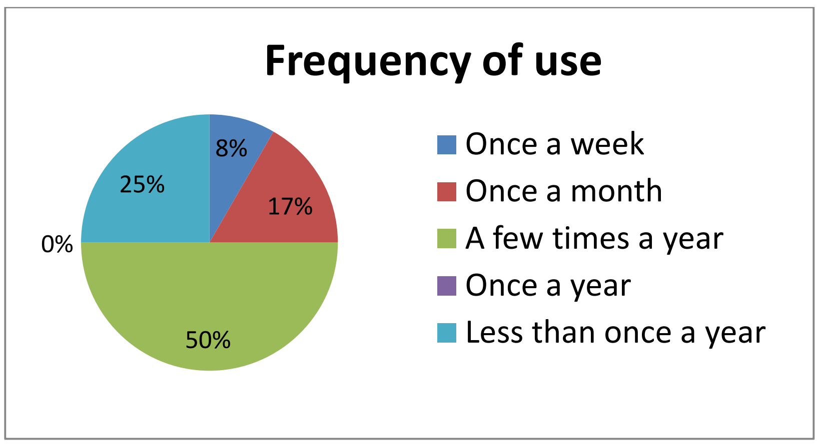


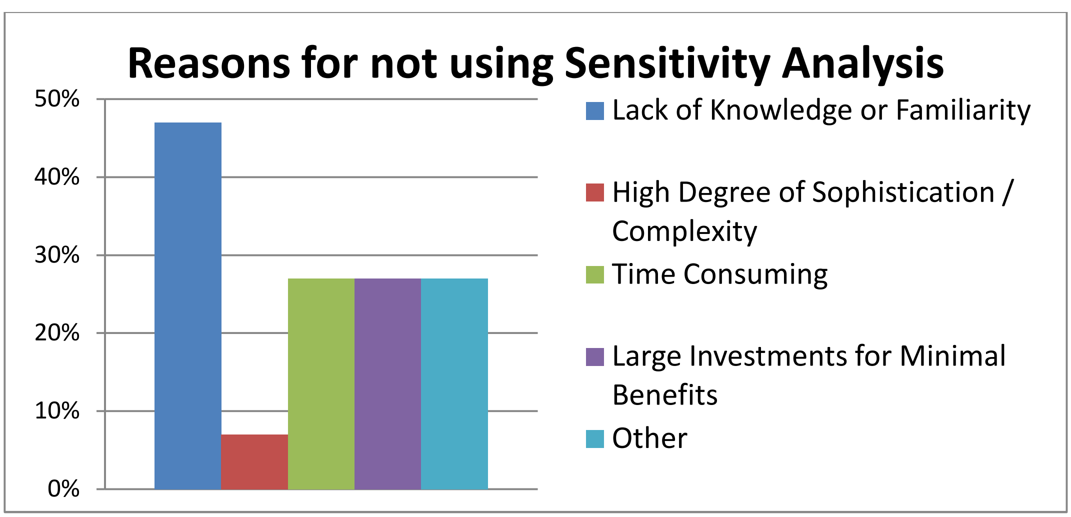

MCS vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

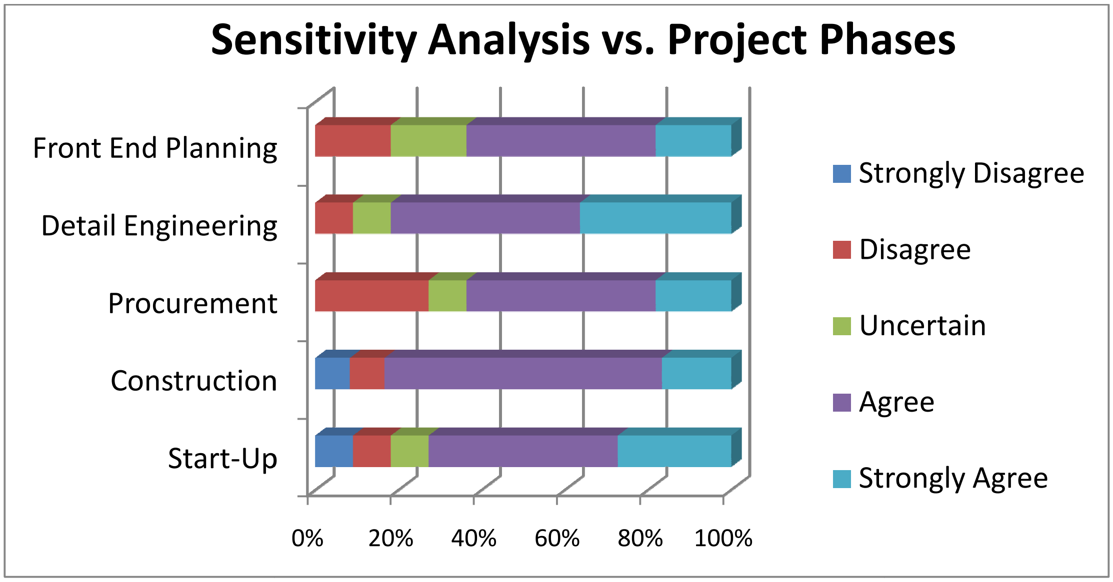

