Quality Assurance in Risk Management

By

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Abstract

This thesis investigated the inherent relationship quality assurance has with risk management processes, specifically focused on the construction industry perception of risk and uncertainty. On the evidence gathered, there is currently a lack of awareness and knowledge about quality assurance in risk management as a means of creating reliable risk analyses in the New Zealand construction industry. Risk assessments reported by those project managers who were interviewed were not representative of what eventually happened in the projects they managed.

A triangulation research approach was adopted, where a literature analysis, a case study and a survey were used in critical analysis of the relationship between quality assurance, risk, and uncertainty as revealed in the research background chapter. The three methods scrutinise this relationship in different ways and eventually addressed all the research questions posed.

A literature analysis was undertaken to establish the perception and definition of the terms risk and uncertainty before the standards and processes to quantify uncertainty were scrutinised in further detail. This allowed understanding of current concerns to be realised, so these could be tested in the thesis.

A case study of a real-life New Zealand construction project was analysed in specific detail ensuring the literature analysis and the survey were grounded in current industry practice. The aim of this case study analysis was to understand the behaviour of people in the industry in comparison to how they are said to perform in the literature. The case study analysis essentially identified the existence of uncertainty in a project and attempted to understand how uncertainties are being controlled.

An online Qualtrics survey was used to further test the perception and processes used for uncertainty management in the industry. The results showed that the New Zealand construction industry does not typically understand the difference between risk and uncertainty on their own. Technique use proved to be comprehensive with quantification of uncertainty occurring through formal techniques whether purposeful or not. The participants noted that complexity and lack of knowledge were the reasons behind the lack of understanding and that the existence of simple processes or formulas could enable the increase of reliable risk analyses in the construction industry.

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1. Introduction

Construction industry members the world over recognize the importance of quality assurance in the building industry (ASQ, 2015; NZQA, 2015; PMI, 2013; PTS, 2015). The American Society for Quality (ASQ) defines quality assurance as:

> *"The planned and systematic activities implemented in a quality system so that quality requirements for a product or service will be fulfilled".*
>
> (ASQ, 2015).

Quality assurance in construction often involves all those planned and systematic actions necessary to provide confidence that the facility will perform satisfactorily in service. Quality assurance in construction addresses the overall problem of obtaining the quality of the facility to be built in the most efficient, economical, and satisfactory manner possible (PTS, 2015). In its broad form quality assurance is considered at each phase of building planning and construction and can reduce risk and uncertainty, and often goes hand in hand with the definition of risk management as identified by Edwards and Bowen (1993):

> *"Risk management is a systematic approach to dealing with risk. A risk management system should: establish an appropriate context; set goals and objectives; identify and analyse risk; influence risk decision making; and monitor and review risk responses".*
>
> (Edwards & Bowen, 1993, pp. 339-349).

It is the aim of this thesis to understand the relationship quality assurance has with risk management processes in the construction industry. In the late 1990's/early 2000's in a conceptually important development, the project management community began to distinguish between risk and uncertainty - risk being the possibility of a negative event occurring (hazard, chance of bad consequence, loss, etc.), and uncertainty being unknowns (hence known–unknowns and unknown-unknowns) (Institution of Civil Engineers, 1998). It is often assumed that decreasing uncertainty to an acceptable level can mitigate risk and ensure quality assurance. Two schools of thought are contrasted in this thesis: in the first, risk is uncertainty; and in the second, risk is distinctly separate from uncertainty. The impact of these two schools of thought on quality assurance is explored.

A question commonly posed in the construction industry regarding risk and uncertainty is:

> *"how do we achieve a level of uncertainty that is acceptable?"*
>
> (Peace, 2015)

This question cannot be universally addressed as uncertainty and risk often stem from project specific variables, dependent on the client, the organisation, and the threat level adopted by different members of industry. This thesis does not aim to answer how one can achieve an acceptable level of uncertainty, rather it provides context for this issue. The thesis investigates New Zealand specific practices for quality assuring quality outcomes when dealing with risk and uncertainty in the context of international construction industry policy.

1.1. The significance of this thesis

Risk management is one of the larger knowledge areas compared to the other areas in the Project Management Body of Knowledge Guide (PMBOK) produced by the Project Management Institute (PMI). The PMI is one of the leading internationally recognised bodies for project management, and thus set the standard for how project management is utilised in the industry (Hodgson & Cicmil, 2006; PMI, 2011). Research in this larger knowledge area may improve project management significantly.

Before the risk management process in construction is scrutinised, it is important to understand current measures of project success. There is significant evidence of overruns on projects, beginning with works such as Marshall and Meckling (1962) and Ruskin and Lerner (1972), and ending with works such as Gitau (2015) and Mohamed (2015). The key text however in summarizing the historical evidence is Morris and Hough (1987). Morris and Hough present 8 case studies and list 33 references to databases of project overruns, arguing that there is little evidence in the literature of underruns. This thesis speculates that unreliable risk assessments are a major source of these project failures.

The project management triple constraint triangle has become the measure of project success and is therefore often quoted as the basis for decision-making in project management (Atkinson, 1999). Figure 1 highlights the fact that the triple constraint triangle (incorporating cost, time, scope and quality) does not explicitly identify risk. This vagueness about risk could be detrimental to project success, in that risk management is a critical part of the decision-making process to enable the success of projects (Zeng et al., 2007).

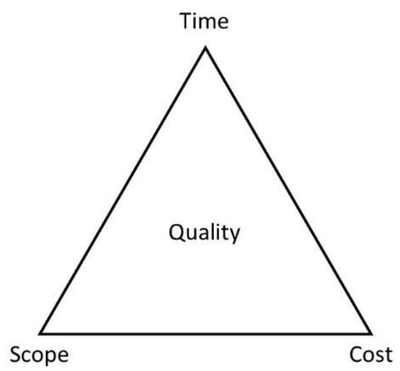

Figure 1: A triple constraint triangle representing the relationship of the project objectives, recreated from Newell and Grashina (2004, p. 9).

There is currently a lack of awareness of how risk is quantified and quality assured (Walker et al., 2003). If the same confusion found in the literature surrounding risk and uncertainty exists in the New Zealand industry, then there is likely to be serious problems in risk identification and management processes. This thesis attempts to provide an improved understanding of the risk management process as a result.

1.2. Aim and research questions

1.2.1. Proposition

The intention of this thesis is to understand the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry. This is achieved by exploring the two schools of thought: risk is uncertainty, and risk is distinctly separate from uncertainty. It is also essential to provide a method to systematically analyse planned and actual risks in a critical path of a construction project. This is an important aspect to consider as, at present, there seems to be no specific checks on the reliability of risk estimates. Current risk assessments rely on the accuracy of each estimate of the probability and impact. The impact on the critical path of errors or uncertainties in these estimates is not typically included in the analysis.

1.2.2. Research questions

This thesis addresses one main research question:

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

This is addressed by three sub-questions:

- Is risk uncertainty, or are risk and uncertainty different?
- Is uncertainty currently being quantified in New Zealand building projects?
- How are uncertainties assessed?

1.2.3. Research techniques

The research methodology applied in this thesis is a triangulation process (Denzin, 1970). A literature analysis, a case study, and a survey are used in combination to investigate the relationship between quality assurance, risk, and uncertainty as realised from the literature. The three methods aim to scrutinise this relationship in different ways, as one method may not reveal the answers to the research questions.

1.2.4. Literature analysis

The literature analysis is split into two main sections. The first, definition of risk and uncertainty; and the second, systematic processes to measure uncertainty. A range of sources is used to evaluate the definition of risk and uncertainty and emphasise the two schools of thought. Current uncertainty quantification techniques are also critically analysed in the literature; limitations, problematic areas and future focus areas are established. Focus is on uncertainty specifically, as reducing uncertainty can ensure quality assurance.

1.2.5. Case study

The case study analysis essentially aims to understand the behaviour of people in the New Zealand construction industry in comparison to how they are said to perform in the literature. The case study analysis explores uncertainty in a construction building project, as a means of ensuring the literature analysis and the survey are grounded in current industry practice. The case study attempts to identify the existence of uncertainty and identifies how it is managed before this is further explored in the New Zealand construction industry through a survey.

1.2.6. Survey

The survey further explores the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry. The intention is to obtain feedback from a representative group of industry professionals who might be expected to know about risk and uncertainty, using definitions derived from the literature and validated by the New

Zealand specific case study. A series of questions is developed under two main headings: treatment and definitions. The first section of the survey is a series of leading questions, aiming to establish common ways of dealing with uncertainties and drivers for their use. The second section of the survey attempts to determine the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry.

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2. Thesis Outline

This section provides an overview of the content of the nine chapters of this thesis.

Chapter 1: Introduction

This chapter introduces the thesis by explaining the research questions in relation to the proposition. The significance of the thesis is addressed, then the research methods are discussed relative to the research questions.

Chapter 2: Research background

This chapter discusses risk and uncertainty in detail, identifying the need for reliable risk assessments. Elements of uncertainty are outlined and relationships established. Quality assurance in risk management is then introduced to provide context for this thesis.

Chapter 3: Methodology

This chapter describes the triangulation method adopted. Each method is described in terms of this thesis. The methods are then discussed relative to the other methods to describe how they work together to realise the research question posed.

Chapter 4: Literature analysis

Two sections are presented in this chapter: definitions, and techniques to assess uncertainty. The literature identifies a fine line between the definition of risk and uncertainty. The definition section critically analyses many definitions placed under the two schools of thought explored, the first; risk is uncertainty; and the second, risk is distinctly separate from uncertainty. The chapter concludes with a review of techniques to assess uncertainty before these are further explored in the case study and the survey.

Chapter 5: Case study analysis

The case study analysis explores uncertainty in a construction building project, as a means of ensuring the literature analysis and the survey are grounded in current industry practice. The aim of this case study analysis is to understand the behaviour of people in the industry in comparison to how they are said to perform in the literature.

Chapter 6: Survey analysis

This chapter analyses the responses obtained from the online Qualtrics survey. After the types of experts that participated in the survey are established, the results are analysed in sections relating to the research question and sub-questions. The survey method is described in the context of the results from the other two research techniques used in this thesis: a literature analysis and a case study.

Chapter 7: Conclusion

This chapter presents the conclusions of this thesis, outlining limitations of the research and methods adopted. The results of each research method are discussed relative to the sub-questions to ensure that they agree and address the main research question posed.

Chapter 8: Future work

This chapter explains the future work that can continue from the results of this thesis. The survey results were a focus since the New Zealand construction industry answered specific questions for the future development of reliable risk assessments.

3. Research background

Two sections, risk and introduction to uncertainties, are presented below to provide background information to the research question proposed:

> What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

These two sections are then discussed in combination with quality assurance to establish gaps in the current literature. The last section, similar studies undertaken, explains the significance of this thesis and investigates the methods used to deal with similar problems.

3.1. Risk

This section provides a background to risk management in order to understand the relationship between quality assurance, risk, and uncertainty.

3.1.1. Quantification of risks

The literature quantifies risk in three main ways: qualitatively, semi-quantitatively and quantitatively. The qualitative assessment typically defines probability and impact by levels such as low, medium and high (usually outlined by criteria). The semi-quantitative method uses numerical rating scales for both probability and impact of the risk. Typically these scores are combined to form a final score, either with or without a relationship or weighting. The quantitative analysis estimates real-world values for both the probability and impact. It aims to produce a reliable risk analysis however, this is not always possible due to: lack of data, the influence of human factors (i.e. uncertainty), or because the effort of assessment is too high. This is when a qualitative or semi-quantitative analysis might be more appropriate (ECES, 2010). This is further substantiated by Bernstein (1996) where he argues that while quantitative analyses can seem convincing, it is often unreliable due to difficulties in obtaining consistent numerical data.

3.1.2. Overview of current risk research

Hall states that unknown-unknowns almost always guarantee that the risk analysis is proven wrong. Care has to be taken to avoid focusing quantification on the wrong risks. There is a danger of tunnel vision (diverting attention to the wrong risks and missing critical new risks). If tunnel vision occurs, risk management essentially narrows the information available instead of widening it. Managers will likely give up with formal risk analyses and instead just live and deal with the risks as they arise since their judgement and experiences seem to be a more effective use of their time (Hall, 1975).

The principle issue discussed in the literature on risk assessment in project management is the question of whether risk estimates represent practical probabilities, or reflect only measures by professional risk assessors that claim no more reliability than similar estimates by laypeople (Klinke & Renn, 2002). Sharder-Frechette categorises two types of professional risk assessors, constructivists and realists. Constructivists claim that risk assessments are made up of mental estimates, though are restricted by experience and ideas. While realists rely on technical estimates that are based on realistic observations and are calculated irrespective of the beliefs of the experts involved. To focus on the realistic estimate only ignores the social treatment of risk information; relying only on the constructive estimate of risk may lead to significantly less project success and more adverse effects than necessary (Shrader-Frechette, 1991). This is further demonstrated by Hansson (2010) where risk is described as a physical fact or a social object. Hansson concludes that neither is rational, risk is both factual and subjective. Each approach is a failed attempt to decrease the complexity of risk.

Ward and Chapman suggest that reducing complexity is the first step to increasing quality assurance in risk management. Some risks may be hard to quantify but simply acknowledging this is critical for the success of the project. The authors note that any form of systematic exercise to identify and rate risks and responses is a valuable exercise, whether quantification is included or not. They argue that the real risks to the project are those that are not predicted (Ward & Chapman, 1991). This concept was a crucial focus point for this thesis, influencing the direction of the survey method.

3.2. Uncertainty management

This section provides a background to uncertainty management to provide context for the specific focus of this thesis which is the relationship between quality assurance, risk, and uncertainty.

Graham (1995) and Loosemore et al. (2006) argue that risk will always include an element of judgment that is not definable and that any verification is itself a judgment and is made on the basis of random, debatable and subjective evidence. Therefore most calculations of risk will contain some degree of uncertainty, especially since a lack of quantified data is the norm rather than the exception in the industry (Loosemore et al., 2006). This evidence indicates that there could be many uncertainties not accounted for in the industry. This thesis aims to explore what actually occurs in the New Zealand construction industry using a case study and a survey. Loosemore et al identifies two main forms of judgement on the estimation of risk: personal biases (associated with a person's own: psychological make-up, education, experience, culture, beliefs, values etc.), and reporting biases which are formed when people communicate with each other (Loosemore et al., 2006).

Many authors acknowledge that uncertainty exists in two main forms: randomness due to variability, and imprecision due to lack of knowledge, judgements, and information. The former is referred to as objective, aleatory or stochastic; and the latter is often referred to as subjective, epistemic or state-of-knowledge (see Figure 2) (Apostolakis, 1990; Hattis & Minkowitz, 1997; Helton & Oberkampf, 2004; Hoffman & Hammonds, 1994; G. W. Parry & Winter, 1981; Pilch et al., 2011). Kiureghian and Ditlevsen state that uncertainties are difficult to reduce, but epistemic uncertainties can be mitigated by gathering more data or controlled through modelling. They argue that focus should be on these epistemic uncertainties; which can result in significant under or overestimations of risk if incorrectly quantified (Kiureghian & Ditlevsen, 2009).

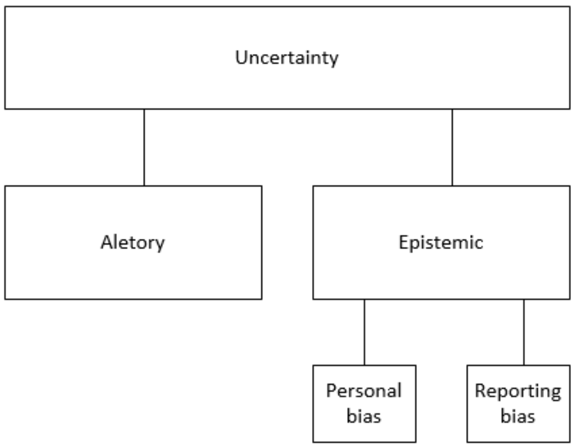

Figure 2: Figure depicting the relationship of the elements of uncertainty, created by author.

Recently the black swan concept has been associated with risk management, the metaphor refers to surprising events or outcomes. The black swan concept was first introduced by a Latin poet, Juvenal. A loose translation is "*a rare bird upon earth, and exceedingly like a black swan*" (Aven, 2013, pp. 44-51). This concept refers to something extremely rare, and also something that may later be disproven (i.e. an uncertainty). Hammond argues that the black swan concept, therefore, cannot be predicted (Hammond, 2009). Lindley disagrees, offering a proof that a black swan nearly always occurs if a person is to see a lot of swans. He argues that "*the calculus of probability is adequate for all kinds of uncertainty and randomness*" (Lindley, 2008, pp. 42-43). Aven scrutinises Lindley's research further, offering his proof that Lindley has concealed the assumption that all swans are white, and has also assumed the reliability of the probability model (Aven, 2013). These are the two forms of uncertainty, epistemic (assumptions) and aleatory (model reliability), discussed above. Aven argues that this black swan concept falls outside the scope of risk analyses, substantiating a need for a vigorous analysis of such techniques. Some events are considered to be surprising because they are based on the knowledge available. This is referred to as an unknown-unknown; no one has thought about that type of event before it has transpired. Thus, unknown-unknowns or uncertainties are not included in typical risk assessments based on the events identified. Aven states that the definition for a black swan in a risk context should, therefore, be "*an extreme, surprising event relative to the present knowledge*" though it is important to define whose knowledge this refers to (Aven, 2013, pp. 44-51). An example of this is the knowledge difference between designers and meteorologists: meteorologists are more aware of, and thus may be less surprised by weather events due to their focus in this area than designers. Aven concludes that it is essential to form frameworks that improve on the current models to include uncertainty, and more research is required to know how to do this in practice (Aven, 2013). This thesis attempts to critically analyse current models for predicting uncertainty, such as, Taleb's model of antifragility, and begins to consider these in practice through a survey.

3.3. Quality assurance, risk, and uncertainty

A common opinion in the industry surrounding risk assessments is that results of the risk analyses are associated with significant uncertainties, and currently, no agreed upon definitions or measures exist (Aven, 2003). Typically: national legislation, industry standards, and company policies often require the inclusion of a quantitative evaluation of the uncertainties to be presented alongside the results, although this is not seen as sufficient for a reliable risk assessment (NS, 1991). Many researchers such as Haimes (2005), Samson et al. (2009) and Ropel and Gajewska (2011) undertook definition reviews, indicating a need to explicitly understand the differences between the terms risk and uncertainty. Reading these analyses of risk management, it became clear that there are two streams or schools of thought: risk is uncertainty, and risk and uncertainty are different. This seems to ensure that guidance and processes for risk management often confuse the two terms risk and uncertainty, and this confusion is a likely cause of a lack of reliable risk assessments.

There has been a significant number of risk management standards and guidelines published globally in the last decade. Preda claims that multiple variations of the same document cause inconsistencies, which has resulted in a lack of followed systematic approaches and confusion around the standard terminology recognised in practice. Risk management standards were not typically applicable to both engineering and management, as a result ISO 9001:2008 – quality management systems: requirements was developed. There is still, however, a need for a global systematic risk management process (Preda, 2013). This emphasises the significance of this thesis; arguing the need for a simple systematic process, and highlighting the lack of consistency across current practices. A case study and a survey are used to further explore processes and consistency in the New Zealand construction industry.

Hansson, Ward, Chapman, Aven and Zio argue that reliable risk management techniques have not been accepted into practice due to the complexity and lack of knowledge, and currently, no convincing framework exists (Aven & Zio, 2011; Hansson, 2010; Ward & Chapman, 1991). This argument is substantiated by the United States Nuclear Regulatory Commission (U.S.NRC). The U.S.NRC recognise that research is still continuing in an attempt to form effective and accepted techniques to assess uncertainty (G. Parry & Drouin, 2009). This thesis attempts to provide context for this specific gap in the New Zealand construction industry.

A potential solution to this issue is described by Taleb. Taleb revisits the black swan concept in a later paper, arguing that although unknown-unknowns cannot be predicted the only available step is to strengthen the robustness and responsiveness of our society so we can better deal with these shocking events. The author introduces three systems in regards to risk management (see Figure 3): a robust or resilient system where the consequences are quite small within a narrow distribution (a), a fragile system where there is no control resulting in large negative consequences (b), and an antifragile system where extreme consequences are only positive (c) (Taleb, 2012).

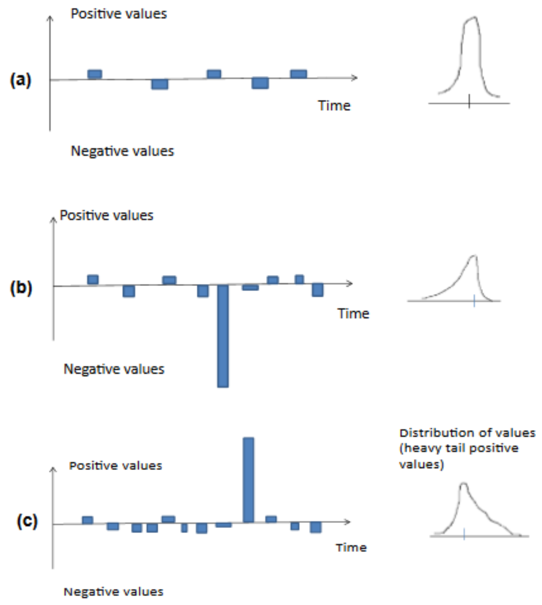

Figure 3: Depiction of the three risk management systems as outlined by Taleb (2012), recreated by Aven (2015, pp. 476-483).

Although the antifragile system is difficult to imagine in real life (a model that ensures no negative results), a real system can be made antifragile to some extent by using processes. Taleb argues that prediction and risk management should be replaced by processes which move away from fragility to antifragility (Taleb, 2012). This thesis builds upon this view, that a simple systematic process is required to improve the reliability of risk assessments. Essentially development of such a method could be considered in future work as this thesis only provided context for this issue. In order to complete the case study analysis a means was developed to systematically compare risk estimates against reality in a critical path for commercial projects through the comparison of risk to budget and programme analyses, and a survey attempts to determine the requirements for such a model in the New Zealand construction industry by questioning possible restrictions and incentives.

3.4. Summary

While quantitative risk analyses can seem convincing, they are often unreliable due to difficulties in obtaining consistent numerical data. Unknown-unknowns or uncertainties are not included in typical risk assessments, yet most calculations of risk contain some degree of uncertainty. Unknown-unknowns almost always guarantee that the risk analysis is proven wrong. Reliable risk assessment techniques have not been accepted into practice due to the complexity and lack of knowledge, and currently, no convincing framework exists. It is essential to form frameworks that improve on the current models to include uncertainty, more research is required to know how to do this in practice. The absence of such frameworks has indirectly caused the confusion between the two terms: risk and uncertainty and this confusion has therefore resulted in a lack of reliable risk assessments. This thesis essentially aims to improve the understanding of the terms risk and uncertainty in the New Zealand construction industry by investigating the inherent relationship quality assurance has with risk management processes.

3.5. Similar studies undertaken

The papers in each numbered section below have very similar research methodologies and aims to the ones presented in this thesis. Hence, they act as a starting point to develop this chapter, aiming to identify the most appropriate methods to use and outline limitations or areas of concern in the thesis.

3.5.1. Practical proposals for managing uncertainty and risk in project planning (Dawson & Dawson, 1998)

This investigation argued that typical planning techniques, such as PERT, and popular software tools are insufficient for projects involving uncertainty in project planning and activity durations. Dawson and Dawson proposed extensions to these planning techniques within existing software packages as a solution to the problem. The technique aimed to extend the function of PERT, allowing a range of routes in a project to be assessed to overcome the current limitations of uncertainties in the assessment of risk. They noted that complexity and lack of simple systematic process have been significantly problematic to uncertainty management. The literature also agrees with this observation (Aven & Zio, 2011; Hansson, 2010; Ward & Chapman, 1991). Dawson and Dawson used a workshop to present the ideas to 50 people. During the workshop, a survey was undertaken with 28 responses. The survey attempted to cover all previous limitations in the study. The results demonstrated that the suggested techniques were possible and practical (Dawson & Dawson, 1998). The function of a survey method in this thesis is also similar. The aim is to further investigate the relationship between quality assurance, risk, and uncertainty, and to explore requirements for such a model in the New Zealand construction industry.

Limitations of the study were:

- 28 replies in a survey were not considered conclusive evidence.
- The participants were not considered experts.
- The tool proposed was not actually developed just discussed as a concept.

- The concept was only tested with one software tool.
- The concept was only applicable to a few software packages.
- The survey assumed that suitable software would be available to allow uptake in the industry.

Although the tool was useful, it did not actually quantify uncertainty or allow the assessment of planned risks against real life. The evidence showed that uptake of the PERT technique is limited, due to the technical capability of an average project manager, and the lack of software tools available. In relation to this thesis, the authors suggested that there needs to be a simple systematic process to deal with uncertainty. Hence, in order to complete the case study analysis a means is developed to systematically compare risk estimates against reality in a critical path for commercial projects. Similarly this thesis does not test the uptake of the specific technique, rather the ideas presented. The survey aims to reduce any limitations or gaps in the thesis. This study identified that conclusions can still be made with less than 30 responses.

3.5.2. Risk management practices in a construction project – a case study (Sweden) (Gajewska & Ropel, 2011)

Gajewska and Ropel aimed to examine how risks and risk management were perceived in the construction industry, arguing that the construction sector is complex and highly risky (Gajewska & Ropel, 2011). This thesis essentially aims to understand something very similar about uncertainties as an extension of this work. The authors argued that uncertainty was not a tangible term thus it was not explored further in the study. There is evidence in the literature that suggests the contrary and these authors hypothesised that uncertainties are the reason for inaccurate risk assessments (Garner, 1962; ISO, 2009; Kaplan & Garrick, 1981).

Two methods, a case study and a survey, were used to investigate risks. Theory was compared to practice, establishing similarities and differences. The authors critically analysed many definitions of risk and uncertainty in the literature, arguing that clear definition was key to fully understanding the risk management concept. The results showed that although people identified risk as something negative, there was no agreement on how risk should be defined (Gajewska & Ropel, 2011). This thesis also undertakes a similar literature analysis as an extension of this work, attempting to fully understand the relationship between quality assurance, risk, and uncertainty. The thesis also uses one case study and a survey to compare theory to actual practice.

Limitations of Gajewska and Ropel's study are listed below:

- The case study included the planning and design phase of a project, but the project was still unfinished when the study was submitted.
- The interviews were held in Swedish. Although the aim was to ensure the best possible answer from the participants, there might be limitations with the translation of the interviews into English.

This thesis uses a completed complex case study to ensure the most realistic interpretation of the survey and of the literature, by placing them in a real world New Zealand construction context. Essentially this study is used to form the survey questions as similar aims and methods were employed.

Gajewska and Ropel concluded that the Swedish construction industry is aware of risks and the risk management process but the use of specific techniques and processes was limited. They concluded that it is important to identify an extensive range of techniques to deal with uncertainties and understand if these are being utilised in real life. The risk management process was rarely used due to lack of knowledge in the industry. This thesis speculates that this is also the same for uncertainty in the New Zealand construction industry. The most crucial conclusion made in relation to this thesis was that there is no structured way of working with risks (Gajewska & Ropel, 2011). This evidence further highlights the importance of this thesis.

3.6. Summary

Two sections, risk and introduction to uncertainties, were presented above to provide background information to the research question proposed:

> What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

These two sections were then discussed in combination with quality assurance to establish gaps in the current literature. This thesis essentially aims to improve the understanding of the terms risk and uncertainty by investigating the relationship quality assurance has with risk management processes. A triangulation research approach is adopted where, a literature analysis, a case study, and a survey are used in combination to achieve this aim.