MCS vs. Project Characteristics
High Complexity
Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

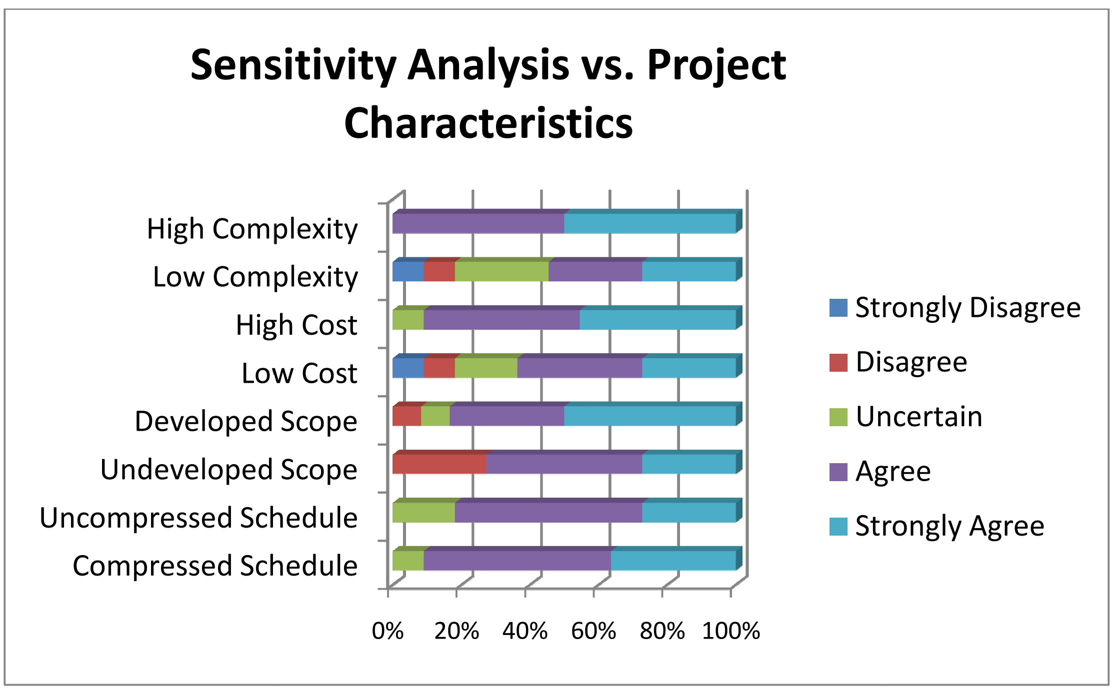
Risk-analysis method 6: Sensitivity Analysis



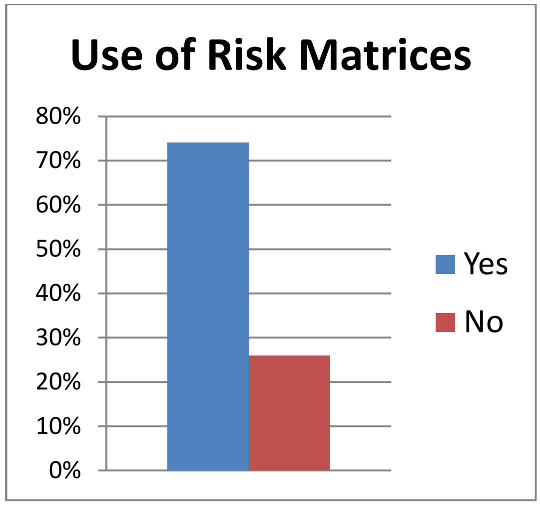


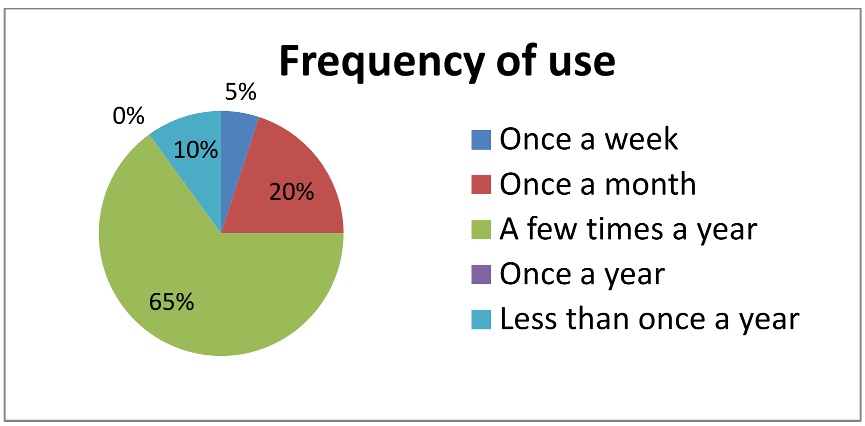


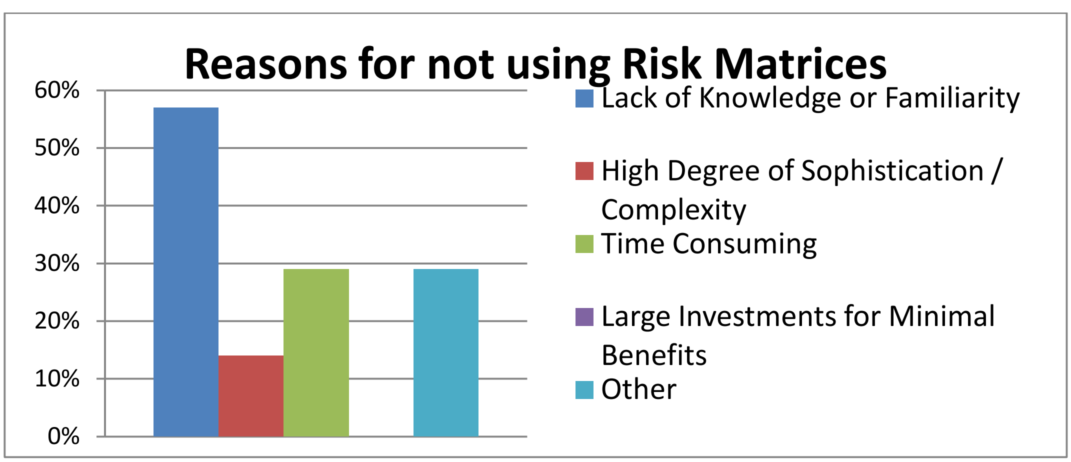

Sensitivity Analysis vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

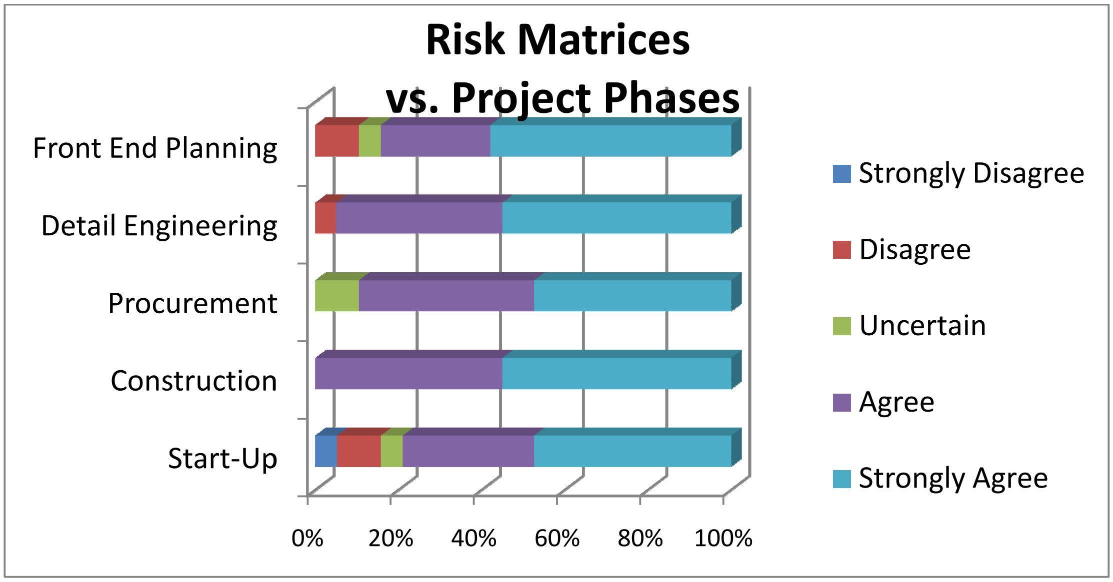

Sensitivity Analysis vs. Project Characteristics
High Complexity
Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