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4. Methodology

4.1. Introduction

This section outlines the methodology for this thesis. A triangulation approach was adopted, where a literature analysis, a case study and a survey were used in critical analysis of the relationship between quality assurance, risk, and uncertainty as revealed from the literature. The three methods scrutinise this relationship in different ways, each method attempting to erase limitations or flaws of the other methods (Denzin, 1970). Each method is critically analysed in terms of this thesis and discussed relative to the other research methods.

The overall research question has been addressed using several sub-questions as realised from the research background. In late 1990's/early 2000's the project management community began to distinguish between risk and uncertainty (Institution of Civil Engineers, 1998), thus it was important to question the relationship between these critical concepts by asking "is risk uncertainty, or are risk and uncertainty different?". The literature identified that complexity and lack of simple systematic process has been significantly problematic to uncertainty management (Aven & Zio, 2011; Dawson & Dawson, 1998; Hansson, 2010; Ward & Chapman, 1991), thus it was also important to understand if there is a systematic method to compare risk assessments against real life.

The three research methods adopted in this thesis addressed each question as follows: literature analysis (LA), case study (CS) and survey (S).

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?
    - Is risk uncertainty, or are risk and uncertainty different? (LA) (S)
    - Is uncertainty currently being quantified in New Zealand building projects? (CS)
    - How are uncertainties assessed? (LA) (CS) (S)

4.2. Literature analysis

The following section establishes the literature analysis as a research tool in relation to this thesis. The literature analysis is discussed relative to the case study and the survey method, in an attempt to mitigate disadvantages and limitations.

The following sub-research questions have been addressed through the literature analysis:

- Is risk uncertainty, or are risk and uncertainty different?
- How are uncertainties assessed?

After a research background was established, it was now important to further scrutinise the relationship between quality assurance, risk, and uncertainty. This was achieved through two main sections: the first, definitions; and the second, techniques to assess uncertainty. The first section aimed to reveal an extensive list of definitions of risk and uncertainty to determine if there was common terminology, and to address the first sub-research question. The second section aimed to review current techniques to quantify uncertainty, highlighting any limitations or problematic areas. A case study and a survey were used to connect the way people are thought to assess uncertainties with the reality in the industry.

4.2.1. Definitions

Having identified two schools of thought in regards to risk and uncertainty a meta-analysis was undertaken. As many references as possible were collected and placed under the two schools of thought explored. Each definition was selected to develop a detailed list. A meta-analysis was then conducted in an attempt to address the first sub-research question and understand if there was common terminology. Some of these definitions were used in the survey to further explore this relationship in the New Zealand construction industry.

4.2.2. Techniques to quantify uncertainty

Risk education material and the wider literature were used to explore the many ways uncertainties can be quantified. This enabled a detailed case study analysis, and the development of a survey that explored the use of these techniques in the New Zealand construction industry in an attempt to address the second sub-research question, how are uncertainties assessed.

4.3. Case study

The following section critically analyses the case study method in relation to this thesis; advantages, disadvantages, and limitations are outlined. The case study method is discussed relative to the literature analysis and the survey method, in an attempt to mitigate these disadvantages and limitations.

The following sub-research questions have been addressed through the case study method:

- Is uncertainty currently being quantified in New Zealand building projects?
- How are uncertainties assessed for New Zealand building projects?

The aim of this case study analysis was to understand the behaviour of people in the New Zealand construction industry in comparison to how they are said to perform in the literature. The case study analysis explored uncertainty in a construction building project, as a means of ensuring the literature analysis and the survey were grounded in current industry practice. The case study analysis essentially identified the existence of uncertainty in a project and attempted to understand how uncertainties are being controlled.

4.3.1. Case study method

This case study method acted as a connection between the theory found through the literature and the reality in the industry (Bell, 2007). One case study was analysed since it identified the existence or non-existence of uncertainty and demonstrated how uncertainties are controlled on a project. The goal was essentially to understand a larger class of case studies by using an in-depth analysis (Seawright & Gerring, 2008). Common projects have a better understanding of their risks and uncertainties, whilst more complex or first-of-its-kind projects tend to have more uncertainty (PMI, 2013). Selection of one unique and complex project appropriately represented the existence of uncertainty in the construction industry. Focus on a specific project was not seen as a limitation to the thesis though each person has a different approach, the main process followed is similar thus the results were comparable (PMI, 2008). Access to one complex construction project enabled the possibility of a larger level of uncertainty to be analysed. A complex project was defined as a specialised project, for example, a theatre. The case study analysis essentially enabled insight to a typical risk assessment in the construction industry.

4.3.2. Research questions

The first aim of the case study was to test the existence or non-existence of uncertainty in a construction building project and identify how the New Zealand industry manages risk. Eight risk analyses spread over the duration of the project was the data used to test this. The analyses were scrutinised for any form of uncertainty identification whether it be assumptions, actual quantification, or the use of techniques that enabled a more reliable risk assessment as found in the literature analysis. A survey was undertaken to further identify how the New Zealand industry manages risks as an extension of the case study method.

4.3.3. Analysis

The case study was scrutinised to identify differences between the first documented analyses and the information available at the conclusion of the project. Several different measurable aspects were identified: risk analyses, programme changes and budget changes. A risk analysis mapped over time was essentially compared to differences in the planned and actual project programme and budget in an attempt to identify how close the initial analyses were to the eventual measure. A scale of uncertainty was also formed by identifying the maximum and minimum changes between the planned and actual assessments. The case study analysis may not have provided evidence of uncertainty or identified ways to control uncertainties, thus, a survey was used to further investigate the findings and allow generalisation of the conclusions drawn.

4.3.3.1. Risks

Each risk analysis was organised in an excel sheet so that the change in quantification could be compared over the whole project. A score range was allocated to each qualitative term so that these could be compared to the quantitative estimates. The final case study quantitative score was out of 25, so the scales were equally quantified accordingly:

- Low was given a scale of 0-7
- Medium was given a scale of 8-16
- High was given a scale of 17-25

Essentially the final quantitative score was compared to the initial qualitative assessment. A red colour was allocated where the final score did not meet the corresponding scale and green where it did meet the criteria. An overall success rating was then determined based on the total amount of green scores.

The quantitative assessment was in two parts: likelihood and severity. Each risk was scored out of 25 based on the score of likelihood and severity. The initial quantitative score for likelihood, severity, and the final score was compared to the corresponding final score. Differences in the scores were established, and these were coloured accordingly (a score of 5 was selected based on the maximum score for one category):

- Green was no change
- Orange was a score of five or lower (positive or negative)
- Red was a score of 6 or higher (positive or negative)

Essentially the initial quantitative score was compared to the final quantitative score. A success rating was then determined based on the total amount of green scores.

4.3.3.2. Schedule

The critical path was identified for the project, essentially forming a list of critical tasks. The first assessment for the amount of days, the start date, and the end date of each task was compared to the final assessment. A difference in the number of days was established and coloured with a graded red-green-red colour scale; large differences (positive or negative) were coloured bright red, in contrast to no differences which were coloured bright green. An inconsistencies rating was then determined based on the number of cells with a difference more than one.

4.3.3.3. Budget

The cost of major phases of the project were compared. The initial cost was compared to the final cost and a difference formed. These were coloured accordingly:

- Red where there was a change (positive or negative)
- Green where there was no change

A total change was then established by adding the positive and negative differences together.

4.4. Survey

The following section presents the survey method and critically analyses its relationship to the other research techniques used in this thesis; advantages, disadvantages, and limitations are outlined. The survey is discussed relative to the literature analysis and the case study method, in an attempt to mitigate these disadvantages and limitations.

The following sub-research questions have been addressed through the survey method:

- Is risk uncertainty, or are risk and uncertainty different?
- How are uncertainties assessed for New Zealand building projects?

A review of the literature revealed two schools of thought in the exploration of the relationship between quality assurance, risk, and uncertainty. The first, risk is uncertainty, and the second, risk and uncertainty are different. Consequently, there were two main aims of the survey: to explore the relationship between risk and uncertainty in the New Zealand construction industry, and to identify techniques used to control uncertainties as an extension of the case study method (Groat & Wang, 2013).

4.4.1. Survey method

The two aims of the survey were realised through a heuristic evaluation method as discussed by Nielsen. He used nineteen evaluators to find sixteen usability problems in a bank voice response system (Nielsen, 1992). Each black square, depicted in Figure 4, indicated the finding of one usability problem by one evaluator. The figure communicates the amount of non-overlap of problems found by different subjects. One cannot simply rely on the best subject's evaluation as this does not allow an appropriate representation of all issues. Therefore, it was best to involve multiple evaluators and produce a representation of all the problems (Nielsen, 1994). This concept was applied to the thesis in the survey analysis. The aim was to form a reasonably comprehensive list of opinions in regards to the two aims outlined above. The goal was essentially to find the number of problems i.e. the range of opinions and techniques, not the typical practice.

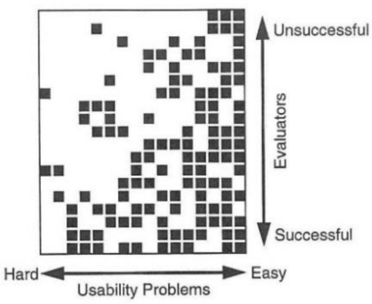


Figure 4: This graph shows which evaluators found which usability problems in a heuristic evaluation of a banking system. Each row represents one of the 19 evaluators, and each column represents one of the 16 problems (Nielsen, 1994, p. 27).

4.4.2. Sample size

Typically, if standard statistical analysis techniques are to be used, a minimum of 30 responses is required on a survey (Groat & Wang, 2013). For example, when average responses are being formed, 30 is the number where sensible statements about the meaning of that average can be made. The aim of the survey was to understand amongst a group of experts the relationship uncertainty has with risk and to identify the many ways uncertainties are dealt with in the New Zealand construction industry. This was only achieved by gathering multiple opinions from informed industry participants around uncertainties. The goal was never to identify a typical or average response.

4.4.3. Risk experts

Nielsen identified three groups of evaluators in the bank voice response case study, the groups were split as follows: usability novices with basic computer knowledge but no particular usability knowledge, single experts who were usability specialists but had little background in user interfaces, and double experts with expertise in both fields. The results showed that the preferred evaluator to use was the single expert as they found 1.8 times the issues than the novice (Nielsen, 1993). Expert is defined as "*a person who is very knowledgeable about or skilful in a particular area*" (Oxford Dictionaries, 2015). Construction project managers were targeted in particular because they were the likely expert group in regards to risk management. Typically risk management is monitored and controlled by the project manager on a construction project (RCP, 2016; TBIG, 2016). Risk managers could have been targeted specifically but there is a limited number of them in the industry and thus, this would have had detrimental effects on the results (Risk NZ, 2014). Hence, the broader title of project manager was more appropriate in this case. To ensure that the participants of the survey were classified as experts in relation to risk management, the survey was distributed to two groups of construction project managers. One group with years of experience or education (single experts), and the other group which are professional project management qualification holders with more than three years of experience (double experts). This group was to act as the equivalent of Nielsen's more knowledgeable experts of the field to determine if experience affected the understanding of uncertainty management. Three years of experience was selected based on the Project Management Institute (PMI) guidelines. The Project Management Professional (PMP) qualification is considered to be one of the most globally recognised certifications for 'leading' or expert project managers (PMI, 2015). To achieve this qualification a degree and at least 3 years of industry experience is required. This choice of years' experience is further substantiated by New Zealand project management firms where more than three years of industry experience is required to be considered a project manager (TBIG, 2006a, 2006b).

4.4.4. Contacts

Sampling errors can arise from the specific selection of participants (Bethlehem, 2010; Couper, 2000; Wang & Doong, 2007). To address this potential limitation, an anonymous survey was made available to a significant amount of project management firms. The main national bodies relevant for this thesis were the Project Management Institute of New

Zealand (PMINZ), the Institute of Management New Zealand (IMNZ), the Institute of Engineering and Technology (IET) and the New Zealand Institute of Building (NZIOB). These bodies acted as a contact database to find experts in the field. Use of the national bodies removed any bias when approaching companies, although these corporations were not just restricted to the project management construction field. Hence, it was important to include background questions at the beginning of the survey to screen out participants that were not from this particular field. Experts within each company had the choice to participate, allowing for more accurate data given from those willing to make the time.

4.4.5. How do risk and uncertainty differ between projects?

Construction projects, in particular, tend to have more risk than other industries due to the complex dynamic nature, and the multiple feedback processes (Loosemore, 2004; Sterman, 1992). The construction phase is usually more risky than other phases of the project (Zou et al., 2006). There was no specific breakdown of different phases in the survey as the case study proved that risks were not assessed over different phases. Another classification brought to attention was the separation of different risk groups such as design, construction, financial/economic, political and environmental (Gould & Joyce, 2002). Again, there was no specific breakdown as the case study proved that risk assessments typically did not change across classifications. These different risk areas require different planning but their separation was not seen to be useful for this analysis of uncertainty. Essentially the focus was on construction classifications, types and sizes. The classification of building types potentially could have an impact on the treatment of uncertainty (Sears et al., 2008), this is discussed further below. Construction types and size could also impact the level or treatment of risk (P. Dey, 2011; P. K. Dey & Ogunlana, 2002). This is also discussed further below.

4.4.5.1. Classification of building types

Statistics New Zealand classifies building types into three main categories:

- Residential
- Non-residential
- Non-buildings

Non-buildings are defined as "*retaining walls, roads, bridges, signs, and wharfs*" (Statistics New Zealand, 2015). Assessing non-buildings was not relevant for this thesis as the focus was on construction projects specifically. Within the residential classification, there are two main sub-classifications: dwelling houses and domestic outbuildings; within the non-residential classification there are many sub-classifications. Focus was on residential and non-residential as a whole so not to limit the data available.

4.4.5.2. Construction types

The New Zealand Building Code covers three main types of work: new, renovation and demolition (New Zealand Government, 1992). Thus, these three construction types were broken down in the survey.

4.4.5.3. Size of construction projects

The Building Energy End-Use Study (BEES) was a six-year investigation undertaken by the Building Research Association of New Zealand (BRANZ) (BRANZ, 2016). Though the focus was on non-residential buildings, this long-term study can be used as a precedent for other New Zealand building studies. Size of the project is defined by the Building Energy End-use Study (BEES) below:

Non-residential size strata						
Floor Area Strata	**1**	**2**	**3**	**4**	**5**	**Total**
Minimum Floor Area	5m^2	650m^2	1,500m^2	3,500m^2	9,000m^2	
Approx. No. of Buildings	33,781	10,081	4,288	1,825	564	50,539
% of Buildings	67%	20%	8%	4%	1%	100%
Total Floor Area (million m^2)	9.9	9.6	9.5	9.6	9.8	48
% Floor	20%	20%	20%	20%	20%	100%

Table 1: BEES non-residential building strata division, recreated by author from table i (Isaacs et al., 2010).

The following categories were created for this thesis:

- Small project - under 650m^2 (20% of total floor area)
- Medium project - between 651-3500m^2 (40% of total floor area)
- Large project - over 3501m^2 (40% of total floor area)

4.4.6. Question types

The questions and conclusions presented in "Risk management practices in a construction project – a case study" as discussed in section 3.5.2 above, were used alongside the other literature to formulate the survey questions and specific answers. For conclusions to be formed from the questions, a number of answers to each question had to be included in the survey. This attempted to form opinions on a scale level (i.e. no understanding – complete understanding) as the respondents were limited to certain answers though many questions contained an "other" category ensuring that all opinions were gathered.

4.4.7. Overall issues that were answered through the survey

The survey was split into two main sections (treatment and definitions) in order to address the two sub-research questions:

- Is risk uncertainty, or are risk and uncertainty different?
- How are uncertainties assessed for New Zealand building projects?

The following list depicts an overview structure of the survey:

Treatment

- Current treatment of uncertainties in practice
  - Identification
  - Assessment
  - Response
  - Monitor and control

Definitions

- Definition of risk and uncertainty
- How these are differentiated
- Current processes recognised
- Effect of uncertainty on actual projects

4.4.8. Formulation of questions in detail

This section outlines the formulation of the survey questions, discussing the purpose and outcomes of each part of the survey. The treatment section was essentially a series of leading questions to establish the understanding of uncertainty, and to determine how uncertainty was dealt with in different situations before the terms risk and uncertainty was separated and further understood. Although participants could misunderstand the term uncertainty at the start of the survey, it was important to gain the answers to the treatment section without any impact likely caused by the definitions section. The definitions section of the survey used definitions from the literature, which essentially implied a difference between risk and uncertainty. It was crucial to structure the survey in this way to form valid conclusions about the perception of uncertainty.

4.4.8.1. General information

The purpose of this section of the survey form was to ensure that the participants were construction project managers as the survey was distributed through several industry bodies. These bodies were not limited specifically to project management or construction. This section presented the first initial uncertainty question to determine industry understanding and to ensure incomplete surveys were still useful. This section also ensured that the participants were considered experts, as determined in section 4.4.3

Risk experts, and to ensure the responses were comparable and applicable to new construction projects. Project types were also defined here, there proved to be a limitation to the thesis in that risks (consequently uncertainties) are treated differently across projects. It was essential to ensure the participant was focusing on one specific project classification when answering all survey questions.

4.4.8.2. Treatment

The purpose of this section of the survey form was to determine how the construction industry deals with uncertainties (similarly to risks through identification, assessment, response, and monitor and control (PMI, 2009)), and to determine the perceived level of impact uncertainties have on projects. These questions also attempted to determine what actions were used and when these actions were taken. The literature suggested that action was usually only taken on higher prioritised risks (PMI, 2013). The survey aimed to understand if this occurs in the New Zealand construction industry, speculating that this could be the major cause for inaccurate risk assessments.

4.4.8.3. Definitions

The aim of this section of the survey form was to further explore the two schools of thought outlined in the literature, either that: risk is different from uncertainty, or that risk is uncertainty. This was achieved by a series of three questions. The participant was first asked to define risk and uncertainty, then to explain how these are different. These answers were compared with several other questions to determine the actual understanding of risk and uncertainty in the New Zealand construction industry.

4.4.9. Testing

Tests were carried out on several different parties to ensure the survey achieved the results expected and that the questions were formulated appropriately. "Experts", "non-experts" and a statistician were utilised to cover all aspects and thus, quality assure this data collection method. Ten people scrutinised in detail the questions themselves and the types of analysis and conclusions expected. Several iterations were made to formulate the final survey questions and methodology. The language of the questions were changed in particular to allow a clearer understanding.

4.4.10. Reporting of results

This section outlines several methods that have been used to analyse and report the results. Different methods were suitable for different situations depending on the type of data and correlations drawn. The following tests were used to ensure reliable results of a small sample size.

4.4.10.1. Automated survey results

To ensure there were no inconsistencies in the presented data, an automated excel sheet was used to present the results. Three files were obtained from Qualtrics: an initial report, a single expert file and a double expert file. These three files were sorted into one excel workbook using a combination of cell copying and the formulae.

To obtain the single experts file some filters were required in Qualtrics:

> Question "*how many years have you spent in the field?*" where "*less than 3 years*" was selected or question "*do you have a project management qualification?*" where "*no*" was selected.

To obtain the double experts file the following filters were required:

> Question "*how many years have you spent in the field?*" where "*more than 3*" was selected and question "*do you have a project management qualification?*" where "*yes*" was selected.

4.4.10.2. Graphs

Graphs were used to communicate the number of responses for each survey question. Conclusions and speculations were then made based on these graphs, and highest picked answers were identified.

4.4.10.3. Fisher's exact test of independence

Fisher's exact test was used to test the independence of two nominal variables. This is more accurate and appropriate than the chi-square test when the sample size is small (McDonald, 2009). Fisher developed this test through an experiment of only 8 cases (Fisher, 1935). This test looked at both the expected and the observed spread of data to communicate the goodness of fit (Toutenburg, 1971). The hypothesis was that the more experience a person has, the more likely they will understand the difference between risk and uncertainty. A punnet square was used to compare the level of experience to the understanding of risk and uncertainty. The null hypothesis tests if variables are similar to each other e.g. the understanding was the same for single experts as it was for double experts. The alternative hypothesis was the one presented in this thesis where it was expected that double experts have more understanding (McDonald, 2009).

4.4.10.4. P-value

The P-value is a quantitative figure which was used to test the null hypothesis in a Fisher's exact test.

- A small p-value (<0.05) shows strong evidence against the null hypothesis; thus, the null hypothesis is disproven.
- A large p-value (>0.05) indicates weak evidence against the null hypothesis; thus, the null hypothesis is true.

(Rumsey, 2010)

4.4.10.5. Exact confidence intervals for a binomial outcome

A binomial outcome can be used to estimate an expected result from a statistical sample. This particular technique is used when the sample size is small. First an observed proportion was realised then a confidence interval found. The confidence interval acts as a "degree of belief" (Morisette & Khorram, 1998, pp. 281-283). The following online calculator was used to find the results (Causascientia, 2016). An example is presented below:

A coin was flipped and achieves heads 8 out of 16 times. This is a proportion of 50% with a confidence interval of 95% between 28% and 72%. Hence, there is 95% confidence that another test or the true expected result will achieve somewhere between 28% and 78% (Mayfield, 2013).

4.5. Summary

A triangulation methodology approach was adopted where a literature analysis, a case study and a survey method were used in combination to address the research question:

> What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

The literature analysis explored the relationship between risk and uncertainty and identified many ways used to assess uncertainties before these were presented in a survey to the New Zealand construction industry. The case study analysis explored uncertainty in a construction building project, as a means of ensuring the literature analysis and the survey were grounded in current industry practice. One complex construction case study was chosen to identify the existence of uncertainty and to establish how uncertainties are treated within a real project before this was further explored through a survey.

5. Literature analysis

The following sub-research questions have been addressed through the literature analysis in an attempt to address the principal research question identified in chapter 1:

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

- Is risk uncertainty, or are risk and uncertainty different?
- How are uncertainties assessed?

Three sections are presented below in an attempt to address these research questions: definitions, techniques to assess uncertainty, and recently developed techniques. This method was used in combination with a case study and a survey analysis to ensure all sub-research questions were addressed and the principal research question realised. Some definitions revealed in the definitions section below were used to form questions in the survey. The techniques realised through this literature analysis were used to allow the critical case study assessment and were also used in the survey.

5.1. Definitions

Many researchers such as Haimes (2005), Samson et al. (2009) and Ropel and Gajewska (2011) undertook definition reviews, indicating a need to explicitly understand the differences between the terms risk and uncertainty. After reading of risk management was undertaken, it became clear that there were two streams or schools of thought. An extensive list of definitions for both risk and uncertainty has been found and consequently placed under the two schools of thought explored: risk is uncertainty, and risk and uncertainty are different (see Figure 5). These definitions reveal a wide range of difference between those who confound these terms and those who clearly see them as distinct. Each definition was selected from the works above based on context. Subsequently other definitions were sought to provide a detailed list of definitions.

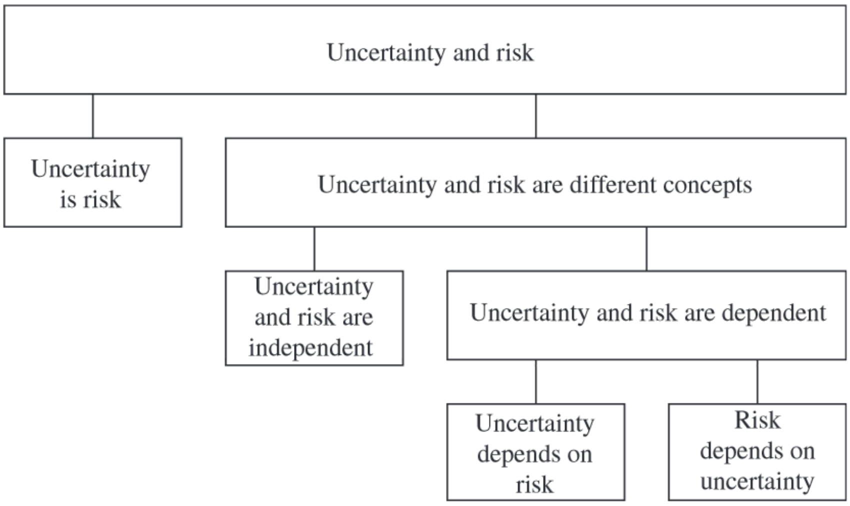


Figure 5: Relationship between risk and uncertainty (Samson et al., 2009, p. 559).

5.1.1. Risk is uncertainty

Author	**Risk definition**	**Uncertainty definition**	**Notes**
(Mehr & Cammack, 1961, pp. 18-19)	"*Risk is defined as uncertainty. It has reference to the uncertainty of a financial loss and little to do with the loss itself, the cause of the loss, or the chance of loss. Risk has principally to do with the uncertainty of a loss…. The degree of risk is measured by the probable variation of actual experience from expected experience. The lower the probable percentage of variation, the smaller the risk*."	*"Risk is defined as uncertainty. It has reference to the uncertainty of a financial loss and little to do with the loss itself, the cause of the loss, or the chance of loss. Risk has principally to do with the uncertainty of a loss…. The degree of risk is measured by the probable variation of actual experience from expected experience. The lower the probable percentage of variation, the smaller the risk."*	Risk is uncertainty.
(Magee, 1961, p. 77)	*"The uncertainty of the happening of an unfavourable contingency has been termed risk. Risk is present when there is a chance of loss…. The various factors contributing to the uncertainty are termed hazards. Ordinarily there are many separate hazards that contribute to the chance or possibility of loss that attach to any particular object or person. The sum total of the hazards constitutes the risk."*	*"The uncertainty of the happening of an unfavourable contingency has been termed risk. Uncertainty is present when there is a chance of loss…. The various factors contributing to the uncertainty are termed hazards. Ordinarily there are many separate hazards that contribute to the chance or possibility of loss that attach to any particular object or person. The sum total of the hazards constitutes the uncertainty."*	Risk is uncertainty.
(Lowrance, 1976)	*"Risk is a measure of the probability and severity of adverse effects."*	*"Risk is a measure of the probability and severity of adverse effects."*	Risk is uncertainty.
(Philippe, 2001)	*"The uncertainty of outcomes. It is best measured in terms of probability outcomes."*	*"The uncertainty of outcomes. It is best measured in terms of probability outcomes."*	Risk is uncertainty.
(PMI, 2012, p. 10)	*"An uncertain event or condition that, if it occurs, has a positive or negative impact on one or more project objectives."*	*"An uncertain event or condition that, if it occurs, has a positive or negative impact on one or more project objectives."*	Risk is uncertainty.

Table 2: A list of definitions that follow the 'risk is uncertainty' school of thought.

Table 2 identifies 5 sources that date from Mehr and Cammack (1961) to PMI (2012), proving that there is considerable evidence where risk can be understood as uncertainty. This is highlighted by the repeat definition seen in both columns and the note in the right column, risk is uncertainty. This evidence is in contrast to the findings below and is significantly problematic for the industry, where the risks mapped will not be indicative of real life due to this missing concept of uncertainty. A current definition of uncertainty is:

> *"The state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequences, or likelihood."*

(ISO, 2009).

Risks are estimations and it is important to quantify these as accurately as possible. If risks are being treated as uncertainties this suggests that inaccuracies in the estimation of risk are not being considered. The definitions above show that a risk is associated with a negative or uncertain outcome, not addressing uncertainty either explicitly or at all. The most important reference to note is the Project Management Institute (PMI). This is one of the main project management institutes in New Zealand and these findings further constitute the need to understand the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry. This thesis speculates that the industry is confused about the relationship between risk and uncertainty, and the use of the PMBOK guide (from the PMI) has caused some of this confusion.