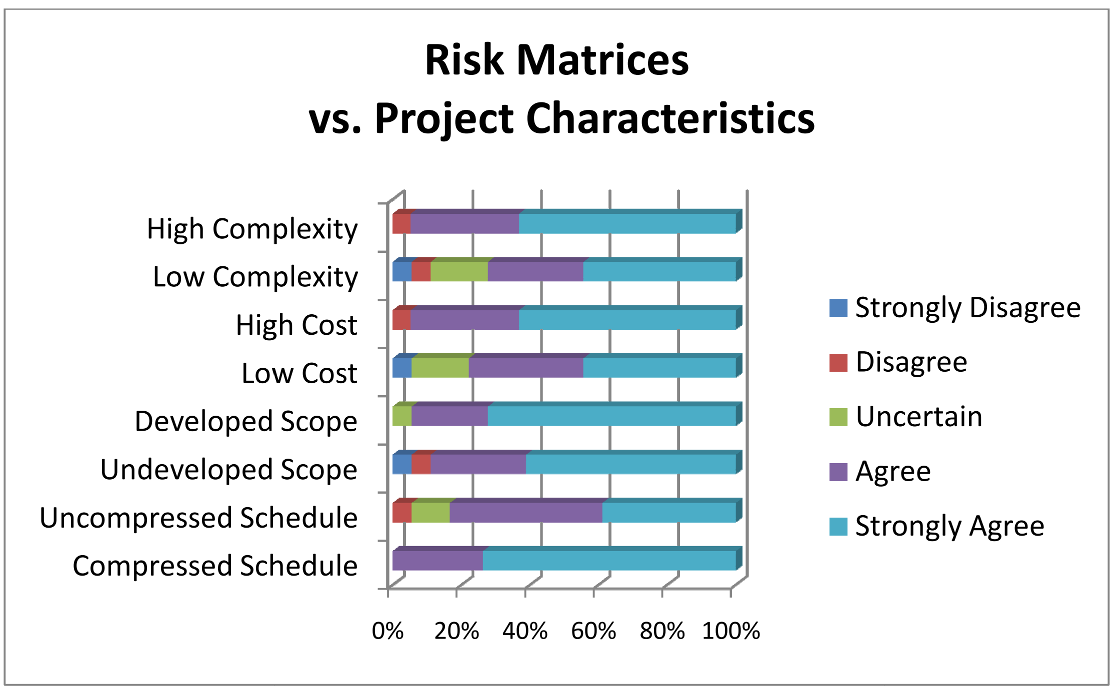
Risk-analysis method 7: Risk Matrices



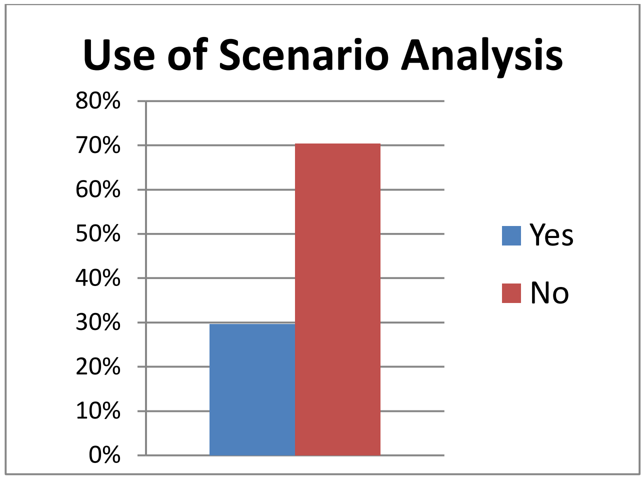


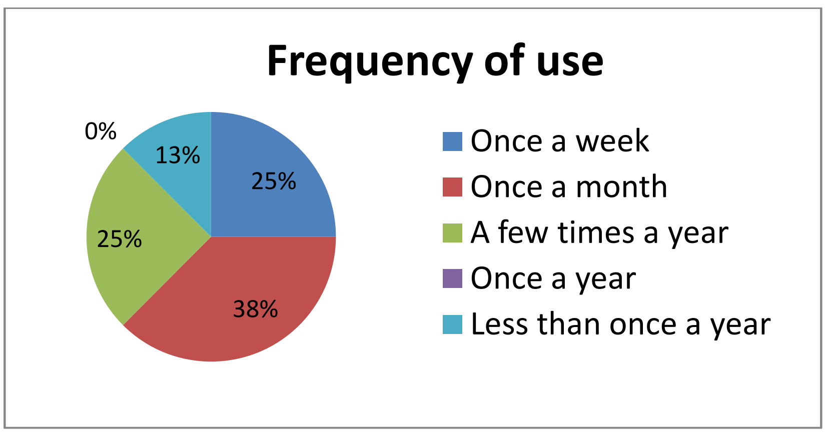


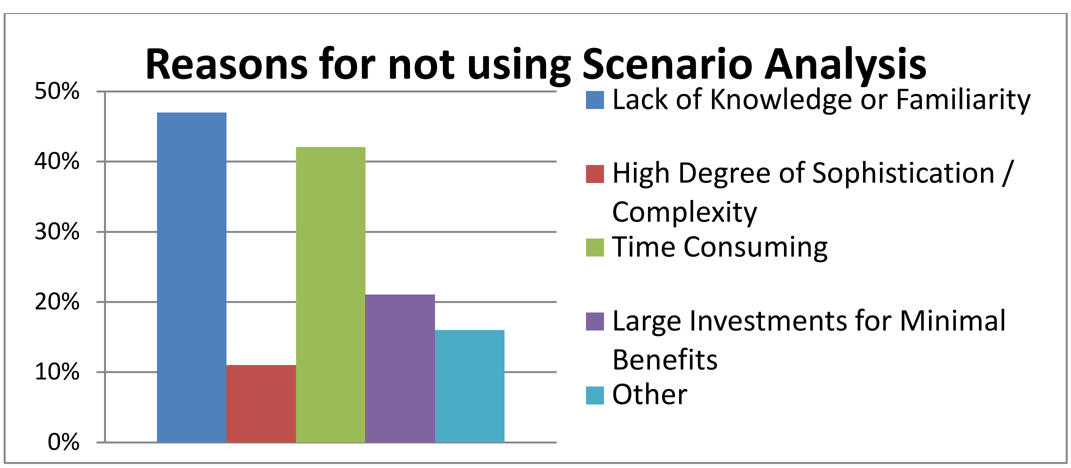

Risk Matrices
vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

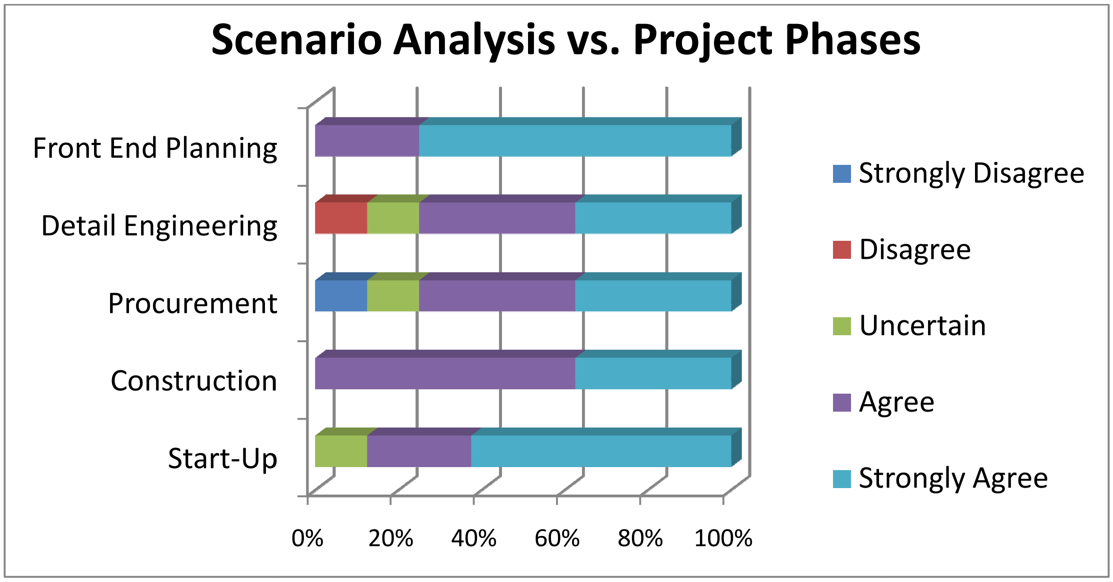

Risk Matrices
vs. Project Characteristics