5.1.2. Risk and uncertainty are different

Author	Risk definition	Uncertainty definition	Note
(Knight, 1921, p. 223)	*"The distribution of the outcome in a group of instances is known. Quantifiable uncertainty."*	*"The distribution of the outcome in a group of instances is unknown, the reason being in general that it is impossible to form a group of instances because the situation dealt with is in a high degree unique. Non-quantifiable uncertainty."*	Risk and uncertainty are independent.
(Keynes, 1937, pp. 213-214)	*"These matters there is scientific basis on which to form any calculable probability."*	*"By uncertainty, I do not mean merely to distinguish what is known for certain from what is only probable. About these matters, there is no scientific basis on which to form any calculable probability whatsoever. We simply do not know."*	Risk and uncertainty are independent.
(Garner, 1962, p. 7)	*"Risk is an event."*	*"The uncertainty of an event is the logarithm of the number of possible outcomes the event can have…"*	Risk and uncertainty are independent.
(Kaplan & Garrick, 1981, p. 12)	*"Risk involves both uncertainty and some kind of loss or damage."*	*"The degree of uncertainty depends upon our total state of knowledge."*	Risk is dependent on uncertainty.
(ISO, 2009)	*"Effect of uncertainty on objectives."*	*"The state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequences, or likelihood."*	Risk is dependent on uncertainty.
(Willett, 1901, p. 4)	*"Objectified uncertainty regarding the occurrence of an undesirable event."*	*"The subjective uncertainty resulting from the imperfection of man's knowledge is uncertainty."*	Uncertainty is dependent on risk.

Table 3: A list of definitions that follow the 'risk and uncertainty are different' school of thought.

The definitions presented in Table 3 demonstrate significant evidence to prove that risk and uncertainty are understood as separate terms within the literature. These 6 sources, in the left column, date back from Willett (1901) to (ISO, 2009) proving that the terms have been well understood for over a century.

Three main connections or sub-relationships between the terms were explored: risk and uncertainty are independent, risk is dependent on uncertainty, and uncertainty is dependent on risk (as seen from the right column). The definitions show that risk is typically understood as a quantifiable concept while uncertainty is not (Keynes, 1937; Knight, 1921). Thus, a question can be raised here; “if uncertainty is considered to be unquantifiable, then how do people identify and respond to it in a project?” This is explored in section 5.2 below, and through a case study and a survey.

Knight is an important source here as he was the first to make the complete distinction between risk and uncertainty, defining them as independent terms. Given that there is confusion surrounding the relationship between risk and uncertainty over the last century (see Table 2), Knight’s work is of much importance. Hundreds of authors, including many of the ones presented above, have based their definitions on his work and been influenced by this argument.

5.1.3. Summary

To conclude, there is no universal definition of risk or uncertainty or an agreement on how they are related across an extensive amount of the literature. Each definition is usually formed based on industry or context. Haimes (2005), Samson et al. (2009) and Ropel and Gajewska (2011) have undertaken similar definition reviews, aiming to develop a more refined description of the terms. As evident from a repeat study every few years, the more descriptive definitions do not erase or solve this confusion between risk and uncertainty. This thesis aimed to explore the relationship between quality assurance, risk, and uncertainty; a more extensive list and understanding was required. Hence, it was important to explore in detail the many definitions and relations of each concept further from these researchers. The analysis shows that risk is different from uncertainty, the earliest definition depicts this and many definitions are based on Knight’s work which also illustrates this. There is still however a fine line between the two terms as established from Table 2. This analysis essentially acted as a starting point to determine if the terms risk and uncertainty are understood in real life. A survey used some of these definitions to test the relationship between risk and uncertainty in the New Zealand construction industry.

5.2. Techniques to assess uncertainty

The findings above produced two opposing arguments: that uncertainty can be quantified and that uncertainty cannot be measured at all. This thesis questions the latter argument, if uncertainty is considered to be unquantifiable, then how does the industry identify and respond to it on a project? This section intends to analyse the many ways uncertainty is assessed in the literature before a survey is undertaken to explore the industry. Education material and the literature were two forms of material that were reviewed in an attempt to analyse the many ways uncertainty is assessed.

5.2.1. Education

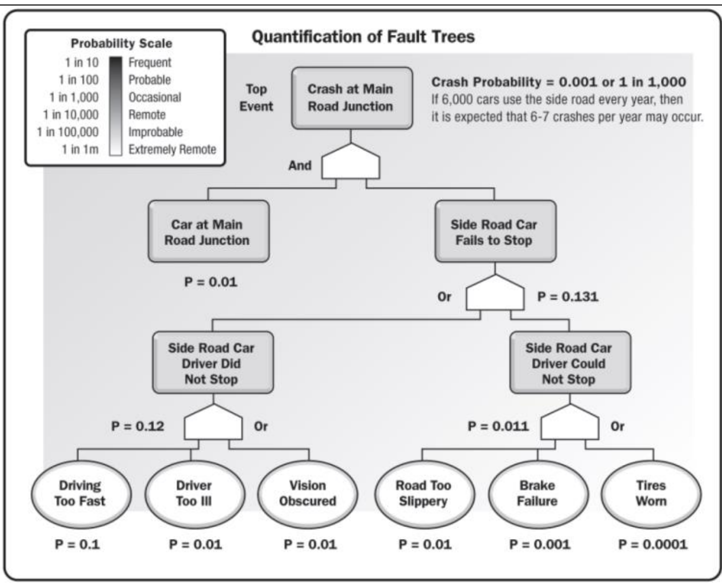
Education is the main driver for effective practice in the industry (Franz, 2008). Two main forms of risk education material were reviewed below in an attempt to understand how uncertainty might be assessed in the New Zealand construction industry. The first, the Project Management Body of Knowledge (PMBOK) guide, and the second, the New Zealand Risk Management Standards. Project management education typically follows the processes set out by the Project Management Institute (PMI). The organisation acts as an "*international standard ensuring project management is understood to a similar level of definition across the world*" (PMI, 2011).

5.2.2. Literature

One aim of this thesis was to explore the many ways uncertainty might be assessed in the New Zealand construction industry. Hence, it was important to explore techniques in international literature as an extension of New Zealand project management education in order to ascertain as many techniques as possible.

5.2.3. Techniques

<table>
<tr><th></th><th>Technique</th><th>Description</th><th>Limitations</th></tr>
<tr><td>1</td><td>Defining risk probability and impact scales</td><td>
<table>
<tr><th colspan="6">Defined Conditions for Impact Scales of a Risk on Major Project Objectives
(Examples are shown for negative impacts only)</th></tr>
<tr><td rowspan="2">Project Objective</td><td colspan="5">Relative or numerical scales are shown</td></tr>
<tr><td>Very low /0.05</td><td>Low /0.10</td><td>Moderate /0.20</td><td>High /0.40</td><td>Very high /0.80</td></tr>
<tr><td>Cost</td><td>Insignificant cost increase</td><td>< 10% cost increase</td><td>10 – 20% cost increase</td><td>20 – 40% cost increase</td><td>> 40% cost increase</td></tr>
<tr><td>Time</td><td>Insignificant time increase</td><td>< 5% time increase</td><td>5 – 10% time increase</td><td>10 – 20% time increase</td><td>> 20% time increase</td></tr>
<tr><td>Scope</td><td>Scope decrease barely noticeable</td><td>Minor areas of scope affected</td><td>Major areas of scope affected</td><td>Scope reduction unacceptable to sponsor</td><td>Project end item is effectively useless</td></tr>
<tr><td>Quality</td><td>Quality degradation barely noticeable</td><td>Only very demanding applications are affected</td><td>Quality reduction requires sponsor approval</td><td>Quality reduction unacceptable to sponsor</td><td>Project end item is effectively useless</td></tr>
</table>
Figure 6: Definition of impact scales for four project objectives (PMI, 2013, p. 318).
</td><td>Some parameters are difficult to quantify. Inconsistencies across projects and firms could be problematic. This could cause focus on the wrong risks as identified by (Hall, 1975).</td></tr>
<tr><td>2</td><td>Assumption analysis</td><td>This method allows assumptions, hypothesis etc. to be identified for each risk so that inaccuracies, instabilities, inconsistencies or incompleteness are outlined (PMI, 2009).</td><td>There is no specific systematic process of assessing their actual impact on the project.</td></tr>
<tr><td>3</td><td>Quality of available information</td><td>This is a technique used to assess the usefulness of the data, it includes assessing the level to which a risk is understood and the accuracy, reliability etc. of the data about the risk. Each of these is rated, if a low-quality risk data level is established then it may be necessary to gather more data (PMI, 2009).</td><td>This process is considered timely, and only major low-quality data is reassessed.</td></tr>
<tr><td>4</td><td>Expert judgement</td><td>This process typically involves discussions with experts to determine the correct weightings of probability and impact that were already assessed (PMI, 2009). Expert opinions can be sufficiently represented by accumulated probability distributions (Paté-Cornell, 1996).</td><td>This technique is usually dependent on the organisation. This is problematic due to the scientific and social nature of these opinions. (Paté-Cornell, 1996).</td></tr>
<tr><td>5</td><td>Program Evaluation and Review Technique (PERT)</td><td>This is where three point estimates are established to form a single point estimate. Experts can be utilised.</td><td>Many believe that there are numerous situations where these approximations are insufficient (Hartley & Wortham, 1966).</td></tr>
</table>

6	What-if analysis	This is used to determine which risks have the highest impact on the project and also the effect of the variation (i.e. uncertainty) in risks on the project objectives (PMI, 2009).	This typically occurs at a late stage of the risk assessment process where many uncertainties may have been overlooked.
7	Control risks process	Some of the processes involved are: testing if the assumptions are still valid, conducting variance analyses, identifying new risks and checking if risks are correct (PMI, 2009).	Not usually included in typical risk assessment processes.
8	Delphi technique	This technique allows a reliable consensus to be formed through expert opinion. Similar to brainstorming, experts express their ideas individually and anonymously while having access to other expert opinions. The technique is typically done in stages, the first stage to establish ideas and the second to form a consensus on the ideas (ECES, 2010).	Generally time intensive. The level to which expert opinion is helpful is questionable (Klinke & Renn, 2002).
9	Scenario analysis	This is a model which represents how the future might occur. Risks can be identified by considering these possible outcomes and exploring their implications. A "best-case, worst-case and expected-case" can be established. This analysis can determine which implications have the most impact on the project (ECES, 2010, pp. 40-42).	This is a technique typically used when there is little or no knowledge on which to based trends although this can be unreliable.
10	Fault tree analysis	 *Figure 7: Example of a fault tree analysis (PMI, 2009, p. 79).*	A major limitation to the fault tree analysis is that uncertainties from the base events are built up into calculations of the probability of the top event and are thus hidden in the analysis (ECES, 2010).

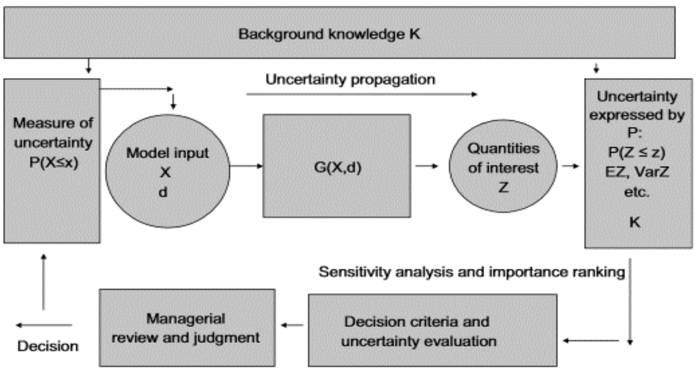
11	Monte Carlo simulation	This provides a way of assessing the effect of uncertainty on systems in various situations. It evaluates a range of possible outcomes and the frequency range of the quantitative values assigned to measures such as time, cost or risk. The model, when modelling uncertainty, is in the form of an equation depicting the relationship between the input and output values. Typically the model is run up to 10,000 times with different input values. Information can then be extrapolated from the analysis such as averages, standard deviations and confidence intervals to communicate the level of uncertainty (ECES, 2010).	Timely and complex. Requires software.
12	Bayesian statistics and bays nets	Outputs of this technique include derivation of point estimates and confidence intervals, the data can be used to communicate correlation or sensitivity of parameters (ECES, 2010).	Prior knowledge is required for the input, and the probabilities are based on assumptions which are subjective.
13	Multi-criteria decision analysis	This is used to compare and assess multiple options. A sensitivity analysis is adopted when single scores are allocated because they are subjective. The analysis determines to what extent the weights and score affect the overall options. The strength of this method is that it provides an effective means to communicate assumptions and select options if there are inconsistencies (ECES, 2010).	This method can be extremely affected by bias or obscure the true bias.
14	Single measure to represent whole uncertainty	The probability that the project will not be on time could be representative of the whole project uncertainty. This single measure can be evaluated against each project variable and used for decision making within the project (Drummond, 1999).	Problematic for complex projects or variables that change over time.
15	First authoritative framework for assessing uncertainty	 *Figure 8: Structure of a modified framework (Aven, 2010, p. 196).*	Is complex and timely. Industry use will likely be low.

Table 4: List of techniques that assess uncertainty.

15 different techniques to assess uncertainty were reviewed above in Table 4, indicating that there may be no consensus way to deal with uncertainty. While 12 of these techniques were reviewed from the education material (ECES, 2010; PMI, 2009), the literature proved

to be much more comprehensive (Aven, 2010; Drummond, 1999; Paté-Cornell, 1996). The main limitations revealed were complexity and unreliability. Although these methods aimed to create a more reliable risk assessment, their unreliable complex nature was detrimental. The U.S.NRC recognise that research is still continuing in an attempt to form effective and accepted techniques to assess uncertainty (G. Parry & Drouin, 2009). This is why it was important to scrutinise several studies that attempted to develop these techniques in the next section.

5.3. Recently developed techniques

There has been a recent development of risk assessment techniques as a result of the increasing complexity of projects and introduction of new technology. The focus of these developments has been on increasing the reliability of models (Aven & Zio, 2011). Reviewed below are some recently developed techniques to assess uncertainty in an attempt to identify current flaws, gaps and focus areas. These current flaws were considered through a survey to the New Zealand construction industry in an attempt to allow a way forward.

5.3.1. A statistical theory for PERT critical path analysis

Research has looked at improving the current PERT (Program Evaluation and Review Technique) model in critical path methodologies. This attempted to allow for a quicker analysis and helped reduce certain assumptions. Many believed that there are numerous situations where these approximations are insufficient, Hartley and Wortham's developed methodology allowed for the improvement of these approximations (Hartley & Wortham, 1966). The original PERT technique defined the total path in the network using the total of average completion times (the pessimistic, optimistic and most likely value), this was expressed as the maximum value. Hartley and Wortham proposed that this idea could be applied to a random sample of completion times, each drawn from the distribution that was relevant to its task. The critical time was, therefore, a single random variable built up from the distribution of critical times. A Monte Carlo simulation was essential in this process as a large number of repetitions of this calculation was required (Chau, 1995).

The developed approach aimed to be more detailed and included:

- Classification of networks into separate types relating to their level of involvement and complexity.
- A calculation to numerically derive the distribution of critical times.

- A Monte Carlo approach to give an approximate solution for more involved activities.
- A diagramming method to display simple network and distribution times.

This paper has currently been cited by 96 different sources, and since this paper was written over 50 years ago it was important to show any development of this theory. A paper produced by Schmidt and Grossmann presented a new technique developed from the paper above. The method calculated an overall time distribution of a project with uncertain task durations, it was used when task durations have independent distributions specifically (Schmidt & Grossmann, 2000). Another paper by F. Lootsma (1997) considered the work furthered by many authors (Burt & Garman, 1971; Clark, 1961; Elmaghraby, 1967, 1977; Fulkerson, 1962; Hartley & Wortham, 1966; F. A. Lootsma, 1966; MacCrimmon & Ryavec, 1964; Martin, 1965) and acknowledged that improvements to the PERT method were developed but to an approximate maximization. Later authors such as (Birge & Maddox, 1995; Cleef & Gual, 1982; Gaul, 1981; Haneveld, 1986; Kleindorfer, 1971; Meilijson & Nádas, 1979; Nadas, 1979; Robillard & Trahan, 1977; Shogan, 1977) admitted that the issue of finding the distributions was theoretically too complicated. Dubois and Prade (1998) applied fuzzy set theory to the PERT method, solving the issue of finding the earliest event times and the minimum project duration. They concluded that this methodology was still too complicated to be applied in the industry. Essentially one of the major restrictions to the uptake of such a technique within the industry was complexity, the survey attempted to question this in the New Zealand construction industry.

5.3.2. Some considerations on the treatment of uncertainties in risk assessment for practical decision-making

There is an extensive amount of literature addressing the issues of the traditional risk assessment method known as probabilistic-based risk assessment (also referred to as quantitative risk assessment) (Aven & Zio, 2011). Reid (1992) argued that it is common to underestimate the uncertainties in risk assessments. The subjectivity and lack of data part of the risk assessment are essentially problematic and need to be closely controlled (Aven & Zio, 2011). Tickner and Kriebel (2006) communicated a trend of people overlooking the uncertainties underlying the risk numbers. Thus developed risk uncertainty models have been created within the following categories (a-d).

a. Probability bound analysis, combining probability analysis, interval analysis (Ferson & Ginzburg, 1996)
b. Imprecise probability (Walley, 1991), the Bayes statistics area (Berger et al., 1994)
c. Random sets (Dempster, 1967)
d. Possibility theory (Dubois, 2006; Dubois & Prade, 1998)

In the probability bound analysis (a) interval analysis is used where aleatory uncertainties cannot be accurately estimated, this approach, however, resulted in wide intervals and left out expert judgements about epistemic uncertainties. The other three frameworks (b-d) allowed for the incorporation and representation of incomplete information. The results produced are epistemic-based uncertainty descriptions and probability intervals, but they have not been widely accepted by the industry due to complexity (Aven & Zio, 2011). Attempts have been made by combining some of these frameworks, an important method to note is the method developed by Aven and Zio. The method is a combined quantitative and qualitative approach where uncertainty factors hidden in subjective probabilities are identified and assessed qualitatively. This was motivated by all risks and uncertainties not able to be represented numerically (Aven & Zio, 2011).

5.3.3. Some reflections on uncertainty analysis and management

Aven presented the first authoritative standard for analysing and quantifying uncertainty. An overall framework was developed using probabilities and other uncertainty representations. A common approach was to use a probability distribution method, expected values and variance can then be derived. A sensitivity study can take place to outline the most critical factors based on the level of variance they displayed (Aven, 2010). De Rocquigny et al. (2008) have recently developed a framework for quantitative uncertainty analysis and management, although Aven saw a potential for improvements considering the common approach. Using the framework as a base, an improved framework was developed. Probability was the method chosen to represent uncertainty, Aven argued that this should be the only tool to express uncertainty as it allowed simplification of the model (Aven, 2010). This study was important because it critically analysed one of the formally developed models for controlling uncertainty in risk assessment, and suggested a method to increase simplification when quantifying uncertainties. This is one systematic process that deals with uncertainty although it seems too complex to be used in a time driven environment that is the construction industry. The New Zealand construction industry was questioned through a survey about current restrictions and possible incentives around uptake.

5.4. Summary

The principal research question that the thesis addressed was:

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

The following sub-research questions were partially addressed through the literature analysis:

- Is risk uncertainty, or are risk and uncertainty different?
- How are uncertainties assessed?

Some authors seemed to understand the terms risk and uncertainty, although no one clearly defined the relationship between quality assurance, risk, and uncertainty. The diagram below was created to communicate this relationship based on the literature studied. Figure 9 highlights two parts to quality assurance in risk management, risk and uncertainty. Once risk has been mitigated and uncertainty has been reduced, quality assurance of the model can be realised. Two schools of thought between risk and uncertainty were explored in the literature. The evidence found that an independent relationship could be the best approach to reducing confusion and realising quality assurance though this is further explored through a survey. There are three possible quantifications of risk (qualitative, semi-quantitative and quantitative), each resulting in different levels of uncertainty. Uncertainty has two elements: aleatory and epistemic. The former related to the reliability of the model and the latter referred to the reliability of the data used. Aleatory uncertainties can be reduced by using a reliable model, whereas epistemic uncertainties can be decreased through gathering more data or using the techniques described above.

Figure 9: The relationship between quality assurance, risk and uncertainty, created by author.

Two forms of New Zealand Education material and international literature were explored to determine how uncertainty can be assessed. There is currently no way of comparing scores of risk against reality, or a simple systematic process to ensure a reliable risk analysis. The absence of such a method has stemmed from multiple variations of the same document, lack of absolute definition, ignorance, and complexity. This thesis identifies Taleb's concept of antifragility and suggests that moving towards processes, and away from specific techniques, could be the best approach to creating a more reliable risk management model. In order to complete the case study analysis, a means was developed to systematically compare risk estimates against reality in a critical path for commercial projects. These ideas were tested further through a New Zealand survey in an attempt to address the principal research question.

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6. Case study analysis

The following sub-research questions have been addressed through the case study method in an attempt to address the principal research question identified in chapter 1:

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

- Is uncertainty currently being quantified in New Zealand building projects?
- How are uncertainties assessed for New Zealand building projects?

The case study method worked as part of a triangulation approach, addressing these questions that were not fully realised through a literature analysis. The case study analysis explored uncertainty in a construction building project, as a means of ensuring the literature analysis and the survey were grounded in current industry practice. The aim of this case study analysis was to understand the behaviour of people in the industry in comparison to how they are said to perform in the literature. The case study analysis essentially identified the existence of uncertainty in a project and attempted to understand how uncertainties are being controlled. A survey was another method used to further analyse this by questioning how New Zealand experts control uncertainty.

6.1. Case description

The case study was a major historic building refurbishment in New Zealand, with complex spaces, a café and a bar. The venture was reasonably extensive with much of the original feature of the building being retained. Costs were tight due to unforeseen building work such as soil contamination and restoration of the existing foundations, this is further analysed below.

6.1.1. Risk analysis

Eight risk analyses were completed throughout the project. The project team reported on the risk analysis at every Project Control Group (PCG) meeting. The people involved were the key consultants including the client, architect, project manager, quantity surveyor, and the contractor (half time). The project manager's task was to update the analysis accordingly (Gurton, 2015).

A list of typical risks was sent out to the key consultants at the beginning of the project, this was used to prompt the development of risks for the project. Every key consultant established a list of risks, the project manager then formed a final list. New risks were added to the analysis after each PCG meeting. There was no time for a detailed analysis to respond, monitor and control all risks on the project, thus, focus was on risks with a probability/impact score of 9 out of 25 or higher. This was indirectly controlled by the identification of new risks or incorrectly estimated risks arising in the PCG meetings (Gurton, 2015).

6.1.2. Budget

A comparison of the planned and actual costs was completed by the quantity surveyor. This was closely monitored and reported to the client by the project manager. The quantity surveyor was responsible for financial reporting and management. The main technique used to form the budget was forecasting. Tracking was also used to monitor and control the budget through daily communication with the contractors (Gurton, 2015).

6.1.3. Programme

An initial programme was completed by the contractor and was tracked over time. The contractor reported site progress weekly, sometimes daily to the project manager. The project manager reviewed progress on site weekly when the project was well underway. Both parties identified and responded to areas running behind schedule by, for example, adding more resources (Gurton, 2015).

6.2. Risk analysis results

Eight risk documents, from initial to final risk analysis, were mapped over time. The results are presented below:

	Final analysis				Difference				
	Description of Risk	**Initial Risk Status**	**Final Score**	**Result when L=0-7, M=8-16, H=17-25**	**Likelihood**	**Severity**	**Score**	**Result when green = no change, Orange = minor change, Red = large change**	**Impact of Risk**
1	ACC do not agree with fire strategy	L	8		0	0	0		Scope, time and cost
2	ACC request additional heritage works	L	0						Cost
3	Acoustic performance is not matching that specified	H	8		1	0	4		Scope, time and cost
4	Agreement is not reached with adjoining building/ ACC to create access	M	4		0	0	0		Cost and time
5	Availability of competent contractors to undertake construction	M	8		0	0	0		Poor quality, cost and time
6	Building footprint not fitting, incorrect interpretation of topo' surveys	L	4		0	0	0		Cost and time
7	Client objections to design proposals	L	3		-1	1	-5		Scope, time and cost
8	Code Compliance requirements are not being picked up in the design	M	3		0	0	0		Cost and time
9	Confusion with respect to agreed design, particularly with respect to the scope of value engineering	M	6		0	0	0		Scope, time and cost
10	Construction impacted by construction of adjoining building	M	4		0	0	0		Time
11	Consultant resource shortages	M	6		0	0	0		Time
12	Contamination in excess of that anticipated by investigation	M	9		0	0	0		Cost and time
13	Contract Documents not reflecting what is actually required	H	9		-1	0	-3		Scope, time and cost
14	Cost Plan overruns	H	16		-1	-1	-5		Poor quality, cost and time
15	Crane oversail license restrictions	M	6		0	0	0		Cost and time
16	Design changes lead to an alteration of the foundation design around the scheduled trees	L	4		0	0	0		Scope
17	Design incompatibility between frame and cladding	M	4		0	0	0		Quality
18	Developing services design affecting architectural layouts	M	9		0	0	0		Cost and time
19	Findings of further Geotech survey result in significant design change	M	9		0	0	0		Cost and time
20	Fire escape route to be maintained	M	6		-1	0	-3		Time
21	Fire rating of escape routes requires higher spec' materials	M	3		-2	0	-6		Scope, time and cost
22	Flooding	M	6		-2	0	-3		Time
23	Interface with adjoining building	M	0						Cost and time
24	Maintenance access strategy approval	L	6		0	0	0		Scope
25	MetroWater/ WaterCare wish to undertake works to their existing services running across the site	L	10		0	0	0		Time
26	Objections are lodged against the Resource Consent application	L	0						Scope
27	Onerous Building Consent Conditions	H	0						Cost and time
28	Over-building to in an attempt to guarantee area tolerances	M	0						Cost
29	Rain	L	4		0	0	0		Time
30	Resource Consent application is treated as Notified	M	0						Time
31	Resource Consent approval includes onerous Conditions	M	0						Scope, time and cost
32	Resource Consent Delay	L	6		0	0	0		Cost and time
33	Resource Consent requirements not being adequately met	M	6		0	0	0		Cost and time
34	Site access restrictions due to neighbours and adjacent construction works	M	6		-1	0	-3		Cost and time
35	Site programme overruns	L	8		0	0	0		Quality, cost and time
36	Site security	M	9		1	0	3		Cost and time
37	Sub-contractor insolvency	M	3		0	0	0		Cost and time
38	Technical equipment is over specified	M	3		-1	0	-3		Cost
39	Tenders exceeding cost plans	M	8		0	0	0		Quality, cost and time
40	Unable to resolve design for the new room, therefore, unable to gain their agreement to build new	M	3		0	0	0		Cost and time
41	Unchartered services delaying works	M	6		-1	0	-3		Cost and time

42	Unforeseen obstructions below ground	H	9		0	0	0		Cost and time
43	Works need to be carried out in such a way that prevents access to rear of existing building	M	6		0	0	0		Cost and time
44	Works need to be sequenced in such a way to minimise disruption to other operation	M	9		0	-1	-3		Cost and time
45	Additional costs due to prolongation of programme	M	0						Cost
46	Satisfying Resource Consent Conditions becomes critical	M	8		0	0	0		Cost and time
47	Require onsite archaeological investigation	M	16		1	1	5		Cost and time
48	ACC Committee meeting dates not met	L	8		0	0	0		Time
49	Poor relationship between Contractor and another project	M	8		0	0	0		Time
50	Complex buildability issues are not picked up during the design	L	8		0	0	0		Cost and time
51	Unable to resolve optimal temperature for the Green room solution	**Success**	10	38%	-1	0	-5		Cost and time
52	ACC approval to heritage works		0		-3	-1	-9		Cost and time
53	Outcome of HQ meetings has significant impact		4		0	0	0		Cost and time
54	Legal agreement is not reached with the other building/ ACC to create access		4		0	0	0		Cost and time
55	Design runs behind other disciplines		12		0	0	0		Cost and time
56	ACC proposals for events impacts project		4		0	0	0		Cost and time
57	Adjoining project operational staff request additional works to the current design		9		-1	0	-3		Cost and time
58	Requirements for open date		9		0	0	0		Cost and time
59	Workings of Separate Contractors		9		0	0	0		Quality, cost and time
60	Key Staff leave project		9		0	0	0		Cost and time
61	Claims from Sub-contractors		9		0	0	0		Quality, cost and time
62	General cost over-runs		8		0	0	0		Cost
63	Design Approvals		8		0	0	0		Cost and time
64	Specialist design runs behind other disciplines		8		0	0	0		Cost and time
65	Damage to other building from works		8		0	0	0		Cost and time
66	Expenditure of contingency		8		0	0	0		Quality, cost and time
67	Provisional Sums exceeding Contract allowance		8		0	0	0		Scope and cost
68	Limited capacity of specialist subcontractors		6		0	0	0		Quality
69	Signage Issues		6		0	0	0		Time
70	Issues with existing buildings		6		0	0	0		Scope, time and cost
71	Pre-cast flooring issues		6		0	0	0		Quality, cost and time
72	Deployable gallery Building Consent issues		6		0	0	0		Time
73	Issues arise when commissioning services		6		0	0	0		Scope, time and cost
74	Unknowns in ground (obstructions/conditions)		3		0	0	0		Cost and time
75	Adjoining project use of temporary facilities		3		-1	0	-3		Cost and time
76	Objections/ complaints from neighbours		4		0	0	0		Cost and time
77	Fire escape routes from adjacent buildings compromised		3		0	0	0		Cost and time
78	Funding agreement obligations are not being addressed		3		0	0	0		Quality, cost and time
79	Crane license is not being agreed		0		-3	-1	-15		Cost and time
80	Lift and gallery building consent issues		6		0	0	0		Time
81	Scheduled trees are damaged or impacted upon outside of consent conditions		3		0	0	0		Cost and time
							Success	78%	

Table 5: A comparison of planned and actual risks on a project, source: undisclosed professional New Zealand firm. This is a screened version for confidentiality reasons. Refer to appendix D for further detail.

The green cells in Table 5 indicate no change between the initial and final risk analysis, orange indicates a small change and red indicates a larger change whether positive or negative. This matrix proves that initial risk assessments are significantly problematic. From the first analysis to the third analysis only low, medium or high values were assigned to qualitatively quantify the risks. This proved to be only 38% successful when the initial and final risks were compared. Also, only 50 risks were identified during the initial risk assessment with a total of 81 risks identified by the seventh analysis after construction was nearly complete. Probability and impact scores were assigned by the fourth analysis and changed by the final analysis, with a 78% success rate. This means that 78% of the quantified estimates were unchanged by the final risk analysis. Though this seems reasonably successful over 81 risks, it is important to note that this was only achieved after the fourth revisit of the risk analysis. The total rate of change in the risk analysis was 76%. At no point were uncertainties in the risk assessment quantified although these are somewhat apparent by the inconsistencies discussed above. To summarise, initial risk assessments proved problematic especially when uncertainties were not quantified. Quantification of uncertainty at early stages of the risk analysis could significantly improve the reliability of the risk assessment and the overall project success.

6.3. Budget analysis results

An initial and final budget was compared during the project closeout phase. This is presented below:

Budget				
	Initial estimate	**Quantity Surveyor estimate**	**Contractor estimate**	**Difference**
Approved budget/tender	$15,307,000	$15,307,000	$13,283,710	$2,023,290
Post funding additions				
Subtotal	$337,000	$337,000	$337,000	$0
Scope changes				
Subtotal	$0	$390,000	$475,000	-$475,000
Base budget items not in tender				
Subtotal	$6,836,000	$6,915,000	$6,928,019	-$92,019
Deferrable budget items				
Subtotal	-$1,662,000	-$79,000	$0	-$1,662,000
Total	$20,818,000	$22,870,000	$21,023,729	-$205,729

Table 6: A comparison of the planned and actual costs on a project, source: undisclosed professional New Zealand firm. This is a screened version for confidentiality reasons, no further detail is available.

The red cells in Table 6 indicate a difference between the initial and final budget whether positive or negative. The full analysis revealed that more detail in the initial estimate results in a more accurate detailed or final estimate. The final cost overrun was only $205,729 or 1% relative to the total project cost. Although there seem to be significant differences in costs between the planned and actual, scope changes, in particular, were met through a final lower contractor approved budget.

6.4. Programme analysis results

The critical path of the project was scrutinised, in particular, this is presented in Table 7.

Critical Path	Planned			Actual			
Task	**Days**	**Start**	**End**	**Days**	**Start**	**End**	**Diff**
Construction	**360**	**10/12/09**	**13/06/11**	**447**	5/11/09	22/07/11	-87
Site establishment and enabling works	**53**	10/12/09	5/03/10	**61**	3/12/09	25/02/10	-8
Green Room temporary build & relocation incl tunnel access	25			72	16/12/09	25/03/10	-47
Demolition	**55**	21/12/09	18/03/10	**72**	16/12/09	25/03/10	-17
Hard demolition of entire building & hard stand	20			0	-	-	20
Site establishment and enabling works	**53**	10/12/09	5/03/10	0	-	-	53
Soil contamination tests (after ACC building demolished)	8			0	-	-	8
New building	**345**			**386**	21/12/09	13/06/11	-41
Substructure	**73**			**58**	25/02/10	17/05/10	15
Bulk earthworks	5			0	-	-	5
Piling	16			0	-	-	16
Detailed excavation including any hand digging by protected trees	10			0	-	-	10
Pile caps	15			0	-	-	15
Foundation beams	15			0	-	-	15
Structure	**166**			**220**	17/05/10	18/03/11	-54
Level 1	**30**			**174**	20/08/10	20/04/11	-144
Institu wall W2	3			0	-	-	3
Precast walls erect W1 & W6 & stitches	4			0	-	-	4
U/slab services	3			0	-	-	3
FRP slab A - D	5			0	-	-	5
Structural steel cols and beams to level 4	15			0	-	-	15
Level 2	**40**			**189**	27/08/10	18/05/11	-149
Land double T's + req. prepping	2			0	-	-	2
FRP topping	6			0	-	-	6
W7 wall panels install & plasters etc.	5			0	-	-	5
W1 panels install & plasters etc.	4			0	-	-	4

Secondary structural steel	3			0	-	-	3
Level 3	**17**			**123**	8/12/10	27/05/11	-106
400 double T's lay & prop	2			0	-	-	2
Comm floor lay	2			0	-	-	2
Place precast stair 6 (lev 2-3)	1			0	-	-	1
FRP topping slab	4			0	-	-	4
W8 in situ wall	6			0	-	-	6
Level 4	**21**			**123**	15/12/10	3/06/11	-102
Erect structural steel levels 4-7	15			0	-	-	15
Level 6	**13**			**124**	20/12/10	9/06/11	-111
Trusses 1 - 6 & secondary steel & purlins	20			0	-	-	20
Envelope	**33**			**149**	20/08/10	16/03/11	-116
Roof	**28**			**108**	18/10/10	16/03/11	-80
Frame & box gutter grideline E + tank	8			0	-	-	8
Battens & ply & lay roof	20			0	-	-	20
Internal	**306**			**212**	20/08/10	13/06/11	94
Insulation & linings wall & ceiling levels 1-2	30			71	2/02/11	11/05/11	-41
Surface finishes & decorating levels 1-2	40			32	3/03/11	15/04/11	8
Services	**105**			**51**	31/03/11	9/06/11	54
2nd fix electrical, data, comms audio etc.	40			0	-	-	40
2nd fix mechanical	40			0	-	-	40
Commissioning and Defecting	**46**	21/03/11	20/05/11	**36**	29/04/11	17/06/11	10
Commissioning	15			36	29/04/11	17/06/11	-21
Sign-offs	5			0	-	-	5
Site works	**127**			**122**	29/11/10	17/05/11	5
Final inspections by client and consultants	10	29/04/11	13/05/11	5	20/06/11	24/06/11	5
Defected items remedied	20			21	20/05/11	17/06/11	-1
Client items - award, building consent uplift, access	**360**			**447**	5/11/09	22/07/11	-87
ACC stop days (contract item)	25			25	20/06/11	22/07/11	0
						Total difference	98%

Table 7: A comparison of the planned and actual critical path estimates of time, source: undisclosed professional New Zealand firm. This is a screened version for confidentiality reasons, no further detail is available.

A colour graded scale conditional formatting rule was applied to the last column in Table 7. The bright red indicates a significant difference between the planned and actual sprogramme while the bright green indicates no change. This table shows that while there are 98% inconsistencies between the planned and actual estimates on the critical path of the project, lower estimates generally balanced the higher estimates. The initial estimate was more detailed like the cost estimate, with final estimates included in other activities on the project. Therefore, it was impossible to compare each initial and final task estimate. This was why the most important activity to scrutinise is the overall construction period. The project started 36 days earlier than planned and was therefore 51 days overrun, this is 11% relative to the overall project.

6.5. Findings

Comparison			
Cost ($)		**Time (days)**	
Change in risk	Change in budget	Change in risk	Change in programme
76%	-$205,729	76%	-51
Relative to project	1%		11%

Table 8: Correlations between risk, cost and time on a project.

Table 8 communicates the correlation between risks, cost and time on the project. Although the change in risk from planned to actual was 76%, this did not affect the cost and time estimates proportionally. The change in the budget was very minimal though the change in programme was more significant. Therefore, the risk analysis on this project had more effect on the programme. This could be different from other projects in the construction industry but was not a focus for this thesis. The intention was to gain an understanding of the existence of uncertainty and how it could impact a project.

A range of risk, budget and programme scores was created from this analysis and can potentially be used on similar projects in the future to quantify uncertainty:

Risk	
	Difference range from estimate
Likelihood out of 5	-3-1
Severity out of 5	-1-1

Table 9: The range in score differences between planned and actual risk estimates.

Budget	
	Difference range from estimate relative to an element item
Cost in NZD	-$66,000-$170,000

Table 10: The range in score differences between planned and actual cost estimates.

Programme (critical path)	
	Difference range from estimate
Time in days	-28-10

Table 11: The range in score differences between planned and actual time estimates.

The figures above in Table 9, 10 and 11 depict the level of uncertainty in each case of risk, time and cost. They show that typically estimates are underestimated. This is expected as overestimates in risk and time make the project appear to be difficult to achieve, and thus not acceptable to the client. However, overestimates of cost were not expected. The focus and driver of projects is typically cost, especially if the project is behind schedule. More resources (i.e. more cost) can usually bring the project back on schedule or to an acceptable level.

6.6. Summary

The principal research question that the thesis addressed was:

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

The following sub-research questions were partially addressed:

- Is uncertainty currently being quantified in New Zealand building projects?
- How are uncertainties assessed for New Zealand building projects?

Although there was no specific quantification of uncertainty in this particular case study, the case study analysis showed evidence of uncertainty in a New Zealand construction project. There was no way to tell how uncertainties are assessed in the New Zealand construction industry, hence this was further tested through a survey. Inaccurate initial risk assessments proved to be problematic, especially if treatment was occurring at early stages of the project. Response on this project was only taken on significant risks i.e. risks with a score of 9 or higher out of 25. Focus on the wrong risks has happened and was detrimental to the success rate of the project (Hall, 1975). Although this projects' incorrect risk analysis did not correlate closely with the time and cost overruns, some inconsistencies did result. A differences range was calculated for each analysis of risk, time and cost to allow an understanding of the uncertainty that was not identified and managed in this project. The project objectives (cost, time, scope and quality) seemed reasonably successful, thus, the overall project was deemed a success despite the inconsistent risk assessment. This case study analysis essentially established the nature of a project in the industry and identified the absence of uncertainty management. Assessing other cases in New Zealand will not change this conclusion. There is now a way to compare risk analyses against real life, this can potentially enable more reliable risk assessments in practice. A survey was undertaken to question the suitability of such a model in the New Zealand construction industry and also aimed to fully address the principal research question further from the other two research methods.

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7. Survey analysis

This chapter analyses the responses obtained from the online Qualtrics survey, refer to appendix A and B for further detail. After the types of experts that participated in the survey are established, the results are analysed in sections relating to the research question and sub-questions. The survey method worked as part of a triangulation approach, addressing questions that were not fully realised from a case study and a literature analysis. One principal research question, described in chapter 1, is summarised below with clarifying sub-questions.

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

- Is risk uncertainty, or are risk and uncertainty different?
- How are uncertainties assessed for New Zealand building projects?

This analysis also attempted to prove the following hypothesis and sub-hypothesis:

- Construction building project managers in the New Zealand industry confuse the terms risk and uncertainty.
  - The more education or experience a person has the better the understanding.

7.1. Experts that participated in the survey

Three sections are presented below to establish the types of experts that participated in the survey: number of experts, qualifications, and years of experience.

7.1.1. Number of experts in the survey

A hyperlink of the online Qualtrics survey was made available and distributed by four national bodies (PMINZ, IMNZ, IET, IOBNZ). The experts participated on a voluntary anonymous basis through a combination of emails and website links. After three weeks of each link being made available, a total of 58 people had responded to the survey. 17 New Zealand experts met the criteria and thus were consulted on risk management, while 41 participants were screened out and did not fully complete the survey. Of the 17, eight were classified as “single experts” and the other nine had sufficient experience and education to be classified as “double experts” according to the target group criteria outlined in chapter 3.

7.1.2. Qualifications

Table 12 shows the types of professional project management qualifications held by the experts. This gives an insight into the most common qualifications in the construction project management industry and the level of expertise held by the double experts. The most common qualifications were CAPM (Certified Associate in Project Management), BBSc (Bachelor of Building Science) and PRINCE2 (Projects IN Controlled Environments).

Qualification	**Number of participants (note, some participants had multiple)**
Tertiary education at Degree level	8
Industry training courses	8
Tertiary education at Masters level	3

Table 12: Qualifications held by participants in the survey, obtained from Qualtrics.

7.1.3. Years of experience

The number of years a participant has in the specific field of construction project management was an important factor to consider. It confirms the reliability of the responses; the assumption is that the more years of experience a person has, the more trustworthy the response. The survey respondents overall were of a relatively young cohort, the majority with less than 6 years of experience.

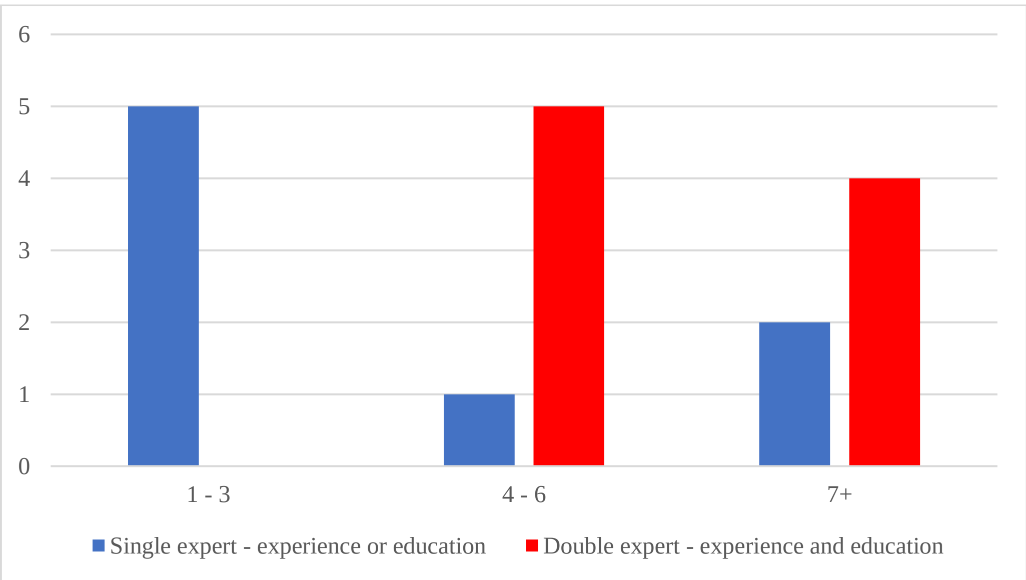

Figure 10: Years of experience of the participants.

7.1.4. Building types

Figure 11 below shows the number of participants in each of the three project types. The most common project type was considered to be a medium-large, new non-residential build. Therefore, the results are more representative of this type of building compared to a residential or demolition project. This is likely due to the need for the involvement of project managers on larger, more complex projects (Morris & Hough, 1987).

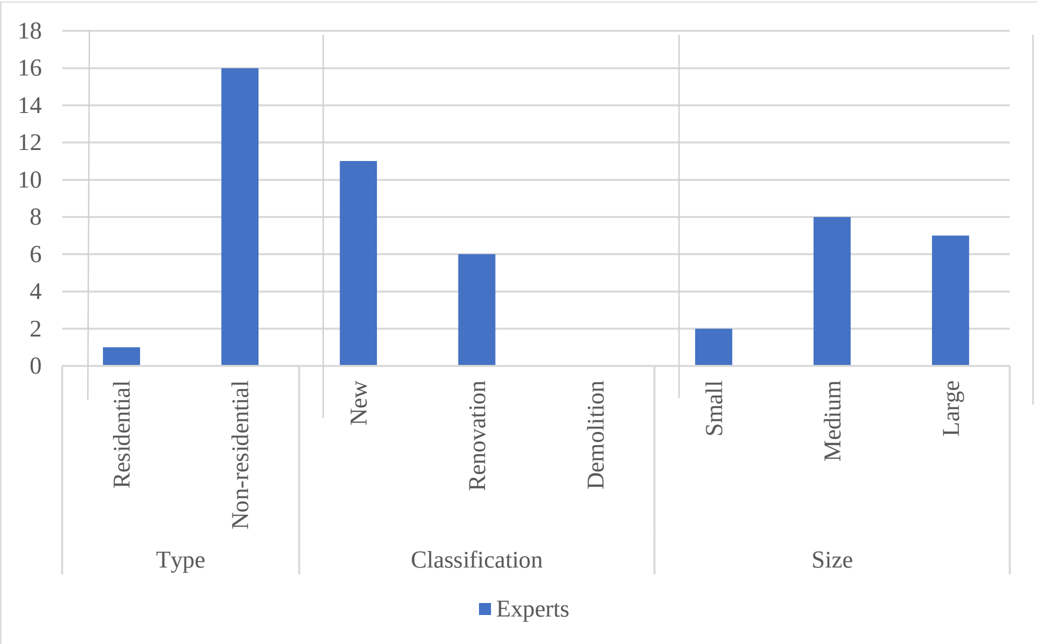

Figure 11: Project characteristics when answering the survey questions.

7.1.5. Summary

To summarise, the range of characteristic selected suggests that across this relatively small sample there was:

a. A restricted range of ages that cannot be generalised for the whole New Zealand industry but can be reasonably representative of people recently trained in the construction industry with several years of experience.
b. A restricted range of buildings that also cannot be generalised for the whole industry but can be reasonably representative of medium and large buildings.

7.2. Is risk uncertainty, or are risk and uncertainty different?

This was the main sub-research question of the thesis and was directly used to address the main research question (What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?). Three sections are presented below in an attempt to address this question: definition of uncertainty in the construction industry, definitions of risks and uncertainty from the literature, and standard use.

7.2.1. Definition of uncertainty in the construction industry

The 17 participants were asked to list five common uncertainties at the beginning of the survey. This was to gain an understanding of the industry perception of uncertainty before the responses were influenced by set definitions. Uncertainty can be defined as:

> "*The intangible measure of what we don't know. Uncertainty is what is left behind when all the risks have been identified. Uncertainty is gaps in our knowledge we may not even be aware of*" (Cleland & Gareis, 2006, pp. 4-5).

	1st	2nd	3rd	4th	5th	Number of uncertainties
1	Existing building conditions	Client brief and requirements	Documentation resulting from items 1 and 2			1
2	Design errors and omissions	Lack of co-ordination between parties	Client slow decision-making	Macro-economic factors	The physical environment	4
3	Cost	Time				0
4	Cost uncertainty	Programme uncertainty	Quality uncertainty	Health & safety	Human error	4
5	Market risk - costs	Additional cost due to incomplete design	Neighbour / landlord constraints	Condition of existing building (if an alteration)	Weather and ground conditions	1
6	Completely project dependant					0
7	Scope	Budget	Time			0
8	Client budget	Programme	Construction costs/ provisional sums	Integration	Final scope	0
9	Site contamination	Financial	Programme	Labour availability	Heritage issues	0
10	Incomplete design	Below the ground	Late instructions from engineers/ designers	Weather	Site access	0
11	Sub-contractor reliability	Health and safety	Consultant design	Time	Client payment	0
12	Client criteria to achieve project outcomes	Scope of construction works	Performance of project team members	Stakeholder buy-in	Territorial Authority requirements to be granted a Resource Consent and/or	1

					Building Consent	
13	Working within an existing building	In ground conditions	Budget restraints	Council requirements	Scope change	0
14	Client specification/ requirements	Contractor availability and skills	Material quality	Pre-existing site/building issues		1
15	Project specification - changes to, scope creep, Change in project deliverables - internal driver	Failure in quality control (poorly defined roles & responsibilities failure in inspection/ testing)	Failure in understanding the customer's quality expectations	Poorly coordinated project activity, design, planning, scheduling	Business case & project benefits not regularly reviewed at each stage boundary	4
16	Client knowledge	New H&S act	Remediation projects / Unknown scope	Scope increase due to the unforeseen	Old buildings / asbestos	3
17	Cost	Time	Skills	Subbies	Council response	1
					Total	20

Table 13: Please list (most common to least common) the main uncertainties, in relation to risk (max. 5). The green shading indicates a clearly identified uncertainty. Obtained from Qualtrics.

Each row in Table 13 indicates the response by each expert. The important question to ask when analysing this data was "is the participant identifying a risk, an uncertainty or both?" This table was compared to the extensive list of uncertainties presented in *Appendix C: Sources of uncertainty*, to allow the separation of risks from uncertainties. Two examples are presented below:

- Risk = time
- Uncertainty = human error

The green highlighted cells, in the table above, indicate a clear identified uncertainty. Though the participants had 85 listed 'uncertainties', true uncertainties were only identified 20 times by 9 individuals. This is only a proportion of 24% with a 95% confidence interval between 15% and 34%. This small proportion and the 95% confidence interval shows that when participants are asked for their definition of uncertainty they typically do not understand this from risks on their own. Note that one participant failed to complete the survey after this point.

7.2.2. Definitions formed from the literature

7.2.2.1. Risk

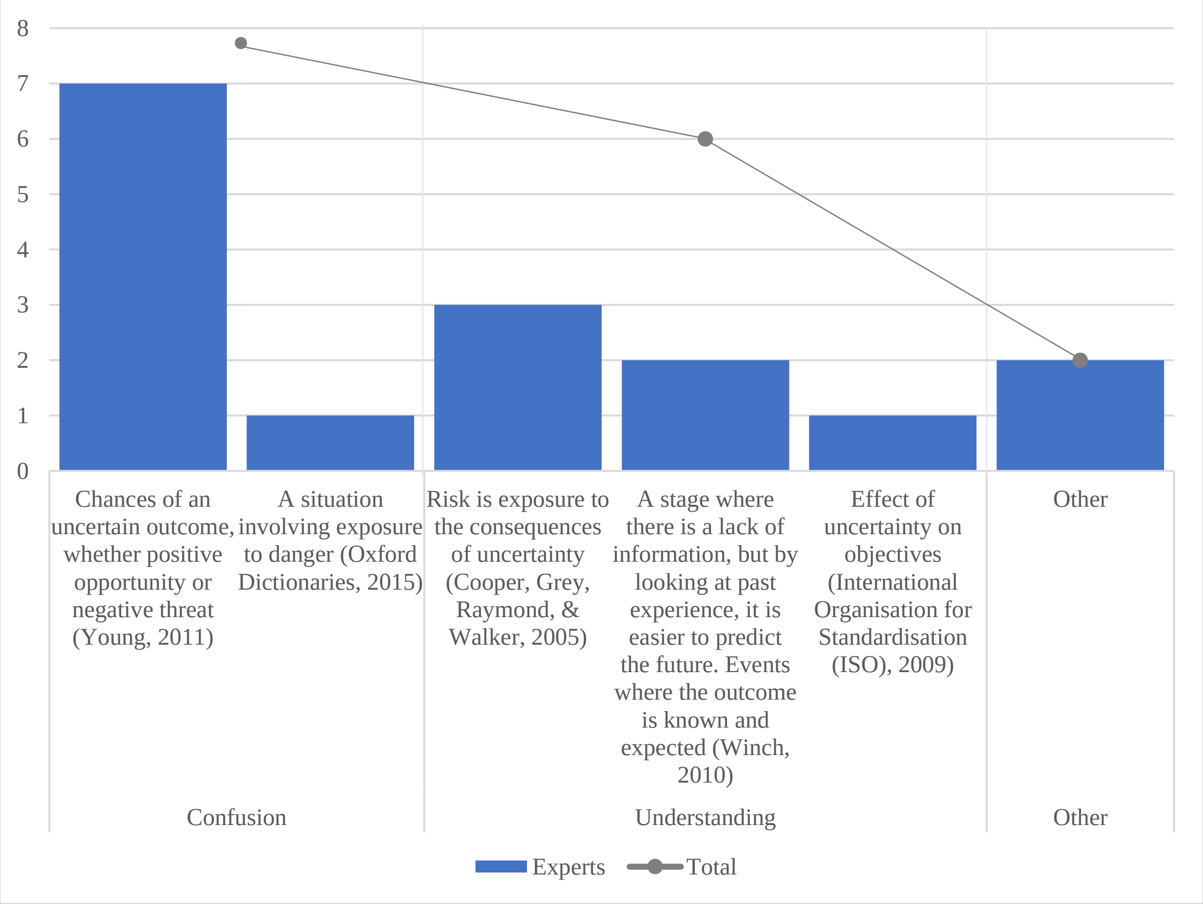

Figure 12: When managing a construction project, how would you define a risk?

The bars in Figure 12 indicate the responses to each answer while the line depicts the total responses within each of the three definition classifications: confusion, understanding, and other (see Table 14). The literature demonstrated that while there seemed to be a clear difference between the terms risk and uncertainty, there proved to be some confusion. Figure 12 shows the understanding of risk in the New Zealand construction industry. The first two definitions indicate where risk and uncertainty are blurred or confused, and the last three definitions indicate an understanding between the two terms. As shown by the line on the graph, approximately half of participants (8) were confused about the definition of risk in relation to uncertainty; while a further 6 seemed to understand a more comprehensive definition.

Other definitions of risk
An item which may result in a negative outcome, these can be known to occur or unknown
The likelihood of something bad happening which is imaginable before it eventuates

Table 14: Definitions of risk given by participants. Obtained from Qualtrics.