High Complexity
Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

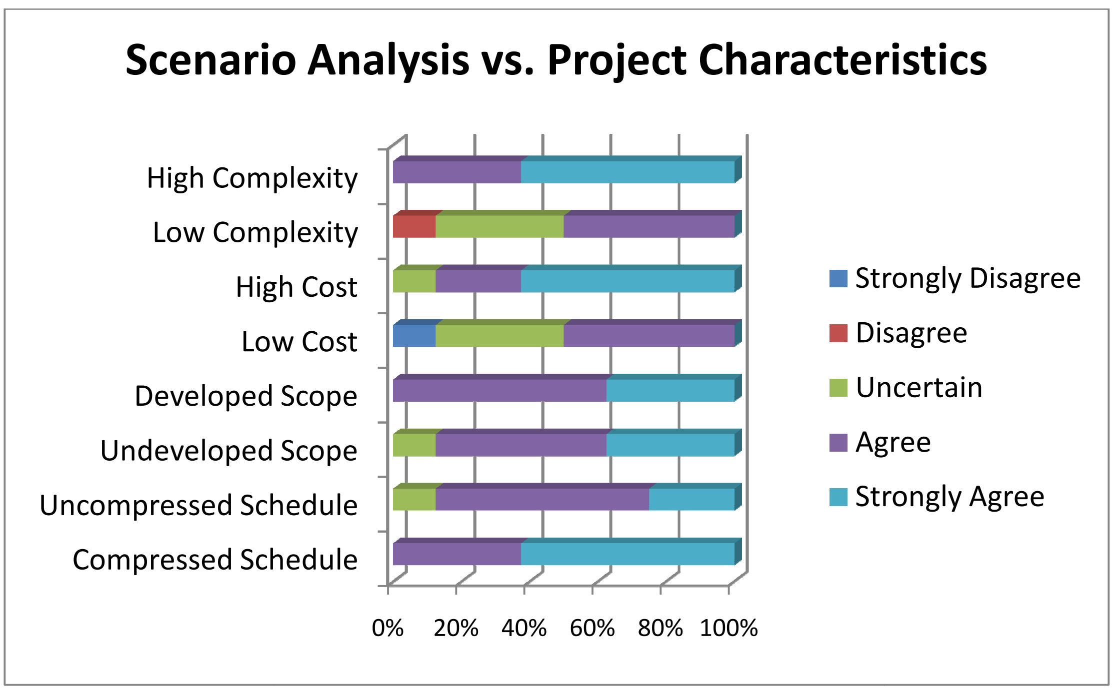
Risk-analysis method 8: Scenario Analysis