These definitions were given by two survey participants that could not associate the term risk with any of the provided definitions. Risk seems to be understood although uncertainty was not specifically considered or included as part of these definitions. Risks are considered as known things (Haimes, 2005; Knight, 1921; Winch, 2010). The use of the word “unknown” in the first definition suggests this participant is confused about the relation of risk to uncertainty; whereas the word “imaginable” in the second definition suggests uncertainty is understood.

7.2.2.2. Uncertainty

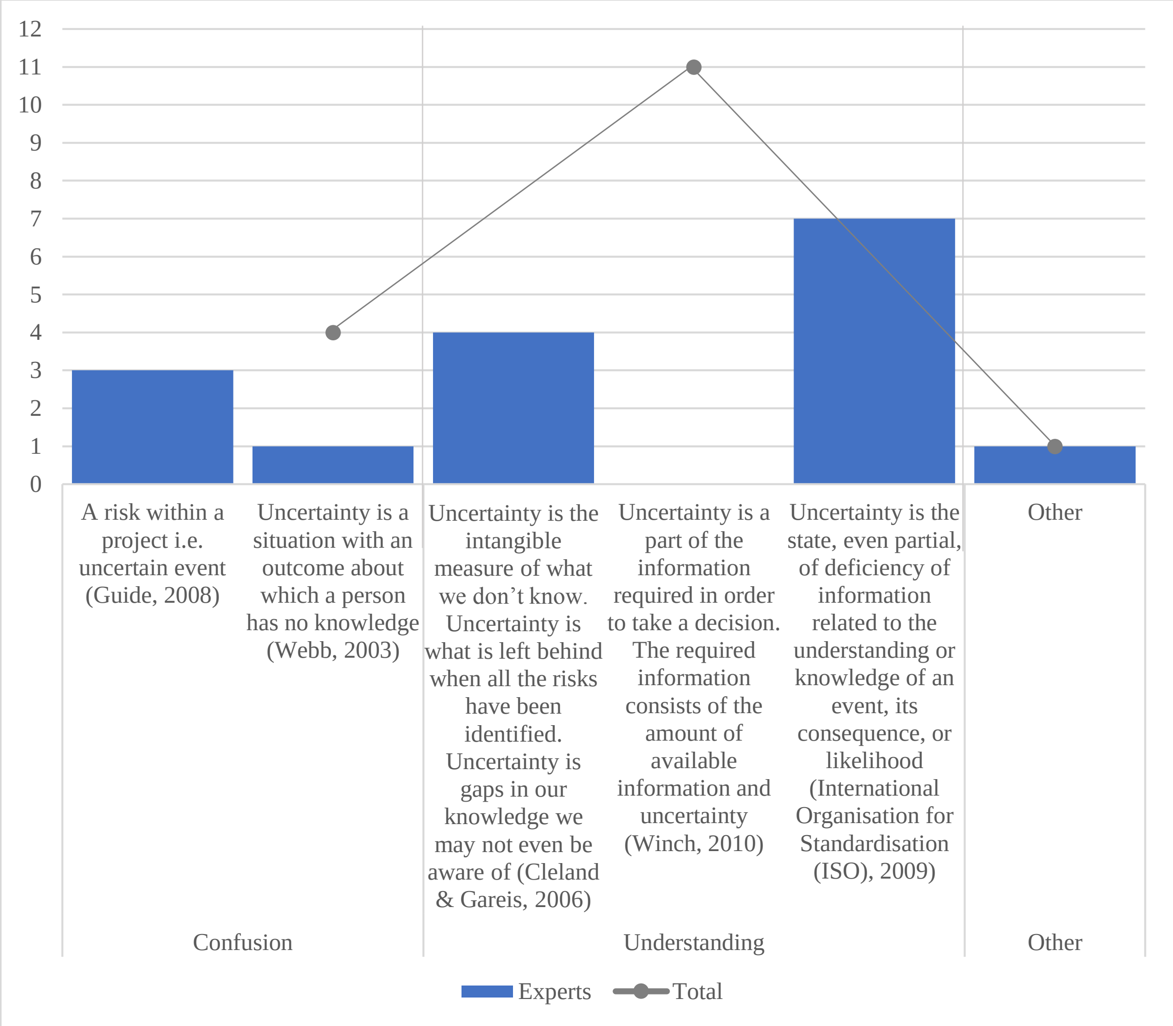

Figure 13: When managing a construction project, how would you define an uncertainty?

The bars in Figure 13 again indicate the responses to each answer while the line depicts the total responses within each of the three definition classifications: confusion, understanding, and other (see Table 15). The uncertainty definitions presented in the graph were also established from the literature. The graph shows the understanding of uncertainty in the New Zealand construction industry. While it appears, shown by the line, that the majority of participants (11) understand uncertainty and how it relates to risk, this was only achieved after the participants were influenced and provided with definitions.

Other definitions of uncertainty
Lack of certainty

Table 15: Definitions of uncertainty given by participants. Obtained from Qualtrics.

This definition was given by a survey participant that could not associate the term uncertainty with any of the provided definitions. It is not completely clear how risk is referred to within this definition.

Since it was difficult to tell how the New Zealand building industry understood risks and uncertainties, the resulting step was to compare both sets of definitions with other questions in the survey to fully understand the results.

7.2.2.3. Risk versus uncertainty

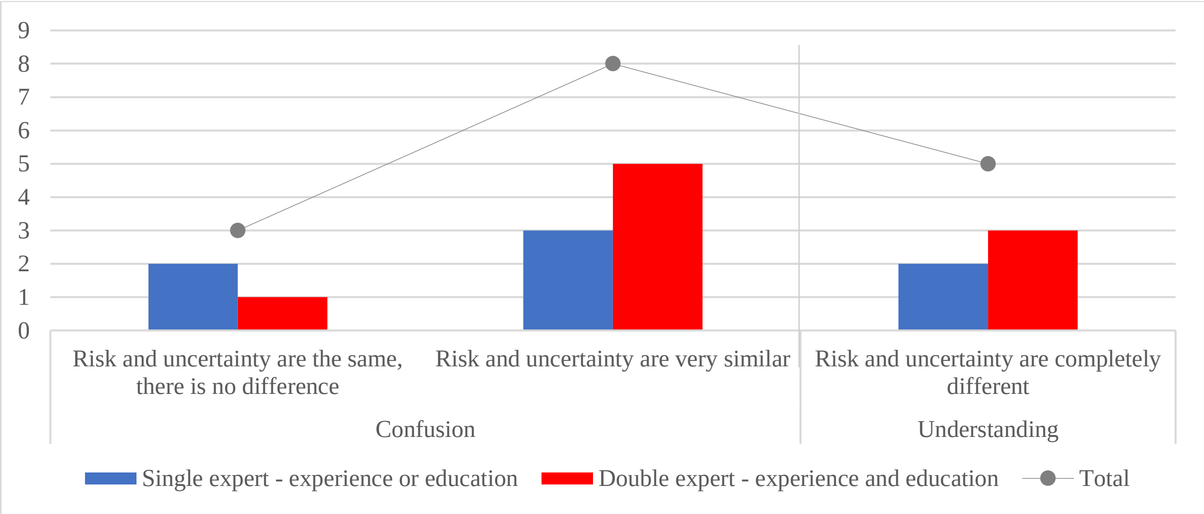

Figure 14: When managing a construction project, which of the following do you believe to be true?

To completely determine the level of industry understanding several questions had to be looked at in combination. The uncertainties listed and the definitions chosen were compared to the identification, assessment, and monitor and control techniques selected. Three categories were established: there is no difference between risk and uncertainty, risk and uncertainty are very similar, and risk and uncertainty are completely different. The first category was true where the participants focused on risks throughout the survey and failed to differentiate between risks and uncertainties. The second category was true where there was some confusion or contradiction between answers, or when it was unclear. The third category was true where the participant clearly defined risk and uncertainty as separate terms and used appropriate treatment techniques. Figure 14 indicates the understanding of the New Zealand construction industry on the difference between risk and uncertainty, and addresses the main research question, "is risk uncertainty, or are risk and uncertainty different?" As communicated by the line in Figure 14, only 5 of the 16 participants are completely aware of the difference between the two terms, and can differentiate this on their own. This is a 31% proportion with an 80% exact confidence interval between 16%

and 50%. Therefore, there is 80% confidence that less than half of the New Zealand construction industry will understand the difference between the terms risk and uncertainty. These results prove the hypothesis, outlined above, that construction building project managers in the New Zealand industry confuse the terms risk and uncertainty. The data above was entered into SPSS for further analysis (see Table 16).

7.2.2.4. SPSS analysis

Expert * Understanding Cross-tabulation					
			Understanding		
			No	Yes	Total
Expert	Double	Count	6	3	9
		Expected Count	6.2	2.8	9.0
	Single	Count	5	2	7
		Expected Count	4.8	2.2	7.0
Total		Count	11	5	16
		Expected Count	11.0	5.0	16.0

Table 16: Data entered into SPSS.

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.042[a]	1	.838		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.042	1	.838		
Fisher's Exact Test				1.000	.635
N of Valid Cases	16				

Table 17: Results when a chi-square test was applied.
a. 3 cells (75.0%) have expected count less than 5. The minimum expected count is 2.19.
b. Computed only for a 2x2 table

Fisher's exact test of independence was applied to this data to test the alternative hypothesis, that there is a difference in understanding between the single and double expert (see Table 17). A p-value of 1.00 was obtained indicating weak evidence against the null hypothesis, thus disproving the alternative hypothesis; understanding was essentially the same between single and double experts. More experience and education does not seem to effect the level of understanding of the terms risk and uncertainty.

7.2.2.5. Standards use

Figure 15: Have you used any of the following on a project?

Other standards
PRINCE2

Table 18: Other standards listed by participants. Obtained from Qualtrics.

Figure 15 shows the use of the many risk management standards in the New Zealand construction industry, while Table 18 shows other standards used that were not listed. The aim of this question was to give an insight to how risk and possibly uncertainty was treated. The chapter *Literature Analysis – Definitions* concluded, while most standards clearly differentiated and defined risk and uncertainty, there was no systematic process that deals with uncertainty. The graph shows that there is a range of use of risk standards in the New Zealand industry. More than half of the participants (10) were familiar with standards though this has clearly not erased the confusion surrounding the definition of risk and uncertainty. These participants were also more familiar with international standards. This raises the question "are New Zealand risk management standards required at all?" Approximately half of the participants (8) were familiar with the PMBOK standard though this is significantly problematic as established from the literature analysis because the PMBOK guide was found to be the only document not to provide clear systematic definitions, and confuse the terms risk and uncertainty throughout. Utilisation of the PMBOK standard in the New Zealand construction industry further suggests that risk is poorly understood.

7.2.3. Are people concerned about uncertainties?

All participants' surveyed noted that they were concerned about uncertainties, and they always experienced a case where uncertainty impacted negatively on a project. Though only a few respondents understood what an uncertainty was, this still informs that there is a concern for risks and uncertainties in the construction industry, showing a need for an increased education.

7.2.4. Summary

To summarise, only 5 of the 16 New Zealand construction project managers clearly understood the difference between risk and uncertainty. Education or experience did not affect the level of understanding, most people confuse the terms risk and uncertainty. This could be due to the high use of the PMBOK guide in the industry that did not systematically differentiate between the two terms, although further research is required to find the exact source of the problem.

7.3. How are uncertainties assessed for New Zealand building projects?

The literature and the case study did not reveal how uncertainties are actually assessed, it was important to determine exactly what occurs in practice through a survey. The results found that even if participants blurred the definition of risk and uncertainty, valid conclusions could still be formed from the questions below.

7.3.1. Formal technique use

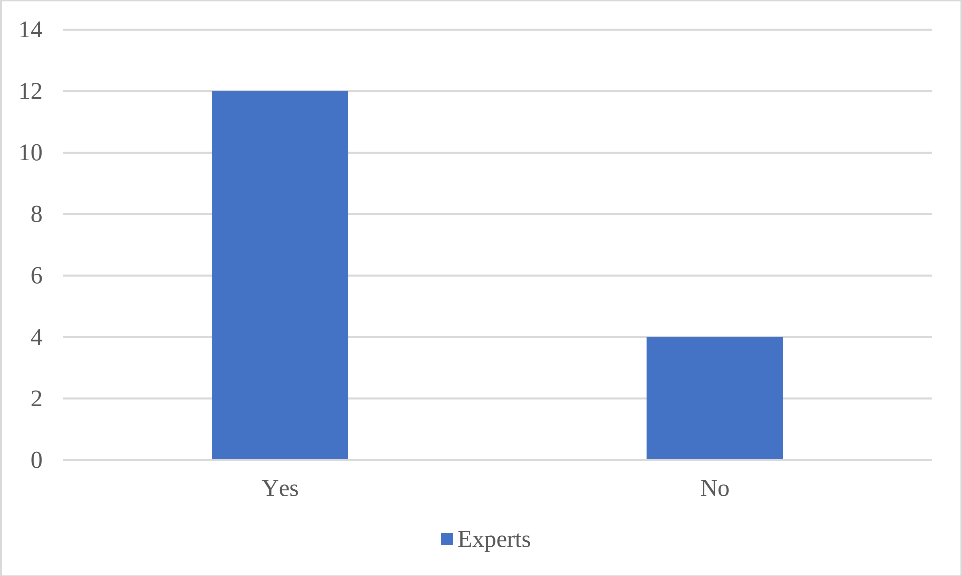

Figure 16: Are you aware of any formal methods (such as formulas or processes e.g. the PERT estimating technique) to analyse uncertainty?

Several different formal techniques were found in the literature that are used to assess uncertainties. Some sources promoted the use of formal techniques for a more successful project (Aven, 2010; Aven & Zio, 2011; Chau, 1995; Dawson & Dawson, 1998; Hartley & Wortham, 1966; Nilsen & Aven, 2003; Paté-Cornell, 1996; Samson et al., 2009; Singhvi, 1980; Tah & Carr, 2000), while others argued that the benefit of using such techniques did not outweigh the learning curve and effort required (ECES, 2010; Gajewska & Ropel, 2011; Hall, 1975). Thus, it was important to understand more about formal technique use in the New Zealand construction industry. As shown by Figure 16 most of the participants were aware of formal techniques. This is a 75% proportion with a 95% confidence interval between 48%-93%.

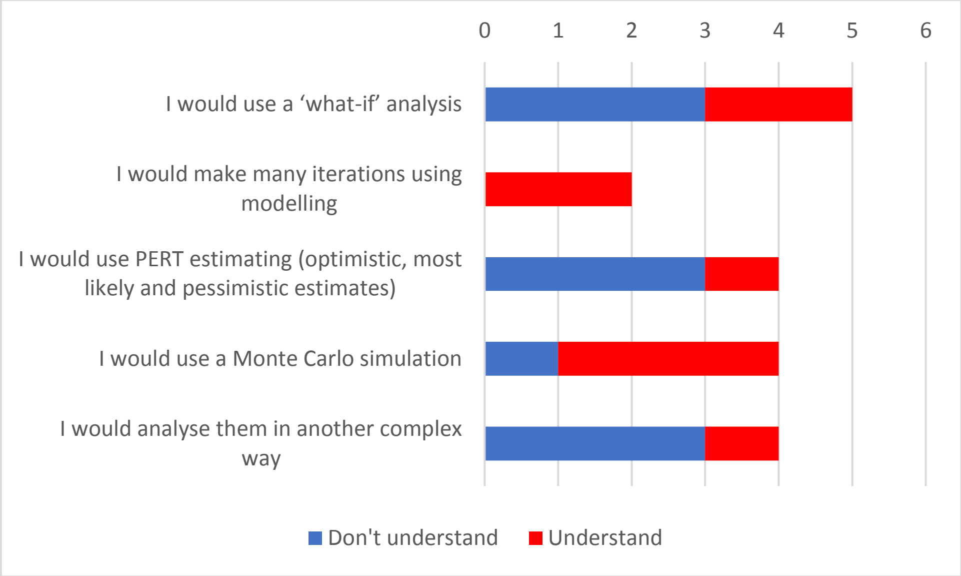

Figure 17: Do you use any of the following formal methods (not standards) to analyse uncertainties in risk? Note this questions allows multiple options to be selected.

Analyse them in another complex way	**Note**
Financial impact vs. likelihood of occurrence in a matrix table to determine most critical risks to manage. Usually presented with a classification as high (red) medium (orange) low (green).	
Event tree analysis, fishbone, cause & effect, FMEA	
Risk Matrix	This is actually an informal technique.

Table 19: Other techniques listed by participants. Obtained from Qualtrics.

All techniques presented in Figure 17 and some in Table 19 quantify some uncertainty. Essentially this graph communicates that even if the terms risk and uncertainty are blurred, there is some quantification of uncertainty in the construction industry whether purposeful or not. 5 of the 16 experts surveyed understood the difference between risk and uncertainty and thus were using these techniques to actually identify the uncertainty. Figure 17 shows that the most common formal assessment techniques are the: what-if analysis, the PERT technique, and a Monte Carlo simulation though several experts use a Monte Carlo simulation to actually assess uncertainty.

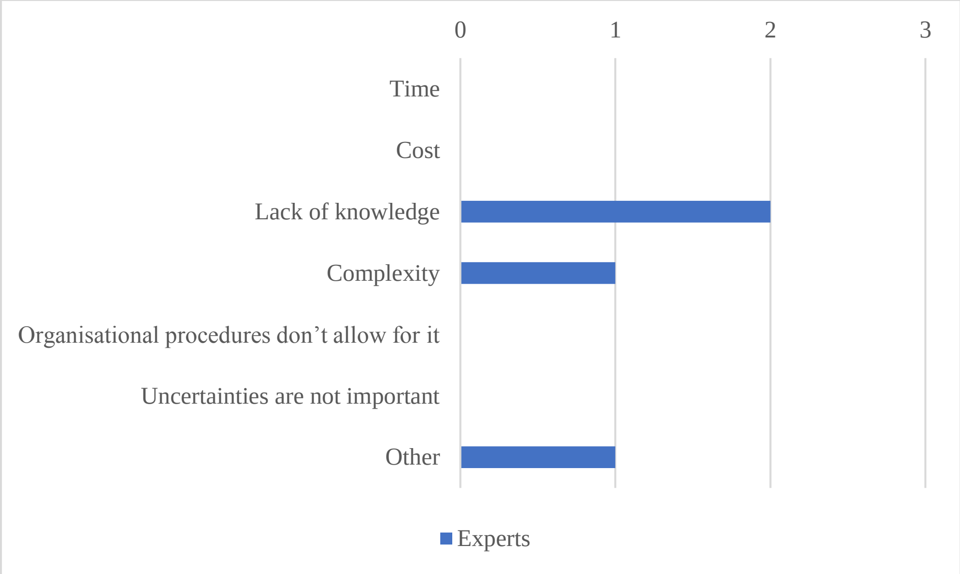

Figure 18: Why don’t you use formal methods to analyse uncertainties in risk?

Figure 16 showed that only four experts did not use formal techniques to assess risks or uncertainties. Current restrictions to the uptake of formal techniques in the industry were found in the literature to be a lack of knowledge and complexity. These results are in line with the evidence found in the literature by Hansson (2010), Ward and Chapman (1991) and Hall (1975); suggesting that this is also true for the New Zealand construction industry. This provides more understanding of the potential opportunities to increase formal technique use in practice. The other category indicated that in-house techniques were used.

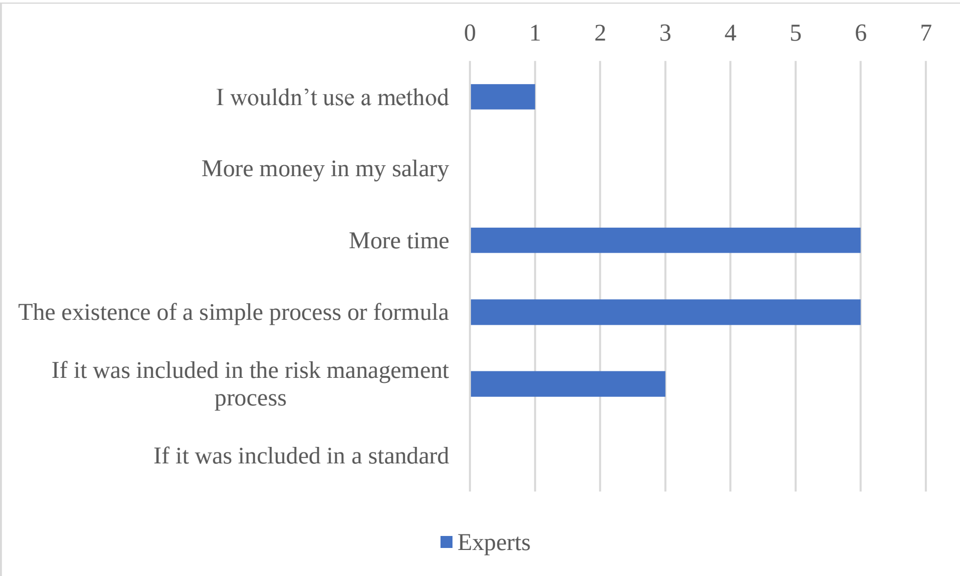

Figure 19: What is the best way to make you start or to allow you to continue using formal methods to analyse uncertainty?

Figure 19 shows that the most common incentives for the uptake of formal technique use in the construction industry were more time and the existence of a simple process or formula. Time is problematic as this is at the discretion of the organisation and is uncontrollable from a research perspective. The above two questions aimed to influence future research in this area. 6 out of 16 participants indicated that the existence of a simple process or formula would increase the use of formal techniques although further research is required in this area to determine suitability for the industry.

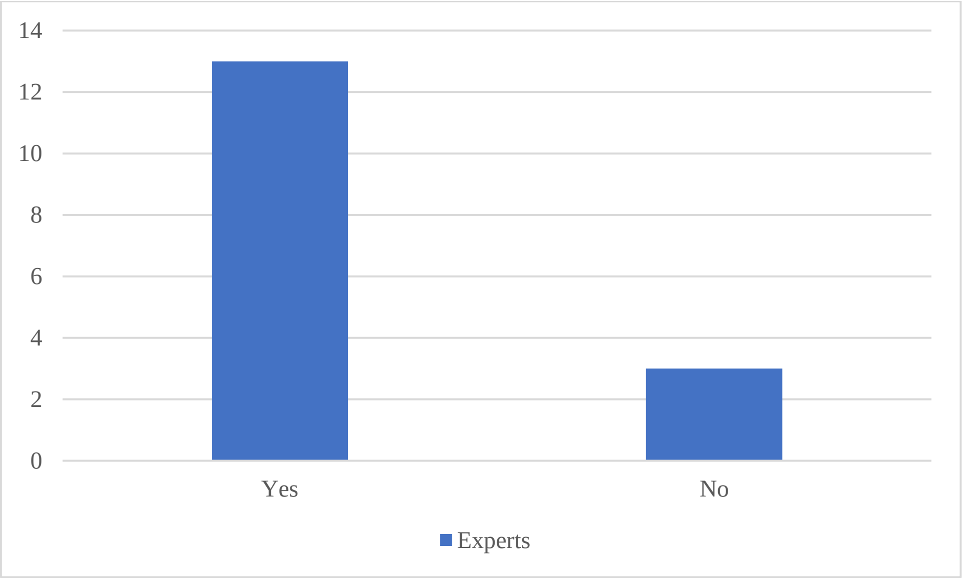

Figure 20: Do you believe that applying structured methods, for analysing uncertainties, will improve overall project success (improvement of time, cost, scope or quality)?

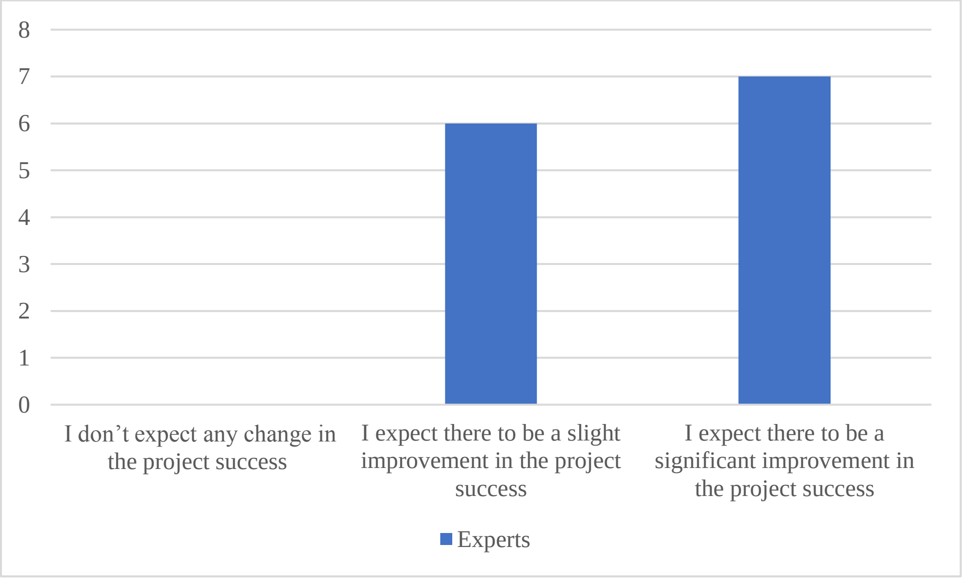

Figure 21: If you use formal methods to analyse uncertainty, what do you think is the most desired outcome?

Figure 20 and 21 show that overall formal techniques are believed to aid the success of the project. This is an 81% proportion with a 95% confidence interval between 54% and 96%. The next question to ask here was "is this warrantable for the uptake of formal techniques in the industry and the development of such a structured process?" Hall (1975) argued that it is likely that managers will give up with formal assessments as their judgement and experiences is a more effective use of their time. These results and the paper produced by Ward and Chapman (1991) disagree with Hall, indicating that this could be the best approach to increasing reliable risk analyses.

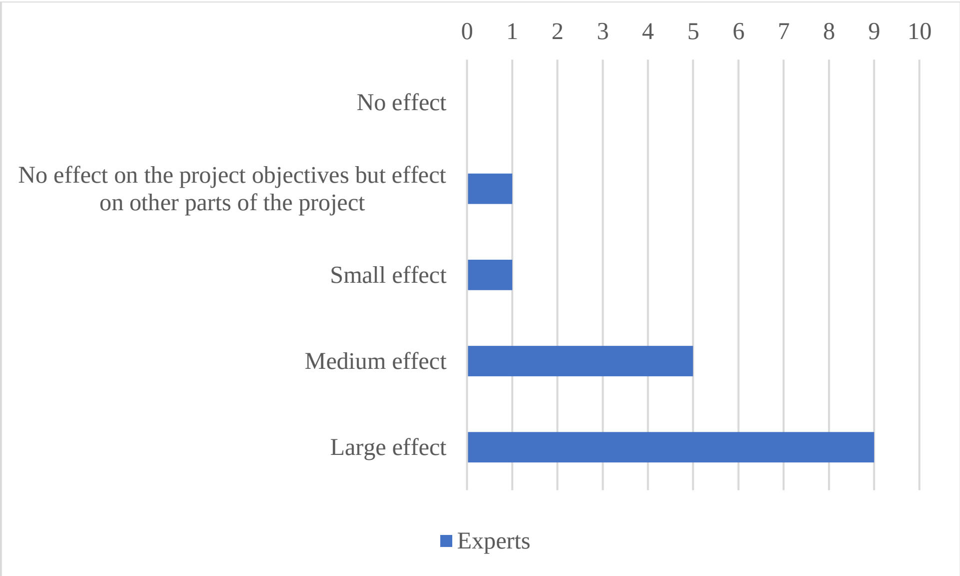

Figure 22: What effects can uncertainties typically have on the project objectives (time, cost, scope and quality) in a project?

It was important to understand how the construction industry perceived the impact of uncertainties on the project objectives, as an extension of the case study analysis. This informs more about the awareness and concern of uncertainties and highlights the significance of this thesis. Figure 22 shows that even if risks and uncertainties are confused, it is likely that uncertainties will have a medium to large effect on the project objectives. This is an 88% proportion with a 95% confidence interval between 62% and 98%.

7.3.2. How often is a risk actually treated as a risk?

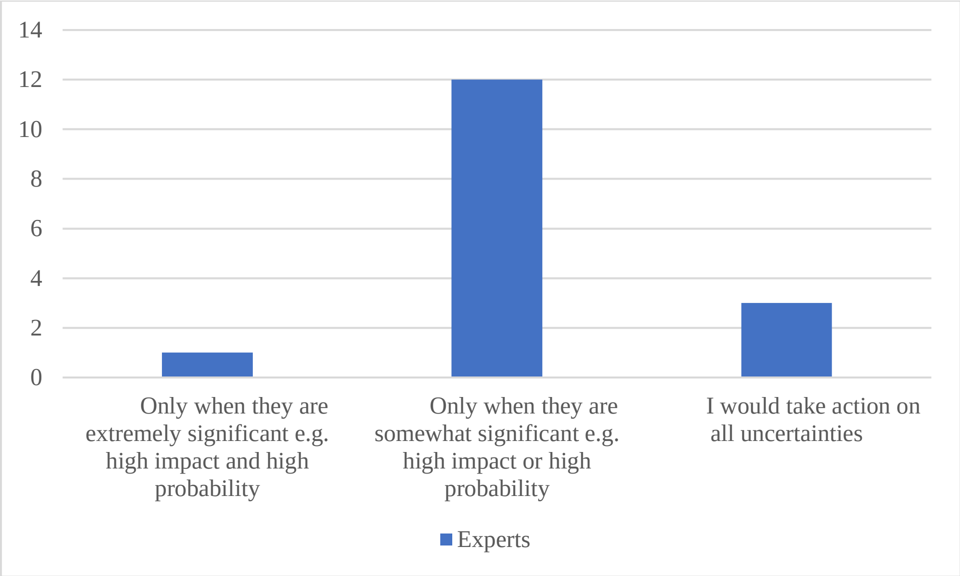

Figure 23: When would you take action on uncertainties?

The question depicted in Figure 23 was important to address, as Hall (1975) argued that people in the industry are taking incorrect action on uncertainties resulting in concentration on the wrong risks. The literature suggested that action was only taken on higher prioritised risks (PMI, 2013), hence, this question aimed to understand if this was true for the New Zealand construction industry. The most common action in the New Zealand construction industry was "only when they are somewhat significant". This is a 75% proportion with a 95% confidence interval between 48% and 93%. These results prove slightly problematic especially if initial estimations of risks are incorrect. Focus could be on the wrong risks throughout the project; having a detrimental effect on the overall success as proved by the case study analysis.

7.3.3. Risk management and uncertainty management process

The survey results showed that all construction industry professionals, whether single or double expert, are aware of the concept of Risk Management. Although this seems promising for increasing reliable risk analyses, it was not clear to which level of detail this process was understood. This could be the reason behind the lack of reliable risk analyses in the New Zealand construction industry.

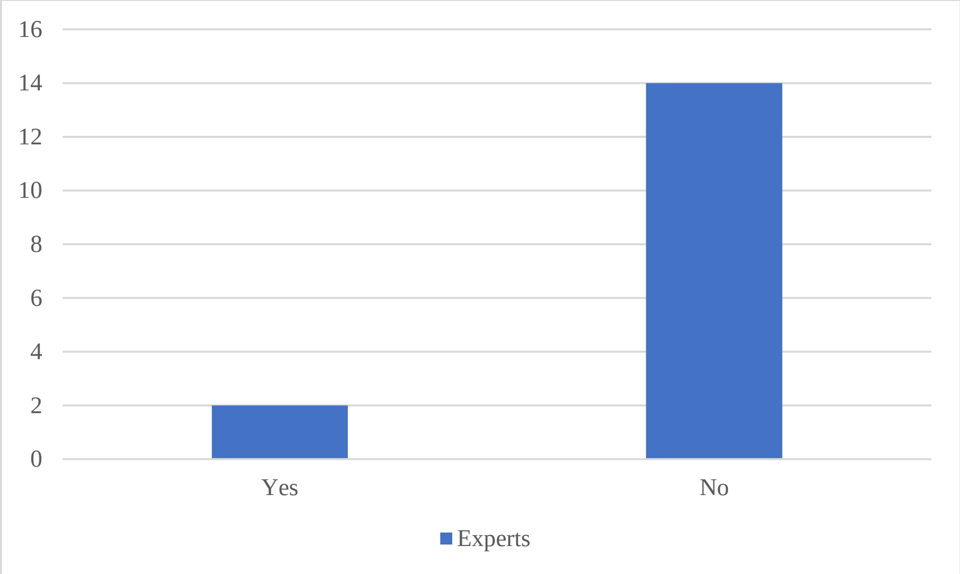

Figure 24: Are you familiar with the concept known as Uncertainty Management?

Figure 24 shows that the majority of construction industry professionals, whether single or double expert, are not aware of the concept of Uncertainty Management. This is an 88% proportion with a 95% confidence interval between 62% and 98%. These results further validate the hypothesis that people in the New Zealand industry are confused about the concept of uncertainty in relation to risk.

The two people that were aware of uncertainty management think that uncertainty is already dealt with in the risk management process. This is problematic, it was concluded in the chapter *Research background - Quality assurance, risk, and uncertainty* that while the risk management process can be extensive, there is no systematic process that deals with uncertainty.

7.3.4. Informal techniques

The next section of the analysis identifies common informal techniques for the treatment of uncertainties, thus, it was important to screen out any responses where risk and uncertainty were confused. It was unclear from the literature and the case study how uncertainties were being treated (identified, assessed, responded to, and monitored and controlled). Hence, this survey assesses this for the New Zealand construction industry. Only 5 of the 16 experts seemed to understand the exact difference between risk and uncertainty, thus, these were the only responses used in forming the results below.

7.3.4.1. *Identification*

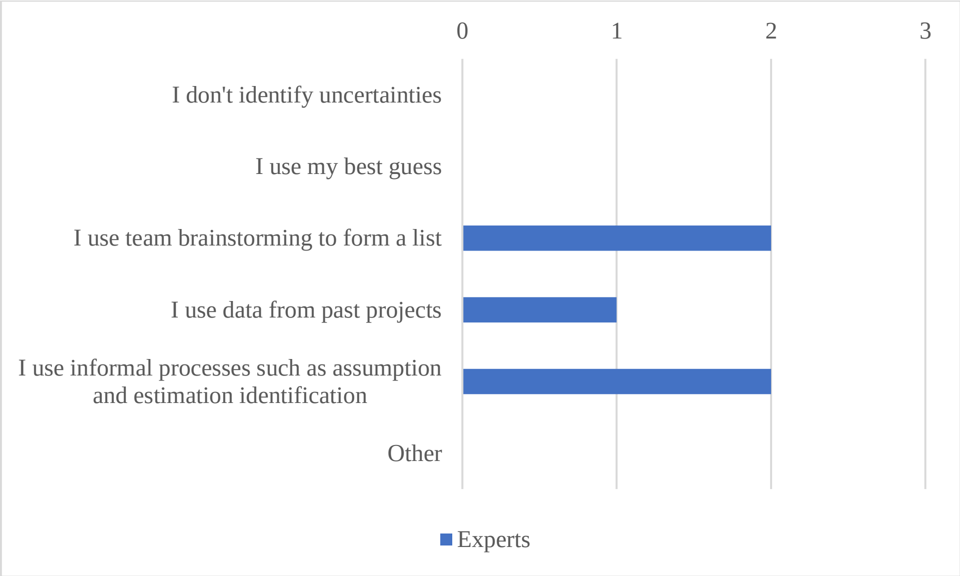

Figure 25: How do you usually identify uncertainties in a building project?

Figure 25 shows that the techniques used to identify uncertainty are: team brainstorming, using data from past projects, and assumption and estimation identification. Although it was not clear which technique is better or more preferred, the last technique does deal specifically with uncertainty.

7.3.4.2. *Assessment*

The only informal assessment technique used to assess uncertainty was "score them based on probability and impact" for both, the people that understood uncertainty, and those that did not. One limitation to the analysis was found to be the change in risk (and potentially uncertainty) across project types. To ensure that this limitation was minimised and the data was comparable across project types, several questions were included in the analysis. The same answers were given for this question and the question below. This suggests that comparison across construction types will not be further informative and that uncertainty is treated similarly for each project.

7.3.4.3. Response

Figure 26: What action do you usually take against uncertainties?

Figure 26 shows that the most common response technique for uncertainties was "I take similar action to risks". This further communicates the lack of change in treatment between project types.

7.3.4.4. Monitor and control

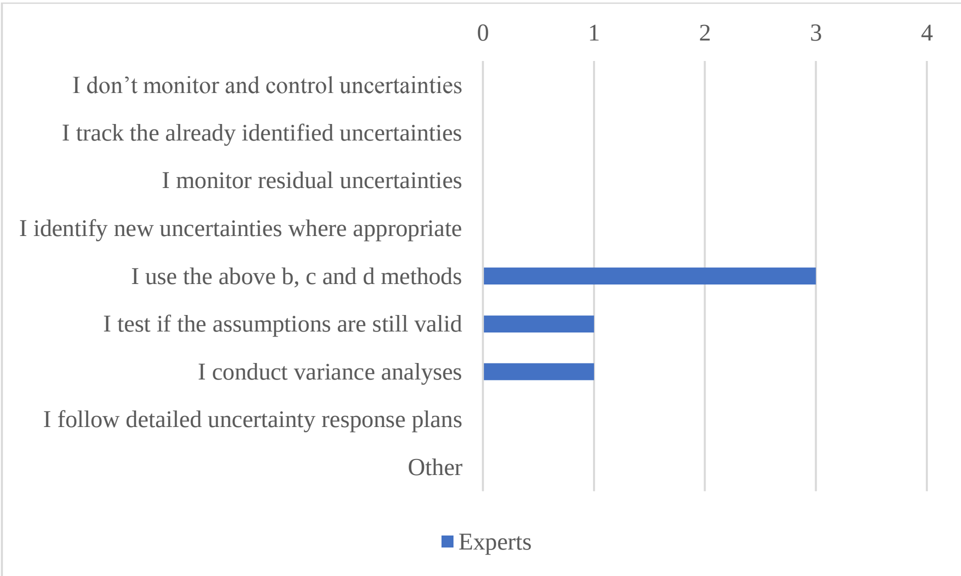

Figure 27: How do you usually monitor and control uncertainties?

Monitoring and controlling uncertainties appropriately through the project lifecycle will significantly improve project success. As discussed by Hall (1975), it was important to ensure focus on the wrong risks or, in this case, uncertainties, is not occurring in projects. The most common technique used in the construction industry to monitor and control uncertainties was "using the above b, c, and d methods" proving that even if reliable risk analyses are not the norm in the industry, they are being improved by the chosen monitor and control techniques.

7.4. Summary

The principal research question that the thesis addressed was:

1. What is the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry?

The following sub-research questions were addressed through this final research method:

- Is risk uncertainty, or are risk and uncertainty different?
- How are uncertainties assessed for New Zealand building projects?

11 of the 16 participants did not understand the difference between risk and uncertainty, thus proving the hypothesis that construction building project managers in the New Zealand industry confuse the terms risk and uncertainty. There was found to be no correlation between the education and experience level of participants and the understanding, essentially disproving the secondary hypothesis. International risk management standards were more commonly used in the industry raising the question of whether specific New Zealand risk management standards are required at all, and the constant development of them might be something to consider. The large familiarisation with the PMBOK guide proved problematic since this standard did not systematically differentiate the terms risk and uncertainty or provide clear definitions. The majority (12) of the participants used formal techniques to assess risks or uncertainties, suggesting that in the New Zealand industry there is some uncertainty quantification in building projects whether people are aware of it or not, despite the lack of uncertainty management found in the case study analysis. The evidence showed that there was a range of techniques used to assess uncertainty, proving that there is no common reliable risk analysis. This analysis essentially looked at all the ways uncertainty is dealt with in practice. Lack of knowledge and complexity proved to be the restriction of formal technique uptake like the literature, with more time and the existence of a simple process key to increasing use. Figure 28 communicates the relationship between quality assurance, risk, and uncertainty in the New Zealand construction industry. The survey proved that risk is uncertainty, and consequently, quality assurance in risk management is lacking as a result. To conclude, the

New Zealand industry does not understand the difference between risk and uncertainty and thus do not reliably analyse risk.

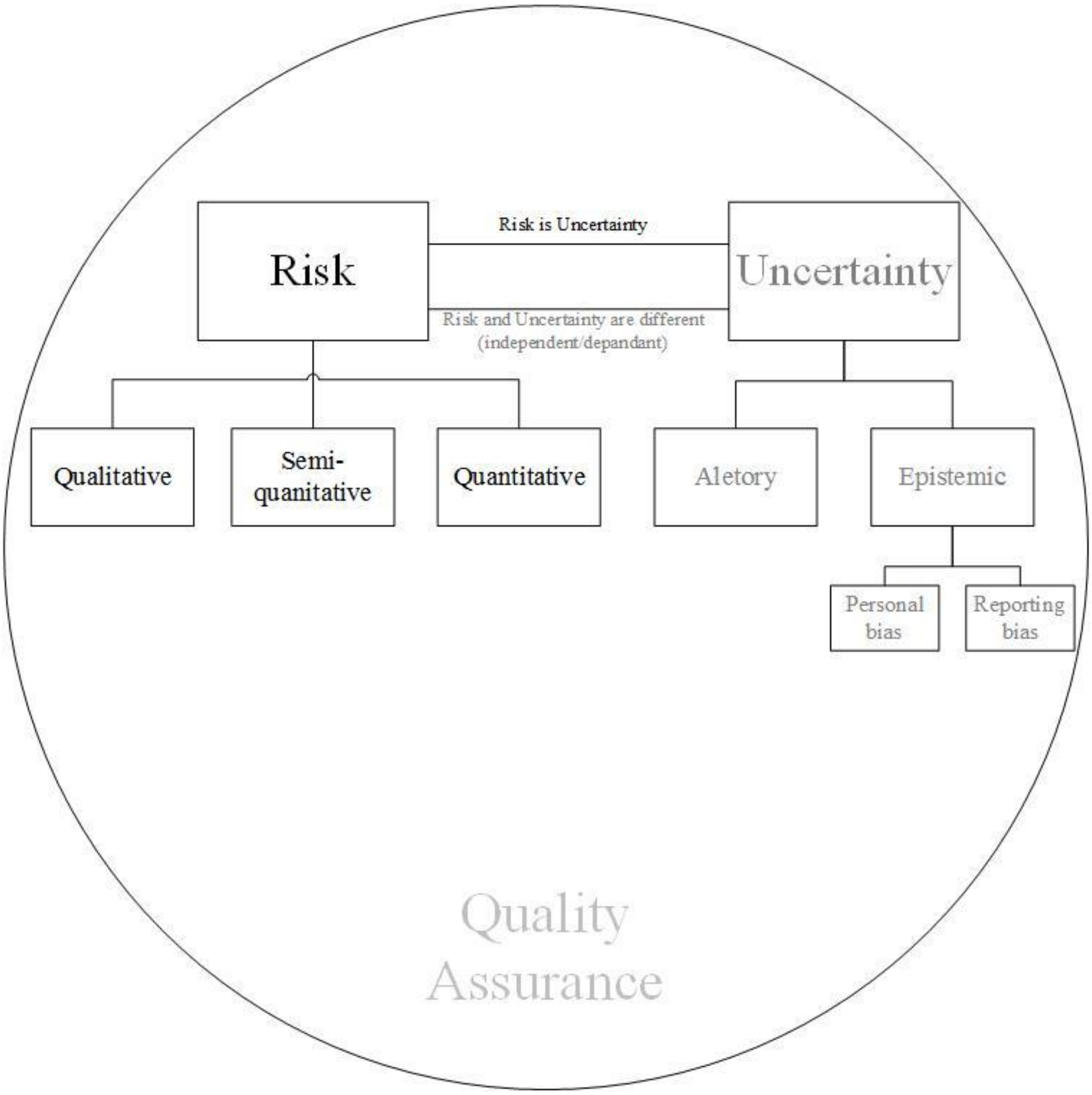

Figure 28: Figure depicting the relationship of quality assurance, risk, and uncertainty in the New Zealand construction industry, created by author.

8. Conclusion

The aim of this thesis was to understand the inherent relationship between quality assurance and construction risk management processes, in particular how quality assurance impacts assessments of risk and uncertainty. Decreasing uncertainty can mitigate risk and thus ensure quality assurance. Two schools of thought were presented: the first: risk is uncertainty, and the second, risk is distinctly separate from uncertainty, and thus in this latter definition there can be an uncertainty in one's assessment of risk. A literature analysis, a case study and a survey were used in the form of a triangulation approach to explore the main aim of this thesis. Each technique addressed the sub-questions in different ways ensuring all options and limitations were explored.

A common opinion in the international industry about risk assessment was that results of risk analyses are associated with significant uncertainties, and currently, no agreed upon definitions or measures to assess risk exist (Aven, 2003). The United States Nuclear Regulatory Commission (U.S.NRC) argued that reliable risk assessment techniques have not been accepted into practice due to the complexity and lack of knowledge, and recognise that research is still continuing to form effective techniques to assess uncertainty in the estimate of risk (G. Parry & Drouin, 2009). A solution to this issue was discussed by Taleb where he argued that prediction and risk management should be replaced by processes which move away from fragility to antifragility (Taleb, 2012).

The literature revealed a fine line between the definition of risk and uncertainty, which in the survey proved to be problematic for the New Zealand construction industry. The terms were not clearly differentiated, many definitions were found and discussed under the two schools of thought. Several techniques to quantify uncertainty were found in the literature (Aven, 2010; Aven & Zio, 2011; Drummond, 1999; ECES, 2010; Hall, 1975; Hartley & Wortham, 1966; Paté-Cornell, 1996; PMI, 2009), although these were not systematic and were considered too complex for industry use (Aven & Zio, 2011; Dawson & Dawson, 1998; Hansson, 2010; Ward & Chapman, 1991). The literature analysis proved that there was no way of comparing scores of risk against reality, rather the techniques focussed on creating reliable risk assessments. This conclusion is based on the survey results where the respondents demonstrated a lack of understanding and use of these such techniques, confirming the literature summarised. The literature revealed that a typical way to manage uncertainty in projects is done through PERT estimating techniques on single point estimates. Several improved models of this exist, although complexity has been suggested to be the major restriction to the uptake of this semi-systematic technique (Hartley & Wortham, 1966). Other more simplistic techniques include: cross-checking of data, clearly quantifying qualitative figures, and assumption, estimation and uncertainty identification (PMI, 2008).

The case study presented in chapter 5 showed that major differences identified in the risk analysis were found to link to time delays and cost overruns, thus proving the existence and impact of uncertainty in a New Zealand construction project. A 76% change in risk was linked to an 11% change in the programme when initial assessments and final assessments were compared. In order to complete the case study analysis, a means was developed to systematically compare risk estimates against reality in a critical path for commercial projects. This can potentially allow consideration of more precise estimates of risk to occur at an earlier stage of the venture.

The survey presented in chapter 6 found that the New Zealand construction industry does not understand the difference between risks and uncertainties. Though uncertainty was not understood there is some quantification occurring through the adoption of informal and formal techniques of risk assessment whether purposeful or not. In practice, the variety of techniques implemented ranged in detail and complexity, examples included: assumption and estimation identification, a what-if analysis, and the PERT technique. The use of these many assessment techniques and absence of consistent systematic processes across many different projects has resulted in confusion and a lack of complete understanding. The survey found that New Zealand construction project managers do not typically understand the difference between risk and uncertainty. Only 5 of the 16 participants actually understood the difference between the two terms.

This thesis essentially showed that the relationship between quality assurance, risk, and uncertainty is heavily dependent on the individual manager’s understanding of risk and uncertainty. Further work is also needed to ensure consistency in the handling of risk and uncertainty between the various different projects and parts of the projects. Without consistency, the likelihood of risk assessment being of practical use seems remote.

9. Future work

The literature argued that the next step to increasing reliable risk assessments was the development of current risk uncertainty methods and techniques to reduce complexity. Many authors have proposed improved systems of risk assessment like PERT, though they found that such techniques were still too complex for the industry (Aven, 2010; Aven & Zio, 2011; Berger et al., 1994; De Rocquigny et al., 2008; Dempster, 1967; Dubois, 2006; Dubois & Prade, 1998; Ferson & Ginzburg, 1996; Hartley & Wortham, 1966; F. Lootsma, 1997; Schmidt & Grossmann, 2000; Walley, 1991). There is a need for a similar process of expressly identifying risk, but in a simpler implement estimation procedure which can be standardised across the New Zealand construction industry. This raised two questions:

1. Whether increased awareness and formal technique use can actually be viable for the New Zealand industry as a whole.
2. Will these processes actually improve currently unreliable risk analyses?

Standards are a familiar process in practice. Although research could look at improving the current risk management standards so uncertainty is more clearly defined, and a systematic approach could be formed, it is questionable to whether this approach will work to achieve reliable risk analyses. Unless the standard is mandated, it is hard to predict how effective this approach will be.

One complex commercial project was a focus for this thesis as it was more likely to have risks that were quantified and thus could be studied. Uncertainty does not just impact the commercial construction sector thus this merits further research.

The project uncertainty approach suggested by Drummond appears to address the confusion around risk and uncertainty, hence, a new contingency model can be used as an initial response to increasing reliable risk assessments and essentially the understanding of risk management (see Figure 29 and 30).

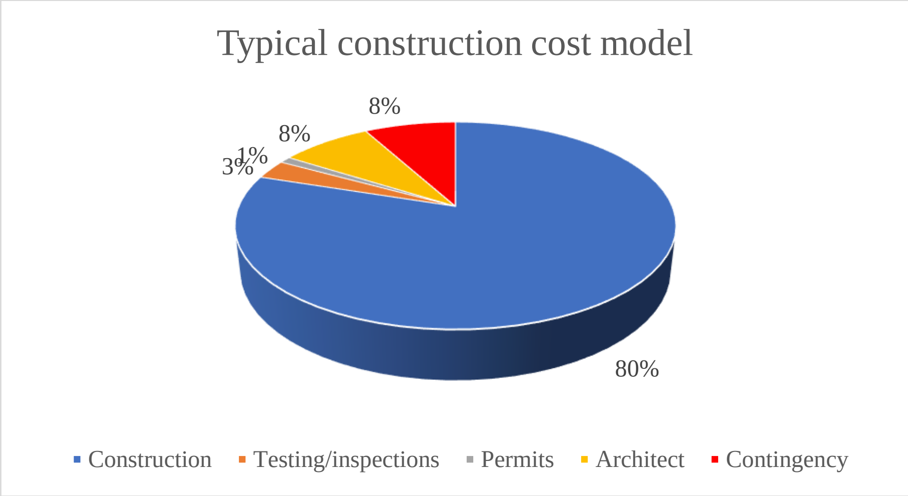

Figure 29: Typical construction costs including an 8% contingency figure, recreated by author from Pasadena City College (2013).

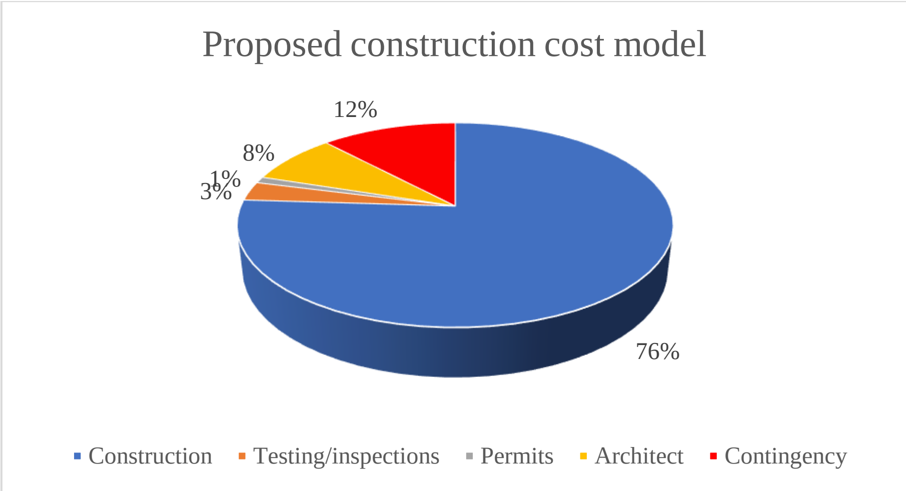

Figure 30: Proposed construction costs including a 12% contingency figure, recreated by author from Pasadena City College (2013).

More responses and extension of the survey questions in this thesis will allow a more detailed analysis between those who are experienced and those who are new to project management, and thus might identify paths to improve practical working experience plans in practices. The survey could also test the international market as an extension of this survey in an attempt to closely compare the results to international literature. More data is required to establish which specific techniques are being used in practice to treat uncertainty, and why these particular techniques are being utilised.

10. Bibliography

Apostolakis, G. (1990). The concept of probability in safety assessments of technological systems. *Science, 250*(4986), 1359-1364.

ASQ. (2015). Design and construction division. Retrieved 15/12, 2015, from http://asq.org/divisions-forums/design/about/index.html

Atkinson, R. (1999). Project management: Cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International Journal of Project Management, 17*(6), 337-342. doi: http://dx.doi.org/10.1016/S0263-7863(98)00069-6

Aven, T. (2003). *Foundations of risk analysis: A knowledge and decision oriented perspective*. New York: Wiley.

Aven, T. (2010). Some reflections on uncertainty analysis and management. *Reliability Engineering & System Safety, 95*(3), 195-201. doi: http://dx.doi.org/10.1016/j.ress.2009.09.010

Aven, T. (2013). On the meaning of a black swan in a risk context. *Safety Science, 57*(0), 44-51. doi: http://dx.doi.org/10.1016/j.ssci.2013.01.016

Aven, T. (2015). The concept of antifragility and its implications for the practice of risk analysis. *Risk Analysis, 35*(3), 476-483.

Aven, T., & Zio, E. (2011). Some considerations on the treatment of uncertainties in risk assessment for practical decision making. *Reliability Engineering & System Safety, 96*(1), 64-74. doi: http://dx.doi.org/10.1016/j.ress.2010.06.001

Bell, J. (2007). *Doing your research project*. USA: McGraw-Hill Education.

Berger, J. O., Moreno, E., Pericchi, L. R., Bayarri, M. J., Bernardo, J. M., Cano, J. A., De la Horra, J., Martín, J., Ríos-Insúa, D., & Betrò, B. (1994). An overview of robust Bayesian Analysis. *Test, 3*(1), 5-124.

Bernstein, P. L. (1996). The new religion of risk management. *Harvard Business Review, March-April* (74 (2)), 47-52.

Bethlehem, J. (2010). Selection bias in web surveys. *International Statistical Review, 78*(2), 161-188.