Scenario Analysis vs. Project Phases
Front End Planning
Detail Engineering
Procurement
Construction
Start-Up
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree


Scenario Analysis vs. Project Characteristics
High Complexity
Low Complexity
High Cost
Low Cost
Developed Scope
Undeveloped Scope
Uncompressed Schedule
Compressed Schedule
0%
20%
40%
60%
80%
100%
Strongly Disagree
Disagree
Uncertain
Agree
Strongly Agree

Appendix G

EXAMPLE OF DECISION TABLES

Note: These tables constitute a model which goes beyond the scope of this investigation. The tables are not validated and must not be used as a reliable tool. They simply aim at being an example to model the relationships between risk-analysis methods and project characteristics and phases.

Front-End Planning

Risk-management step	Tools	Complexity		Cost		Schedule		Scope	
		Low	High	Low	High	Uncompressed	Compressed	Developed	Undeveloped
Identification	Brainstorming		✓		✓	✓	✓		✓
	Checklists	✓	✓	✓	✓	✓	✓	✓	✓
	RBS	✗		✗				✓	✗
Analysis	Brainstorming		✓		✓	✓	✓		✓
	EV		✓		✓		✓		✓
	MCS		✓		✓	✓	✓	✓	
	Sensitivity Analysis	✗		✗	✗	✗		✗	✗
	Risk Matrices		✓		✓		✓	✓	✓
	Scenario Analysis	✗	✓	✗	✓	✓	✓	✓	✓

Detail Engineering

Risk-management step	Tools	Complexity		Cost		Schedule		Scope	
		Low	High	Low	High	Uncompressed	Compressed	Developed	Undeveloped
Identification	Brainstorming	✘		✘				✘	
	Checklists	✓	✓	✓	✓		✓	✓	✓
	RBS		✓		✓	✓		✓	✘
Analysis	Brainstorming	✘		✘				✘	
	EV		✓			✘		✘	
	MCS	✓	✓	✓	✓	✓	✓	✓	✓
	Sensitivity Analysis	✘		✘		✘		✘	✘
	Risk Matrices	✓	✓	✓	✓	✓	✓	✓	✓
	Scenario Analysis	✘		✘					

Procurement

Risk-management step	Tools	Complexity		Cost		Schedule		Scope	
		Low	High	Low	High	Uncompressed	Compressed	Developed	Undeveloped
Identification	Brainstorming	✗		✗				✗	
	Checklists	✓	✓	✓	✓		✓	✓	✓
	RBS	✗		✗		✗		✓	✗
Analysis	Brainstorming	✗		✗		✗		✗	
	EV		✓		✓	✗			✓
	MCS		✓		✓	✓	✓	✓	
	Sensitivity Analysis	✗		✗	✗	✗		✗	✗
	Risk Matrices	✓	✓	✓	✓		✓	✓	✓
	Scenario Analysis	✗		✗		✗			

Construction

Risk-management step	Tools	Complexity		Cost		Schedule		Scope	
		Low	High	Low	High	Uncompressed	Compressed	Developed	Undeveloped
Identification	Brainstorming	✗	✓	✗					✓
	Checklists	✓	✓	✓	✓	✓	✓	✓	✓
	RBS	✗		✗		✗		✓	✗
Analysis	Brainstorming			✗					✓
	EV		✓			✗			
	MCS	✓	✓	✓	✓	✓	✓	✓	✓
	Sensitivity Analysis	✗		✗		✗		✗	✗
	Risk Matrices	✓	✓	✓	✓	✓	✓	✓	✓
	Scenario Analysis	✗		✗					✓

Start-Up

Risk-management step	Tools	Complexity		Cost		Schedule		Scope	
		Low	High	Low	High	Uncompressed	Compressed	Developed	Undeveloped
Identification	Brainstorming	✗	✓	✗					✓
	Checklists	✓	✓	✓	✓		✓	✓	✓
	RBS	✗		✗		✗	✗		✗
Analysis	Brainstorming							✗	✓
	EV		✓			✗			
	MCS		✓	✓	✓	✓			
	Sensitivity Analysis	✗		✗	✗	✗		✗	✗
	Risk Matrices	✓		✓			✓		
	Scenario Analysis	✗	✓	✗	✓	✓	✓	✓	✓