Birge, J. R., & Maddox, M. J. (1995). Bounds on expected project tardiness. *Operations Research, 43*(5), 838-850. doi: 10.1287/opre.43.5.838

BRANZ. (2016). About BEES. Retrieved 05/02, 2016, from http://www.branz.co.nz/cms_display.php?sn=128&st=1

Burt, J. M., & Garman, M. B. (1971). Conditional Monte Carlo: A simulation technique for stochastic network analysis. *Management Science, 18*(3), 207-217. doi: 10.1287/mnsc.18.3.207

Causascientia. (2016). Is your answer correct? Retrieved 18/02, 2016, from http://www.causascientia.org/math_stat/ProportionCI.html

Chau, K. W. (1995). Monte Carlo simulation of construction costs using subjective data. *Construction Management and Economics, 13*(5), 369-383. doi: 10.1080/01446199500000042

Clark, C. E. (1961). The greatest of a finite set of random variables. *Operations Research, 9*(2), 145-162.

Cleef, H. J., & Gual, W. (1982). Project scheduling via stochastic programming. *Mathematische Operationsforschung und Statistik. Series Optimization, 13*(3), 449-468. doi: 10.1080/02331938208842807

Cleland, D. I., & Gareis, R. (2006). *Global project management handbook: Planning, organizing, and controlling international projects* (2nd ed.). New York: McGraw-Hill.

Cooper, D., Grey, S., Raymond, G., & Walker, P. (2005). *Project risk management guidelines: Managing risk in large projects and complex procurements*: Wiley.

Couper, M. P. (2000). Review: Web surveys: A review of issues and approaches. *Public opinion quarterly*, 464-494.

Dawson, R. J., & Dawson, C. W. (1998). Practical proposals for managing uncertainty and risk in project planning. *International Journal of Project Management, 16*(5), 299-310. doi: http://dx.doi.org/10.1016/S0263-7863(97)00059-8

De Rocquigny, E., Devictor, N., & Tarantola, S. (2008). *Uncertainty in industrial practice: A guide to quantitative uncertainty management*. England: John Wiley & Sons.

Dempster, A. P. (1967). Upper and lower probabilities induced by a multivalued mapping. *The annals of mathematical statistics*, 325-339.

Denzin, N. K. (1970). *The research act: A theoretical introduction to sociological methods*: Transaction publishers.

Dey, P. (2011). Issues and challenges of managing projects in India: A case study *Doing business in India : Building research-based practice* (pp. 147-163): Routledge.

Dey, P. K., & Ogunlana, S. O. (2002). Risk based decision support system for effective implementation of projects. *International Journal of Risk Assessment and Management, 3*(2), 189-204.

Drummond, H. (1999). Are we any closer to the end? Escalation and the case of Taurus. *International Journal of Project Management, 17*(1), 11-16.

Dubois, D. (2006). Possibility theory and statistical reasoning. *Computational statistics & data analysis, 51*(1), 47-69.

Dubois, D., & Prade, H. (1998). Possibility theory: qualitative and quantitative aspects *Quantified representation of uncertainty and imprecision* (Vol. 1, pp. 169-226): Springer.

ECES. (2010). IEC/ISO 31010:2009 Risk management: risk assessment techniques (pp. 90). Brussels: European Committee for Electotechnical Standardisation.

Edwards, P. J., & Bowen, P. A. (1993). Risk and risk management in construction: A review and future directions for research. *Engineering, Construction and Architectural Management, 5*(4), 339-349.

Elmaghraby, S. E. (1967). On the expected duration of PERT type networks. *Management Science, 13*(5), 299-306. doi: 10.1287/mnsc.13.5.299

Elmaghraby, S. E. (1977). *Activity networks: project planning and control by network models*: Wiley.

Ferson, S., & Ginzburg, L. R. (1996). Different methods are needed to propagate ignorance and variability. *Reliability Engineering & System Safety, 54*(2–3), 133-144. doi: http://dx.doi.org/10.1016/S0951-8320(96)00071-3

Fisher, R. A. (1935). *The design of experiments*: Oliver and Boyd.

Franz, J. M. (2008). A pedagogical model of higher education/industry engagement for enchancing employability and professional practice. *Work Integrated Learning (WIL): Transforming Futures, Practice, Pedagogy, Partnerships*, 164-169.

Fulkerson, D. R. (1962). Expected critical path lengths in PERT-type networks. *Operations Research, 10*, 808-817.

Gajewska, E., & Ropel, M. (2011). *Risk management practices in a construction project: A case study*. (Master of Science Thesis in the Master's Programme Design and Construction Project Management), Chalmers University of Technology, Goteborg Sweden. Retrieved from publications.lib.chalmers.se/records/fulltext/144253.pdf

Garner, W. R. (1962). *Uncertainty and structure as psychological concepts*. New York: Wiley.

Gaul, W. (1981). Bounds for the expected duration of a stochastic project planning model. *Journal of Information and Optimization Sciences, 2*(1), 45-63. doi: 10.1080/02522667.1981.10698686

Gitau, L. (2015). *The effects of risk management at project planning phase on performance of construction projects in Rwanda.* (Master of Science in Project Management), Jomo Kenyatta University of Agriculture And Technology, Kenya.

Gould, F. E., & Joyce, N. E. (2002). *Construction project management*. Upper Saddle River: Prentice Hall.

Graham, J. D. (1995). Verifiability isn't everything. *Risk Analysis, 15*(2), 109. doi: 10.1111/j.1539-6924.1995.tb00304.x

Groat, L., & Wang, D. (2013). *Architectural research methods*. New York: John Wiley and Sons.

Gurton, B. (2015, 11/08/15). [Personal meeting].

Haimes, Y. Y. (2005). *Risk modeling, assessment, and management* (Vol. 40): John Wiley & Sons.

Hall, W. K. (1975). Why risk analysis isn't working. *Long Range Planning, 8*(6), 25-29. doi: http://dx.doi.org/10.1016/0024-6301(75)90022-9

Hammond, P. (2009). *Adapting to the entirely unpredictable: Black swans, fat tails, aberrant events, and hubristic models* (Vol. 10). Warwick: The University of Warwick Bulletin of the Economics Research Institute.

Haneveld, W. (1986). Robustness against dependence in PERT: An application of duality and distributions with known marginals. In A. Prékopa & R. B. Wets (Eds.), *Stochastic Programming 84 Part I* (Vol. 27, pp. 153-182): Springer Berlin Heidelberg.

Hansson, S. O. (2010). Risk: objective or subjective, facts or values. *Journal of risk research, 13*(2), 231-238. doi: 10.1080/13669870903126226

Hartley, H. O., & Wortham, A. W. (1966). A statistical theory for PERT critical path analysis. *Management Science, 12*(10), B-469-B-481. doi: doi:10.1287/mnsc.12.10.B469

Hattis, D., & Minkowitz, W. S. (1997). *Risk evaluation: Legal requirements, conceptual foundations, and practical experiences in the United States*: Akad. für Technikfolgenabschätzung in Baden-Württemberg.

Helton, J. C., & Oberkampf, W. L. (2004). Guest editorial: alternative representation of uncertainty. *Reliability Engineering and System Safety*(85), 1-10.

Hodgson, D., & Cicmil, S. (2006). *Making projects critical*: Palgrave Macmillan.

Hoffman, F. O., & Hammonds, J. S. (1994). Propagation of uncertainty in risk assessments: The need to distinguish between uncertainty due to lack of knowledge and uncertainty due to variability. *Risk Analysis, 14*(5), 707-712.

Institution of Civil Engineers. (1998). *RAMP - Risk Analysis and Management for Projects: A strategic framework for managing project risk and its financial implications*. UK: Thomas Telford.

ISO. (2009). ISO Guide 73:2009 Risk management: vocabulary. Retrieved 02/07, 2015, from http://www.iso.org/iso/catalogue_detail?csnumber=44651

Kaplan, S., & Garrick, B. (1981). On the quantitative definition of risk. *Risk Analysis, 1*, 11-27. doi: 10.1111/j.1539-6924.1981.tb01350.x

Keynes, J. M. (1937). *The general theory of employment* (3 ed. Vol. 51): Q J Econ.

Kiureghian, A. D., & Ditlevsen, O. (2009). Aleatory or epistemic? Does it matter? *Structural Safety, 31*(2), 105-112. doi: http://dx.doi.org/10.1016/j.strusafe.2008.06.020

Kleindorfer, G. B. (1971). Bounding distributions for a stochastic acyclic network. *Operations Research, 19*(7), 1586-1601. doi: 10.2307/169180

Klinke, A., & Renn, O. (2002). A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies. *Risk Analysis, 22*(6), 1071-1094.

Knight, F. H. (1921). *Risk, uncertainty and profit*. Boston and New York: Houghton Mifflin Company.

Lindley, D. V. (2008). The black swan: The impact of the highly improbable. *Reviews, March*, 42-43.

Loosemore, M. (2004). *Essentials of construction project management*. Australia: UNSW Press.

Loosemore, M., Raftery, J., Reilly, C., & Higgon, D. (2006). *Risk management in projects* (2nd ed.). London and New York: Taylor & Francis.

Lootsma, F. (1997). Stochastic and fuzzy PERT *Fuzzy logic for planning and decision making* (Vol. 8, pp. 39-65): Springer US.

Lootsma, F. A. (1966). Network planning with stochastic activity durations: An evaluation of PERT. *Statistica Neerlandica, 20*(1), 43-69. doi: 10.1111/j.1467-9574.1966.tb00492.x

Lowrance, W. W. (1976). *Of acceptable risk: Science and the determination of safety*. USA: William Kaufmann.

MacCrimmon, K. R., & Ryavec, C. A. (1964). An analytical study of the PERT assumptions. *Operations Research, 12*(1), 16-37. doi: 10.1287/opre.12.1.16

Magee, J. H. (1961). *General insurance* (6th ed.). Homewood, Illinois: R. D. Irwin.

Marshall, A. W., & Meckling, W. H. (1962). Predictability of the costs, time, and success of development *The rate and direction of inventive activity: Economic and social factors* (pp. 461-476): Princeton University Press.

Martin, J. J. (1965). Distribution of the time through a directed, acyclic network. *Operations Research, 13*(1), 46-66. doi: 10.1287/opre.13.1.46

Mayfield, P. (2013). Understanding binomial confidence intervals. Retrieved 24/02, 2016, from http://www.sigmazone.com/binomial_confidence_interval.htm

McDonald, J. H. (2009). *Handbook of biological statistics* (2 ed.). Baltimore, MD: Sparky House Publishing

Mehr, R. I., & Cammack, E. (1961). *Principles of insurance* (3rd Ed.). Homewood, Illinois: R.D. Irwin INC.

Meilijson, I., & Nádas, A. (1979). Convex majorization with an application to the length of critical paths. *Journal of Applied Probability, 16*(3), 671-677. doi: 10.2307/3213097

Mohamed, M. B. I. (2015). *A study of project delay in Sudan: Construction industry.* (Master of Project Management in Science of Project), Universiti Tunku Abdul Rahman, Malaysia.

Morisette, J., & Khorram, S. (1998). Exact binominal confidence intervals for proportions. *Photogrammetric engineering and remote sensing*, 281-283.

Morris, P. W. G., & Hough, G. H. (1987). *The anatomy of major projects: A study of the reality of project management*: Wiley.

Nadas, A. (1979). Probabilistic PERT. *IBM Journal of Research and Development, 23*(3), 339-347. doi: 10.1147/rd.233.0339

Nawab, A. S. (Producer). (2013, 16/04/15). Risk and uncertainty in construction projects. [PowerPoint Presentation] Retrieved from http://www.slideshare.net/SameerNK/risk-and-uncertainty-in-construction-projects-25985797

New Zealand Government. (1992). Building regulations schedule 1. Retrieved 05/02, 2016, from http://www.legislation.govt.nz/regulation/public/1992/0150/latest/DLM162576.html

Newell, M. W., & Grashina, M. N. (2004). *The project management question and answer book*. USA: AMACOM, American Management Association.

Nielsen, J. (1992). *Finding usability problems through heuristic evaluation*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Monterey, California, USA.

Nielsen, J. (1993). *Usability engineering*. MA, USA: AP Professional.

Nielsen, J. (1994). *Usability inspection methods.* Paper presented at the Conference companion on Human factors in computing systems.

Nilsen, T., & Aven, T. (2003). Models and model uncertainty in the context of risk analysis. *Reliability Engineering & System Safety, 79*(3), 309-317. doi: http://dx.doi.org/10.1016/S0951-8320(02)00239-9

NS. (1991). Norwegian Standard 5814. Risk analysis requirements: Norwegian Standards.

NZQA. (2015). National Diploma in Construction Management (Level 6). Retrieved 15/12, 2015, from http://www.nzqa.govt.nz/nzqf/search/viewQualification.do?selectedItemKey=0356

Oxford Dictionaries. (2015). Risk. Retrieved 18/05, 2015, from http://www.oxforddictionaries.com/definition/english/risk

Parry, G., & Drouin, M. (2009). *Risk-informed regulatory decision-making at the U.S NRC: dealing with model uncertainty.* Paper presented at the Nuclear Regulatory Commission, US.

Parry, G. W., & Winter, P. W. (1981). Characterization and evaluation of uncertainty in probabilistic risk analysis. *Nucl. Saf (United States), 22*(1), 28-42.

Pasadena City College. (2013). Project office: Project budgets. Retrieved 07/03, 2016, from http://www.pasadena.edu/bond/office/budget.cfm

Paté-Cornell, M. E. (1996). Uncertainties in risk analysis: Six levels of treatment. *Reliability Engineering & System Safety, 54*(2), 95-111.

Peace, C. (2015, 11/06). [Personal meeting].

Philippe, J. (2001). *Value at risk: The new benchmark for managing financial risk*. New York: McGraw-Hill Professional.

Pilch, M., Trucano, T. G., & Helton, J. C. (2011). Ideas underlying the quantification of margins and uncertainties. *Reliability Engineering & System Safety, 96*(9), 965-975. doi: http://dx.doi.org/10.1016/j.ress.2011.03.016

PMI. (2008). *Project Management Body of Knowledge (PMBOK® GUIDE).* Paper presented at the Project Management Institute, Newtown Square.

PMI. (2009). *Practice standard for risk management*. Pennslyvania, USA: Project Management Institute.

PMI. (2011). Project Management Institute New Zealand: professional development. Retrieved 22/06, 2015, from http://www.pmi.org.nz/pmi/?q=professional_development

PMI. (2012). *PMI lexicon of project management terms* (pp. 18). Retrieved from http://www.pmi.org/PMBOK-Guide-and-Standards/~/media/Registered/PMI_Lexicon.ashx

PMI. (2013). *A guide to the Project Management Body of Knowledge (PMBOK Guide)*. Newtown Square: Project Management Institute, Four Campus Boulevard.

PMI. (2015). Project Management Professional (PMP). Retrieved 20/05, 2015, from http://www.pmi.org/Certification/Project-Management-Professional-PMP.aspx

Preda, C. (2013). Implementing a risk management standard. *Journal of Defense Resources Management, 4*(1), 111-120.

PTS. (2015). Construction QA/QC. Retrieved 15/12, 2015, from http://www.processtechnicalservices.com/quality-assurance.asp

RCP. (2016). Risk management. Retrieved 16/02, 2016, from http://www.rcp.co.nz/blog/our-approach/risk-management

Reid, S. G. (1992). Acceptable risk. *Engineering safety*(D.I. Blockley), 138-166.

Risk NZ. (2014). Register of consultants. Retrieved 17/08, 2015, from http://www.risknz.org.nz/resources/register-of-consultants/

Robillard, P., & Trahan, M. (1977). The completion time of PERT networks. *Operations Research, 25*(1), 15-29. doi: 10.1287/opre.25.1.15

Ropel, M., & Gajewska, E. (2011). *Risk management practices in a construction project: A case study*. (Master of Science in the Master's Programme Design and Construction Project Management), Chalmers University of Technology, Sweden. Retrieved from http://publications.lib.chalmers.se/records/fulltext/144253.pdf

Rumsey, D. J. (2010). *Statistics essentials for dummies*. USA: John Wiley & Sons.

Ruskin, A. M., & Lerner, R. (1972). Forecasting costs and completion dates for defense research and development contracts. *Engineering Management, IEEE Transactions on, EM-19*(4), 128-133. doi: 10.1109/TEM.1972.6448400

Samson, S., Reneke, J. A., & Wiecek, M. M. (2009). A review of different perspectives on uncertainty and risk and an alternative modeling paradigm. *Reliability Engineering & System Safety, 94*(2), 558-567. doi: http://dx.doi.org/10.1016/j.ress.2008.06.004

Schmidt, C. W., & Grossmann, I. E. (2000). The exact overall time distribution of a project with uncertain task durations. *European Journal of Operational Research, 126*(3), 614-636. doi: http://dx.doi.org/10.1016/S0377-2217(99)00316-1

Sears, S. K., Clough, R. H., & Sears, G. A. (2008). *Construction project management: A practical guide to field construction management*: John Wiley & Sons.

Seawright, J., & Gerring, J. (2008). Case selection techniques in case study research: A menu of qualitative and quantitative options. *Political Research Quarterly, 61*(2), 294-308. doi: 10.2307/20299733

Shogan, A. W. (1977). Bounding distributions for a stochastic pert network. *Networks, 7*(4), 359-381. doi: 10.1002/net.3230070407

Shrader-Frechette, K. S. (1991). *Risk and rationality: Philosophical foundations for populist reforms*: University of California Press.

Singhvi, S. S. (1980). A practical approach to risk and sensitivity analyses. *Long Range Planning, 13*, 8.

Statistics New Zealand. (2015). Implementing classification and other changes to building consent statistics: Description of building categories. Retrieved 04/02, 2016, from http://www.stats.govt.nz/browse_for_stats/industry_sectors/Construction/building-consent-changes-2015.aspx

Sterman, J. D. (1992). System dynamics modeling for project management. *Unpublished manuscript, Cambridge, MA*, 12.

Tah, J. H. M., & Carr, V. (2000). A proposal for construction project risk assessment using fuzzy logic. *Construction Management and Economics, 18*(4), 491-500. doi: 10.1080/01446190050024905

Taleb, N. (2012). *Antifragile: Things that gain from disorder*. New York: Random House.

TBIG. (2006a). Assistant project manager. Retrieved 15/12, 2015, from http://www.thebuildingintelligencegroup.co.nz/jobs/tauranga-vacancies/tauranga-assistant-project-manager/

TBIG. (2006b). Project manager. Retrieved 15/12, 2015, from http://www.thebuildingintelligencegroup.co.nz/jobs/christchurch-vacancies/

TBIG. (2016). Project management services. Retrieved 16/02, 2016, from http://www.thebuildingintelligencegroup.co.nz/who_we_are/

Tickner, J., & Kriebel, D. (2006). The role of science and precaution in environmental and public health policy *Implementing the precautionary principle* (pp. 42-62). Massachusetts: Edward Elgar Publishing.

Toutenburg, H. (1971). Fisher, R. A., and F. Yates: Statistical tables for biological, agricultural and medical research. 6th Ed. Oliver & Boyd, Edinburgh and London 1963. X, 146 P. Preis 42 s net. *Biometrische Zeitschrift, 13*(4), 285. doi: 10.1002/bimj.19710130413

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluijs, J. P., van Asselt, M. B., Janssen, P., & Krayer von Krauss, M. P. (2003). Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support. *Integrated assessment, 4*(1), 5-17.

Walley, P. (1991). *Statistical reasoning with imprecise probabilities* (Vol. 42). Australia: Department of Mathematics, The University of Western Australia.

Wang, H.-C., & Doong, H.-S. (2007). *Validation in internet survey research: Reviews and future suggestions.* Paper presented at the System Sciences, 2007. HICSS 2007. 40th Annual Hawaii International Conference on.

Ward, S. C., & Chapman, C. B. (1991). Extending the use of risk analysis in project management. *International Journal of Project Management, 9*(2), 117-123. doi: http://dx.doi.org/10.1016/0263-7863(91)90071-3

Webb, A. (2003). *The project manager's guide to handling risk*: Gower Publishing, Ltd.

Willett, A. H. (1901). *The economic theory of risk and insurance*. New York: Columbia University Press.

Winch, G. M. (2010). *Managing construction projects*: John Wiley & Sons.

Young, J. (2011). *The framework for successful project management* (Third ed.): PrintStop.

Zeng, J., An, M., & Smith, N. J. (2007). Application of a fuzzy based decision making methodology to construction project risk assessment. *International Journal of Project Management, 25*(6), 589-600. doi: http://dx.doi.org/10.1016/j.ijproman.2007.02.006

Zou, P. X., Zhang, G., & Wang, J.-Y. (2006). *Identifying key risks in construction projects: Life cycle and stakeholder perspectives.* Paper presented at the Pacific Rim Real Estate Society Conference.

11. Appendices

Appendix A - Survey questions

Please select one answer for each question selecting the most relevant answer.

A1: General information

1. Have you worked on construction building projects within the last five years? (Includes residential, commercial, retail, civil, industrial etc.)
   - ☐ Yes
   - ☐ No (stop survey)
2. Would you consider yourself as a project manager?
   - ☐ Yes
   - ☐ No (stop survey)
3. Please list (**most common to least common**) the main uncertainties, in relation to risk (max. 5)? (max 30 words)

4. How many years have you spent in the field as a project manager? (to ensure the applicant is an "expert" in relation to risk management)
   - ☐ Less than 3 years
   - ☐ 3 or more years, please specify (max 5 words)

5. Do you have a professional project management qualification?
   - ☐ Yes, please specify: (max 20 words)

- ☐ No

6. What type of project do you work more than 50% of the time on?
   - ☐ Residential
   - ☐ Non-residential
7. What classification of project do you work more than 50% of the time on?
   - ☐ New projects
   - ☐ Renovations
   - ☐ Demolitions
8. What is the typical size of the projects you work on?
   - ☐ Small (less than 650m^2)
   - ☐ Medium (between 651m^2 and 3,500m^2)
   - ☐ Large (over 3,501m^2)

A2: Determining how people deal with uncertainties

Considering your answers to the questions above in regards to types of projects you work on, please answer the following:

Identification:

9. How do you **usually** identify uncertainties in a building project?
   - ☐ I don't identify uncertainties
   - ☐ I use my best guess
   - ☐ I use team brainstorming to form a list
   - ☐ I use data from past projects
   - ☐ I use informal processes such as assumption and estimation identification
   - ☐ Other, please specify (max 10 words)

Assessment:

10. Assuming that you have identified a number of uncertainties in a project, how would you **usually** quantify them?
    - ☐ I wouldn't quantify them

- ☐ I would number them from high to low priority
- ☐ I would number them within categories and sub-categories
- ☐ I would give them a score based on high/low priority
- ☐ I would score them based on probability and impact
- ☐ I would score them in another way, please specify: (max 20 words)

11. What effects can uncertainties **typically** have on the project objectives (time, cost, scope and quality) in a project?
    - ☐ No effect
    - ☐ No effect on the project objectives but effect on other parts of the project
    - ☐ Small effect
    - ☐ Medium effect
    - ☐ Large effect
12. Are you aware of any formal methods (such as formulas or processes e.g. the PERT estimating technique) to analyse uncertainty?
    - ☐ Yes (skip question 14)
    - ☐ No (skip question 13)
13. Do you use any of the following formal methods (**not standards**) to analyse uncertainties in risk?
    - ☐ I would use a "what-if" analysis
    - ☐ I would make many iterations using modelling
    - ☐ I would use PERT estimating (optimistic, most likely and pessimistic estimates)
    - ☐ I would use a Monte Carlo simulation
    - ☐ I would analyse them in another complex way, please specify: (max 20 words)

14. Why don’t you use formal methods to analyse uncertainties in risk?
    - ☐ Time
    - ☐ Cost
    - ☐ Lack of knowledge
    - ☐ Complexity
    - ☐ Organisational procedures don’t allow for it
    - ☐ Uncertainties are not important
    - ☐ Other, please specify (max 20 words)

15. What is the best way to make you start or to allow you to continue using formal methods to analyse uncertainty?
    - ☐ I wouldn’t use a method
    - ☐ More money in my salary
    - ☐ More time
    - ☐ The existence of a simple process or formula
    - ☐ If it was included in the risk management process
    - ☐ If it was included in a standard
16. Do you believe that applying structured methods, for analysing uncertainties, will improve overall project success (improvement of time, cost, scope or quality)?
    - ☐ Yes
    - ☐ No (skip question 17)
17. If you use formal methods to analyse uncertainty, what do you think is the most desired outcome?
    - ☐ I don’t expect any change in the project success
    - ☐ I expect there to be a slight improvement in the project success
    - ☐ I expect there to be a significant improvement in the project success

Response:

18. What action do you **usually** take against uncertainties?
    - ☐ I don’t take any action (skip question 19)
    - ☐ I maintain awareness of the uncertainties

- ☐ I take a similar action to risks: avoid, transfer, mitigate, or accept

19. When would you take actions on uncertainties?
    - ☐ Only when they are extremely significant e.g. high impact **and** high probability
    - ☐ Only when they are somewhat significant e.g. high impact **or** high probability
    - ☐ I would take action on all uncertainties

Monitor and control

20. How do you **usually** monitor and control uncertainties?
    - ☐ I don't monitor and control uncertainties
    - ☐ I track the already identified uncertainties
    - ☐ I monitor residual uncertainties
    - ☐ I identify new uncertainties where appropriate
    - ☐ I use the above b, c and d methods
    - ☐ I test if the assumptions are still valid
    - ☐ I conduct variance analyses
    - ☐ I follow detailed uncertainty response plans
    - ☐ Other, please specify (max 100 words)

A3: Determining the definition of risk and uncertainty

21. When managing a construction project, how would you define a risk?
    - ☐ Chances of an uncertain outcome, whether positive opportunity or negative threat (Young, 2011)
    - ☐ A situation involving exposure to danger (Oxford Dictionaries, 2015)
    - ☐ Risk is exposure to the consequences of uncertainty (Cooper et al., 2005)
    - ☐ A stage where there is a lack of information, but by looking at past experience, it is easier to predict the future. Events where the outcome is known and expected (Winch, 2010)
    - ☐ Effect of uncertainty on objectives (ISO, 2009)
    - ☐ Other, please explain (max 30 words)

22. When managing a construction project, how would you define an uncertainty?

- ☐ A risk within a project i.e. uncertain event (PMI, 2008)
- ☐ Uncertainty is a situation with an outcome about which a person has no knowledge (Webb, 2003)
- ☐ Uncertainty is the intangible measure of what we don't know. Uncertainty is what is left behind when all the risks have been identified. Uncertainty is gaps in our knowledge we may not even be aware of (Cleland & Gareis, 2006)
- ☐ Uncertainty is a part of the information required in order to take a decision. The required information consists of the amount of available information and uncertainty. The level of uncertainty will decrease the further a project is proceeding throughout the lifecycle (Winch, 2010)
- ☐ Uncertainty is the state, even partial, of deficiency of information related to the understanding or knowledge of an event, its consequence, or likelihood (ISO, 2009)
- ☐ Other, please explain (max 30 words)

23. When managing a construction project, which of the following do you believe to be **true**?

- ☐ Risk and uncertainty are the same, there is no difference
- ☐ Risk and uncertainty are very similar
- ☐ Risk and uncertainty are completely different

24. Are you familiar with the concept known as Risk Management?

- ☐ Yes
- ☐ No (skip question 25 and 26)

25. Are you familiar with the concept known as Uncertainty Management?
    - ☐ Yes
    - ☐ No (skip question 26)
26. Where does uncertainty management fit into the concept of risk management?
    - ☐ It doesn't fit into this concept, they are the same thing
    - ☐ Uncertainty is already dealt with within the risk management process
    - ☐ There is no systematic process that deals with uncertainty
27. Have you used any of the following on a project? (this question allows multiple options to be selected)
    - ☐ AS/NZS ISO 31000 - risk management principles and guidelines
    - ☐ AS/NZS IEC 62198 - managing risk in projects: application guidelines
    - ☐ PMBOK – guides and standards
    - ☐ SA/NZS HB 463 – risk management guideline: companion to AS/NZS 31000:2009
    - ☐ ISO Guide 73 – risk management vocabulary
    - ☐ IEC 31010 – risk management: risk assessment techniques
    - ☐ SA/SNZ HB 89 – risk management: guidelines on risk assessment techniques, companion to IEC 31010
    - ☐ Other, please specify (max 20 words)

    - ☐ I haven't used any of the above
28. Are you concerned about uncertainties?
    - ☐ Yes
    - ☐ No
29. In past projects, has uncertainty impacted negatively on a project?
    - ☐ Yes, what percentage of the time? (max 5 words)

    - ☐ No

A4: Other

1. At the completion of this project, would you like to receive a copy of the final report? (you need to email me to do so)
    - ☐ Yes
    - ☐ No
2. Were there any issues regarding the completion of this survey?
    - ☐ Yes, please explain (max 100 words)

- ☐ No

Thank you for your time in completing this survey. If you have any further questions or would like to get in contact, please email me at:

dykmanalex@myvuw.ac.nz

Thank you

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Appendix B - Dealing with gaps in uncompleted surveys

B1: Missing information in completed surveys

Missing information was only possible in one question of the survey due to the force response option in the online Qualtrics survey. Question 7 asked "Please list (**most common to least common**) the main uncertainties, in relation to risk (max. 5):" This question forced the participant to list a minimum of one uncertainty, this was because participants might not be able to contemplate five uncertainties whilst completing the survey. It was more important to form a richer analysis rather than to force a response to this type of question. The aim of this question was to ensure that the participants can communicate their understanding of the term uncertainty, different from risk. This was further confirmed by other questions in the survey. Another aim of the question was to potentially form a list of common uncertainties present across construction projects.

This question required different approaches to be taken in the analysis. When each response was viewed the first question to ask was "is the participant identifying risks, uncertainties or both?" The incomplete questions could be included in this analysis. This had no effect on proving the first aim of the question: communicating the understanding of uncertainty, or the second aim of this question: to form a list of common uncertainties in the construction industry.

B2: Non-completed surveys

Incomplete surveys could have been a significant limitation to the thesis. The survey essentially consisted of a series of leading questions on the treatment of uncertainty before a difference between risk and uncertainty was implied. If surveys were not completed then it was likely that the definitions section of the survey was left unanswered. To ensure valid conclusions could be formed, it was important to pose a question at the beginning asking the participant to define their understanding of uncertainty, see question 7 above.

A table was created to show which level of survey completion could be useful in forming valid conclusions.

Question		Usefulness	Comment
5	Have you worked on construction building projects in the last ten years?	Not useful	Gave insight into level of participants reached
6	Would you consider yourself as a project manager?	Not useful	Gave insight into level of participants reached
7	Please list (most common to least common) the main uncertainties in relation to risk:	Useful	Showed that the participant is understanding exactly what an uncertainty is and allow a common list to be formed
8	How many years have you spent in the field as a project manager?	Not useful	Gave insight to the level of expertise of the industry, single expert or double expert.
9	Do you have a professional project management qualification?	Not useful	Gave insight into most common project management qualifications
10	What type of projects do you work more than 50% of the time on?	Not useful	Gave insight into the most common type of project
11	What classification of project do you work more than 50% of the time on?	Not useful	Gave insight into the most common type of project
12	What is the typical size of the projects you work on?	Not useful	Gave insight into the most common type of project
15	How do you usually identify uncertainties in a building project?	Not useful/Useful	Depended on answer to question 7

17	Assuming that you have identified a number of uncertainties, how would you usually quantify them?	Not useful/Useful	Depended on answer to question 7
18	What effects can uncertainties typically have on the project objectives?	Useful	Depended on answer to question 7 although could be discussed
19	Are you aware of any formal methods to analyse uncertainty?	Useful	Depended on answer to question 7 although could be discussed
20	Do you use any formal methods (not standards) to analyse uncertainties in risk?	Useful	Depended on answer to question 7 although could be discussed
21	Why don't you use formal methods to analyse uncertainties in risk?	Useful	Future work could be aligned
22	What is the best way to make you start or allow you to continue using formal methods to analyse uncertainty?	Useful	Future work could be aligned
23	Do you believe that applying structured methods, for analysing uncertainties, will improve the overall project success?	Useful	Future work could be aligned
24	If you use formal methods to analyse uncertainties, what do you think is the desired outcome?	Useful	Depended on answer to question 7 although could be discussed
26	What action do you usually take against uncertainties?	Not useful/Useful	Depended on answer to question 7
27	When would you take actions on uncertainties?	Useful	Depended on answer to question 7
29	How do you usually monitor and control uncertainties?	Not useful/Useful	Depended on answer to question 7 although can be discussed

31	When managing a construction project, how would you define a risk?	Useful	Depended on answer, half show confusion and half show understanding
32	When managing a construction project, how would you define an uncertainty?	Useful	Confirmed understanding, validated usefulness of the previous questions
33	When managing a construction project, which if the following do you believe to be true?	Useful	Further confirmed understanding
34	Are you familiar with the concept known as Risk Management?	Useful	
35	Are you familiar with the concept known as Uncertainty Management?	Useful	
36	Where does uncertainty management fit into the concept of risk management?	Useful	
37	Have you used any of the following on a project (standards)?	Useful	
38	Are you concerned about uncertainties?	Useful	Depended on understanding although could be discussed
39	In past projects, has uncertainty impacted negatively on a project?	Useful	Depended on understanding although could be discussed

Table 20: Usefulness of uncompleted surveys.

It was important to considering the table above when reporting on the results. It might not be appropriate to include all the results in some cases, this was noted and explained where possible in the final analysis.

Appendix C: Sources of uncertainty: an extensive list

Throughout the literature many sources of uncertainty were identified, these are presented in the extensive list below. This list and the findings through the survey method has formed a comprehensive database of uncertainties.

Uncertainty	**Reference**
Abnormal situations	(Haimes, 2005; Klinke & Renn, 2002)
Approximation uncertainty	(Haimes, 2005; Klinke & Renn, 2002)
Assumptions	(Haimes, 2005; Klinke & Renn, 2002)
Data gaps	(Haimes, 2005; Klinke & Renn, 2002)
Data quality	(Haimes, 2005; Klinke & Renn, 2002)
Different data formats of project data, design and document files	(Nawab, 2013)
Disordered management of project documents, leads to duplication, lack of clarity, major differences, and revisions	(Nawab, 2013)
Disagreement	(Haimes, 2005; Klinke & Renn, 2002)
Excluded variables	(Haimes, 2005; Klinke & Renn, 2002)
Extrapolation error	(Haimes, 2005; Klinke & Renn, 2002)
Flawed judgement	(Haimes, 2005; Klinke & Renn, 2002)
Identification and justification of probabilities linked to past data or systematic observations	(Haimes, 2005; Klinke & Renn, 2002)
Ignorance	(Haimes, 2005; Klinke & Renn, 2002)
Indeterminacy: resulting from genuinely unpredictable relationships between cause and effects. Examples include random events or misunderstood nonlinear relationships	(Haimes, 2005; Klinke & Renn, 2002)
Lack of management tools and ineffective organisation on site	(Nawab, 2013)
Lack of training, experience and qualification of team members	(Nawab, 2013)

Lack of understanding	(Haimes, 2005; Klinke & Renn, 2002)
Language inconsistencies	(Haimes, 2005; Klinke & Renn, 2002)
Model inconsistencies	(Haimes, 2005; Klinke & Renn, 2002)
Parameter issues	(Haimes, 2005; Klinke & Renn, 2002)
Random error in measurements	(Haimes, 2005; Klinke & Renn, 2002)
Risk assessment process	(Haimes, 2005; Klinke & Renn, 2002)
Risk assessor bias	(Haimes, 2005; Klinke & Renn, 2002)
Risk assessor competence	(Haimes, 2005; Klinke & Renn, 2002)
Sampling errors	(Haimes, 2005; Klinke & Renn, 2002)
Social cost/benefit of risk	(Haimes, 2005; Klinke & Renn, 2002)
Subjective judgements	(Haimes, 2005; Klinke & Renn, 2002)
Surrogate variables	(Haimes, 2005; Klinke & Renn, 2002)
System boundaries	(Haimes, 2005; Klinke & Renn, 2002)
Systematic error	(Haimes, 2005; Klinke & Renn, 2002)
Unacceptable planning of works	(Nawab, 2013)
Unclassified order of project stages and breaches of company procedures leads to waste if time, duplication of responsibility and procedures, un-coordination	(Nawab, 2013)
Unclear responsibility and contractual obligations	(Nawab, 2013)
Un-estimated work amounts	(Nawab, 2013)
Unpredictability	(Haimes, 2005; Klinke & Renn, 2002)
Using unified terms and definitions and project documentation leads to misunderstanding	(Nawab, 2013)
Variability	(Haimes, 2005; Klinke & Renn, 2002)

Table 21: Sources of uncertainty: an extensive list.

Appendix D: Case study risk assessment

Second risk assessment for the case study				
No.	**Description of Risk**	**Impact of Risk**	**Risk Status**	**Proposed Action**
1	Resource Consent Delay	Overall project delay and the possible need to resequence works. Cost impact.	L	Lodgement made in good time. Monitor planning process, and liaise as required with ACC. Collate & provide information required by conditions.
2	Unable to resolve design for new Green Room with adjoining building, therefore unable to gain agreement to build new.	Prolonged construction duration due to complexity of building over existing GR.	M	Develop design for new servicing layout and GR and agree with adjoining building. C.Arch to then work with other building to finalise design. Agree that other building will find temporary GR during construction.
3	Resource Consent application is treated as Notified	Delay in receiving Approval, possible abortive design works.	M	Good liaison to be had with ACC to seek early decision. If RC is notified design works should progress without delay, and early feedback from ACC should be sought in regards to the design.
4	Resource Consent approval includes onerous Conditions	Cost impact, further investigations, additional construction works.	M	Early direction sought from ACC. Draft copy of Conditions to be reviewed by Team prior to ACC final issue.
	Resource Consent requirements not being adequately met	Delays to works, disruption, cost impact.	M	Monitor planning process, provide required information for amendments and conditions.
5	Objections are lodged against the RC application	Delay to approval, design change.	L	No objection thought likely to be lodged, bar possibly partial site. Continue liaison who has a meeting with ACC to discuss retaining the Building.
6	Works need to be sequenced in such a way to minimise disruption to other building's operation	Programme delay due to out of sequence working, cost impact.	M	PM to work with the other building, to understand their concerns and operations, then develop an agreed construction methodology.
7	Works need to be carried out in such a way that prevents access to rear of existing buildings	Objections from Tenants, programme delay, cost impact.	M	PM to develop construction methodology to minimise disruption, and maintain good relationship with current tenants through regular liaison.

8	MetroWater/ WaterCare wish to undertake works to their existing services running across the site	Programme delay.	L	PM to liaise with MetroWater and WaterCare to inform them of the development, and ensure that any refurbishment works to their services are carried out in advance of construction.
9	Design changes lead to an alteration of the foundation design around the scheduled trees	Re-design, further approvals required.	L	Foundation solution agreed with ACC arborist. Seek approval in principle sign-off on internal layout to minimise risk of future changes.
10	ACC request additional heritage works	Cost impact.	L	Close liaison with ACC/ HPT through RC process. Challenge any additional works requested as appropriate.
11	Agreement not reached with the other building/ ACC to create access	Out of sequence working, cost impact, programme impact.	M	PM to gain early agreement with ACC/ the other building to create this access (temporary or permanent).
12	Onerous Building Consent Conditions	Programme delay, cost overrun.	H	Consent strategy and programme to be developed and agreed. Liaise regularly with Council.
13	Client objections to design proposals	Design change, disruption, delay and cost impact.	L	PM to ensure Client is fully aware of the emerging design through focused design reviews. PM to confirm Room Schedule.
14	Confusion with respect to agreed design, particularly with respect to the scope of value engineering	Design change, disruption, delay and cost impact.	M	The design team are to notify PM of the changes and these are to be agreed. Any further VE is to be overtly notified so as to ensure the design complies with the Client's requirements. QS to advise of any Provisional Sums.
15	Code Compliance requirements not being picked up in the design	Disruption to works, delay and cost impact.	M	C.Arch to continue close liaison with sub-contractor and ACC Building Consent Officer. Design to be reviewed against Code requirements at completion of each Stage.
16	Maintenance access strategy approval	Delay to procurement and the need for site alterations to accommodate any change to the access arrangements.	L	Develop workable solution for building maintenance access and agree.
17	Interface with other project	Late alterations to work, cost and programme impact.	M	Close liaison with ARCH required during design. Construction contract to provide for liaison with other Contractor during build.
18	Flooding	Programme delay and disruption to works.	M	Contractor to establish flood mitigation strategy, and carry out drainage works as early as possible.

19	Rain	Programme delay and disruption to works.	L	Establish mean rainfall trends and allow for winter working, temporary protection.
20	Fire escape route to be maintained	Programme delay and disruption to works.	M	Sub-contractor to establish requirements, temporary and permanent, and review with C.Arch the most practical solution.
21	Technical equipment is over specified	Cost Impact.	M	Review schedule by independent experts, cost schedule items, and allow informed decision as to what items should form part of base-build. Temporary route during construction to be discussed with PM.
22	Sub-contractor insolvency	Programme delay, cost overrun.	M	Hand pick key sub-contractors on basis of resource capability and output quality. Due diligence on all subs prior to appointment.
23	Construction impacted by construction of other project	Programme delay and disruption to works.	M	PM to establish construction methodology, and consider other project construction phasing, allowing a contingency plan.
24	Availability of competent contractors to undertake construction	Poor quality, cost and programme impact.	M	Approach market early to establish availability, and commence tender period as early as possible.
25	Findings of further Geotech survey result in significant design change	Delay and cost implications.	M	Contractor to incorporate report into early design and notify all members of any significant change.
26	Cost Plan overruns	Reactive cost cutting and project quality compromise and delay.	H	QS to work closely with Team to ensure that 'unsustainable' design solutions are not progressed to a point of commitment. Feedback required from QS.
27	Tenders exceeding cost plans	Reactive cost cutting and project quality compromise and delay.	M	As above, value engineering proposals to be validated, agreed and appropriate approvals obtained.
28	Consultant resource shortages	Unable to maintain document issue in line with documentation programme. Delay to programme.	M	Resource plans for each consultant. Lock programme into agreements. Specify deliverables and dates.
29	Unforeseen obstructions below ground	Disruption to works, delay and cost impact.	H	Develop design to be as flexible as possible so as to minimise disruption if change has to occur. Contractor to develop action plan for dealing with this scenario, being able to work on other areas if suddenly stopped due to obstructions. Complete early clearance of obstructions and contamination. Allowance within programme and budget.

30	Site programme overruns	Accelerated fitout, project overrun, dispute and LAD's.	L	Frequent progress/ 'early warning' meetings to be held and reports to be produced to 'flag-up' any potential overruns so that an action plan to recover programme is implemented. PM to ensure that the Contractor keeps the right level of management on the project at all times.
31	Unchartered services delaying works	Disruption to the works, time and cost implications.	M	Contractor to liaise closely with service contractor in this respect. Exploration trenches may need to be opened up to verify the current information. Services from carpark across site in particular.
32	Site access restrictions due to neighbours and adjacent construction works	Disruption to the works, time and cost implications.	M	PM to develop detailed site logistics plan to be agreed with neighbours and other contractors through Integration meetings. Careful consideration to be given to the proposed phasing of the other works.
33	Crane oversail license restrictions	Disruption to the works, time and cost implications. Possible need for Luffing jibs.	M	Crane plan to be developed and appropriate licenses obtained as soon as possible by Contractor.
34	Acoustic performance not matching that specified	Retrospective works to rectify, cost and disruption impact.	H	Contractor to work closely with consultant to ensure that the acoustic requirements are met. Agree whether any acoustic testing is to be carried out after completion.
35	Building foot print not fitting, incorrect interpretation of topo' surveys	Costly reactive alteration, delay.	L	Contractor to set out works as soon as possible.
36	Design incompatibility between frame and cladding	Excessive movement, affected warranties, substandard quality.	M	Architect to work closely with contractor to develop a design that minimises incompatibility. Building movement strategy to be implemented by contractor.
37	Contract Documents not reflecting what is actually required	Change to the contract works, unforeseen costs, delay and disruption.	H	QS to ensure that the Contract Documents and Contractor's Proposal contain the appropriate obligations. Main Contract procurement to be delayed if necessary whilst any ambiguity is clarified. Design Team to ensure that the latest design information is included and QS must ensure that the agreed contract sum is based upon the latest information.
38	Developing services design affecting architectural layouts	Disruption, delay and cost implications.	M	Architect to coordinate this design working closely with the specialist equipment consultants.

39	Site security	Health and safety breakdowns, theft from site, malicious damage, delay.	M	PM to develop outline site logistics plan to be agreed with neighbours and other contractors. Plan to be developed by Contractor, overall site control to be with Contractor.
40	Fire rating of escape routes require higher spec' materials	Design change, disruption and cost.	M	Design coordination issue.
41	Over-building to in an attempt to guarantee area tolerances	Unnecessary project cost and waste.	M	Strict tolerances to be agreed as part of Contract Documents.
42	Contamination in excess of that anticipated by investigation	Disruption, delay and cost implications.	M	Contractor to liaise closely with sub-contractor as works progress beneath ground, observing any RC conditions as necessary. Allow within programme and budget.
43	ACC do not agree with fire strategy	Design change, disruption and cost.	L	Sub-contractor to chase ACC for written approval of strategy once submitted.

Table 22: Second risk assessment for the case study project, source: undisclosed professional New Zealand firm.

Sixth risk assessment for the case study						
No.	**Description of Risk**	**Impact of Risk**	**Likelihood**	**Severity**	**Score**	**Proposed Action**
1	Resource Consent Amendment Delay	Overall project delay and the possible need to resequence works. Cost impact.	2	3	6	Lodgement to be made in accordance with programme, float allowed. Monitor planning process, and liaise as required with ACC. Collate & provide information required by conditions.
2	Unable to resolve design for new Green Room with the other building	Prolonged design period required to gain agreement.	1	3	3	Early regular meetings to be arranged with the other building. ACC to be kept abreast of progress. Sign-off required from the other building at Dev. Design.
3	Unable to resolve optimal temp. Green room solution.	Programme and cost impact.	2	5	10	Discussions underway with the other building to progress solution in chair store. PM to push forward.
4	Satisfying Resource Consent Conditions becomes critical	Cost & programme impact.	2	4	8	Early direction sought from ACC. Draft copy of Conditions to be reviewed by Team prior to ACC final issue.
5	Resource Consent requirements not being adequately met	Delays to works, disruption, cost impact.	2	3	6	Monitor planning process, provide required information for conditions well in advance, in accordance with planning tracking schedule.
6	Works need to be sequenced in such a way to minimise disruption to the other building's operation	Programme delay due to out of sequence working, cost impact.	3	3	9	Client/PM to work with the other building, to understand their concerns and operations, then develop an agreed construction methodology.
7	Works need to be carried out in such a way that impacts on access to rear of existing buildings	Objections from Tenants, programme delay, cost impact.	2	3	6	PM to develop construction methodology to minimise disruption, and maintain good relationship with current tenants through regular liaison.
8	MetroWater/ WaterCare wish to undertake works to their existing services running across the site	Programme delay.	2	5	10	PM have formally advised MetroWater of the development programme.

9	Design changes lead to an alteration of the foundation design around the scheduled trees	Re-design, further approvals required.	1	4	4	Foundation solution agreed with ACC arborist, as per Resource Consent. Change to be resisted.
10	ACC approval to heritage works	Cost / Time impact.	2	3	6	HPT issues addressed within RC, obligations to be met. Liaison between Arch and HPT continues.
11	HPT require onsite archaeological investigation	Cost/ Time impact.	4	4	16	Proposal from archaeologist to be sought for desk top study, required by HPT, to determine if onsite work is required.
12	Legal agreement not reached with the other building/ ACC to create access through route	Late alterations to work, cost and programme impact.	1	4	4	PM to gain early agreement with ACC/ the other building to create legal arrangement.
13	Client objections to design proposals	Design change, disruption, delay and cost impact.	2	4	8	PM to ensure Client is fully aware of the emerging design through focused design reviews. PM to confirm Room Schedule with client.
14	Confusion with respect to agreed design	Design change, disruption, delay and cost impact.	2	3	6	The design team are to notify PM of the changes and these are to be agreed with client. Any further changes are to be overtly notified to ensure the design complies with the Client's requirements. QS to advise of any Provisional Sums.
15	Code Compliance requirements not being picked up in the design	Disruption to works, delay and cost impact.	1	3	3	Arch to continue close liaison with fire consultant and ACC Building Consent Officer. Design to be reviewed against Code requirements at completion of each Stage.
16	Maintenance access strategy approval	Delay to procurement and the need for site alterations to accommodate any change to the access arrangements.	2	3	6	Develop workable solution for building maintenance access and agree with client.

17	Interface with other project	Late alterations to work, cost and programme impact.	-	-	0	Close liaison with Arch required during design. Construction contract to provide for liaison with other Contractor during build.
18	ACC Committee meeting dates not met.	Delay to the programme.	2	4	8	Meeting dates fixed within programme. Sufficient time allowed to coordinate with ACC, and to ensure that prior to submission information is agreeable and as required.
19	Flooding during works	Programme delay and disruption to works.	2	3	6	Contractor to establish flood mitigation strategy, and carry out drainage works as early as possible.
20	Rain	Programme delay and disruption to works.	2	2	4	Contractor to establish mean rainfall trends and allow for winter working, temporary protection.
21	Fire escape route to be maintained	Programme delay and disruption to works.	2	3	6	Fire consultant to establish requirements, temporary and permanent, and review with Arch the most practical solution. Internal layouts to be reviewed by fire consultant.
22	Technical equipment is over specified	Cost Impact.	2	3	6	Review schedule by independent experts, cost schedule items, and allow informed decision by client as to what items should form part of base-build. Temporary route during construction to be discussed with PM.
23	Sub-contractor insolvency	Programme delay, cost overrun.	1	3	3	Diligent procurement process, including assessment of contractor's financial status/ history. Hand pick key sub-contractors on basis of resource capability and output quality. Due diligence on all sub-cons. Prior to appointment.
24	Construction impacted by construction of other project	Programme delay and disruption to works.			0	PM to establish construction methodology, and consider other project construction phasing, allowing a contingency plan.
25	Availability of competent contractors to undertake construction	Poor quality, cost and programme impact.	2	4	8	Approach market early through an EOI to establish availability, and commence tender period as early as possible.

26	Findings of further Geotech survey result in significant design change	Delay and cost implications.	3	3	9	Contractor to incorporate report into early design and notify all members of any significant change.
27	Cost Plan overruns	Reactive cost cutting and project quality compromise and delay.	3	3	9	QS to work closely with Team to ensure that 'unsustainable' design solutions are not progressed to a point of commitment. Feedback required from QS.
28	Tenders exceeding cost plans	Reactive cost cutting and project quality compromise and delay.	2	4	8	As above, value engineering proposals to be validated, agreed and appropriate approvals obtained.
29	Consultant resource shortages	Unable to maintain document issue in line with documentation programme. Delay to programme.	2	3	6	Resource plans for each consultant. Lock programme into agreements. Specify deliverables and dates.
30	Unforeseen obstructions below ground	Disruption to works, delay and cost impact.	3	3	9	Develop design to be as flexible as possible so as to minimise disruption if change has to occur. Contractor to develop action plan for dealing with this scenario, being able to work on other areas if suddenly stopped due to obstructions. Complete early clearance of obstructions and contamination. Allowance within programme and budget.
31	Site programme overruns	Accelerated fitout, project overrun, dispute and LAD's.	2	4	8	Frequent progress/ 'early warning' meetings to be held and reports to be produced to 'flag-up' any potential overruns so that an action plan to recover programme is implemented. PM to ensure that the Contractor keeps the right level of management on the project at all times.
32	Unchartered services delaying works	Disruption to the works, time and cost implications.	3	3	9	Contractor to liaise closely with services contractor in this respect. Exploration trenches may need to be opened up to verify the current information. Services from carpark across site in particular. PM to liaise with sub-contractor on ASR services.

33	Site access restrictions due to neighbours and adjacent construction works	Disruption to the works, time and cost implications.	3	3	9	PM to develop detailed site logistics plan to be agreed with neighbours and other contractors through Integration meetings. Careful consideration to be given to the proposed phasing of the works.
34	Crane oversail license restrictions	Disruption to the works, time and cost implications. Possible need for Luffing jibs.	2	3	6	Crane plan to be developed and appropriate licenses obtained as soon as possible by Contractor.
35	Acoustic performance not matching that specified	Retrospective works to rectify, cost and disruption impact.	1	4	4	Acoustics contractor to work closely with Arch. to ensure that the acoustic requirements are met. Agree whether any acoustic testing is to be carried out during/ after completion.
36	Building foot print not fitting, incorrect interpretation of topo' surveys	Costly reactive alteration, delay.	1	4	4	Contractor to set out works as soon as possible.
37	Design incompatibility between frame and cladding	Excessive movement, affected warranties, substandard quality.	1	4	4	Arch to work closely with contractor to develop a design that minimises incompatibility. Building movement strategy to be implemented by contractor.
38	Contract Documents not reflecting what is actually required	Change to the contract works, unforeseen costs, delay and disruption.	2	3	6	PM to ensure that the Contract Documents and Contractor's Proposal contain the appropriate obligations. Main Contract execution to be delayed if necessary whilst any ambiguity is clarified. Design Team to ensure that the latest design information is included and PM must ensure that the agreed contract sum is based upon the latest information.
39	Detailed services design affecting architectural layouts	Disruption, delay and cost implications.	3	3	9	Arch to coordinate this design working closely with the other consultants through coordination meetings.
40	Site security	Health and safety breakdowns, theft from site, malicious damage, delay.	2	3	6	PM to develop outline site logistics plan to be agreed with neighbours and other contractors. Plan to be developed by Contractor, overall site control to be with Contractor.

41	Fire rating of escape routes require higher spec' materials	Design change, disruption and cost.	3	3	9	Design coordination issue.
42	Contamination in excess of that anticipated by investigation	Disruption, delay and cost implications.	3	3	9	Contractor to liaise closely with sub-contractor as works progress beneath ground, observing any RC conditions as necessary. Allow within programme and budget.
43	ACC do not agree with fire strategy	Design change, disruption and cost.	2	4	8	Chase ACC for written approval of strategy once submitted.
44	Poor relationship between Contractor and the other building	Lack of understanding leads to disruption to both parties, project perception is damaged.	2	4	8	Establish good working relationship prior to Contractor appointment. Ensure regular liaisons meetings are in place, in advance of construction. Communication of events and construction works/ methodology to be made well in advance.
45	Complex buildability issues not picked up during the design	Cost and programme impact.	2	4	8	Specialist advice to be provided. Detailed construction methodology and programme to be developed, to include all temporary and enabling works. Methodology to be discussed with all affected parties, i.e. adjacent projects/ neighbours.
46	Design runs behind other disciplines	Cost / Time impact.	3	4	12	Close monitoring of agreed MDE deliverables.
47	Outcome of HQ meetings has significant impact	Cost/ Time impact.	1	4	4	PM to liaise closely with ACC through HQ meetings to ensure all are well informed.

Table 23: Sixth risk assessment for the case study project, source: undisclosed professional New Zealand firm.